Rebuilding a Utility Radio Communication Network: New Challenges and New Technologies

By

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A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

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Acknowledgements

Many thanks to my manager and mentor on this project, Richard Hird, P.Eng. His many years of telecom and scada experience have provided guidance on this complicated project. I would also like to acknowledge my thesis advisor Dr. Peter McLaren for his guidance and instruction throughout my graduate studies.

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Abstract

The topic of this thesis is to present the research used to solve problems faced when completing a utility communication network replacement. Specifically, I have focused on digital microwave capacity, multiplexer switching platform, Ethernet network design, and new radio site infrastructure. Preliminary research was completed on each of these topics, and then the solution designed.

The Alberta transmission network ties together provincial generation and load centers. 138, 240, and 500kV transmission lines deliver electricity generated using Coal, Natural Gas, Wind and Water. Along with those transmission lines come substations and telecommunications. The planning involved with installing a communication network is introduced. Designs for route planning, bandwidth capacity, emergency restoration, and network synchronization are discussed.

Microwave radio provides the transport mechanism. The path design and equipment chosen must meet design specifications to maintain reliability levels. Equipment selection is based on backbone, major spur, or last mile radio links. Teleprotection operation and the need for fast, reliable communications between substations are shown, with calculations for expected delays. The problem of predicting telecommunication latency is addressed by breaking down the communication link into its constituent components and adding the separate delays.

Subsequent sections present the need for multiplexers. Beginning with T1 multiplexers and an overview of TDM multiplexing, analysis shifts to ATM multiplexers and the core switching hardware selected for use in the AltaLink network rebuild. An overview of ATM theory and the planned deployment of multiplexer equipment throughout the network follow.

Substation Ethernet networks and the demand for wide-area network access to substation equipment are a common topic of today's utility communication engineers. To include an Ethernet network requires significant planning prior to deployment to ensure that all utility access requirements are met. The problem firstly is how to obtain access to the substation followed by how to ensure that network access is adequate and safely secured.

Significant infrastructure must be designed for a telecommunications facility to operate effectively. Based on the design philosophies imposed by utilities, the building, power supplies and environmental systems must coordinate to ensure equipment can operate efficiently and also be protected in the event of system disturbance. The design specified for the AltaLink network is examined.

Finally, conclusions are drawn from the research into how utility telecommunications are expected to operate, and insight into how one utility accomplished its network rebuild is assessed.

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1. Introduction

The communication system's primary role is to be the eyes and ears of the system operator. Scada information is back-hauled on the network to a central control location permitting real-time control and monitoring of the power system. Equally important are the teleprotection circuits. Teleprotection circuits assist protective relaying devices by ensuring appropriate reaction times to system faults. They allow intelligent relaying devices to communicate with coordinating devices protecting segments of the electrical grid. Improved speed and lowered reaction time result in better protection for installed equipment and smoother system operation overall. Voice circuits provide a means for on-site staff to communicate with offices and the outside world. New Ethernet-based wide-area networks allow for remote interrogation of devices such as protective relays, remote terminal units, fault recorders, and meters, all from the central office. This saves operational time and makes information available in near real-time.

To allow for these features and abilities, communication infrastructure requires periodic technology upgrades. These upgrades are step changes rather than gradual progressions. This is due to the network operating as one complete system – upgrading a portion offers little benefit unless the entire system receives the same upgrades.

The topic of this thesis is to detail the challenges in incorporating the previously mentioned components when conducting an upgrade to the communication network. Beginning with a description of the power system in Alberta today allows the reader to gain a perspective of the problem. How does a utility upgrade its infrastructure while still maintaining reliable service? What hardware platform should be installed, and what additional functionality does it provide? What is the expected lifecycle of this equipment?

Using AltaLink's Alberta network upgrade as an example, the engineering decisions made to solve those problems are described. This solution, while not unique, could apply to most any utility facing a similar upgrade requirement. It should also be noted that the design presented within this thesis uses microwave radio for the majority of the communication requirements. Fiber optics are deployed in some instances, but only where the use of microwave radio is not possible, or economically viable.

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2. The Alberta Power System

Throughout the province of Alberta, electricity generation consists of hydroelectric, wind, fossil fuel, and waste steam (co-generation). With the exception of nuclear sources, every commonly known method of electricity generation has a presence in Alberta. This diverse combination of energy sources creates a widely interconnected power system. Wind farms are located in the southwestern corner of the province while coal-fired generation is centrally located near the mines. Co-generation facilities exist in the north and south, primarily near Fort McMurray in conjunction with tar-sands development. All generators vary in size and capacity, supplying energy to the primary load centers of Calgary and Edmonton.

The interconnected transmission system consists of transmission lines similar to those of any other electrical system in Canada. Lines run all across the province, beginning with the high-voltage transmission corridor between Calgary and Edmonton. High-capacity lines feed smaller lines that in turn feed the distribution network. Generation is often remotely located, complicating construction and operation of transmission lines. Included with the transmission network is the substation communication system. Line-of-sight radio links typically used to communicate with substations are often difficult to construct due to the locations of generators, and by the rugged terrain of the Rocky Mountains.

The Alberta power system has two tie lines to other utilities. The first link and the largest transmission line in the province is a 500kV line that ties Alberta with British Columbia. The second and smaller tie connects Alberta to Saskatchewan through a back-to-back HVDC station.

2.1 Coal-fired Generation

There are many generators located across the province of Alberta. This section attempts to highlight the largest of these coal-fired plants, but is by no means an exhaustive list. The power system is a dynamic environment with new plants coming online every year.

The largest of these plants are coal-fired thermal-electric plants owned and operated by TransAlta Utilities, Epcor, and ATCO Power. Four plants are located around Lake Wabamun approximately 75 km west of Edmonton. TransAlta owns Wabamun, Sundance, and Keephills, with Epcor owning the Genesee plant. The fifth and sixth plants, located in central Alberta, are Sheerness and Battle River. TransAlta and ATCO Power jointly own Sheerness with Battle River owned entirely by ATCO Power.

The following table lists these coal-fired plants in descending order of capacity:

Plant Name	*Installed Capacity (MW)*
Sundance	2029
Genesee	820
Keephills	754
Sheerness	732
Battle River	670
Wabamun	569
Total	5574

Table 1-Coal-fired Generation in Alberta >500MW[1]

These plants are located in rural parts Alberta near the open-pit coal mines that supply them with fuel. Proximity to cooling water is also a factor, given the quantity of water required by each plant and the few lakes of sufficient size in Alberta

The following figure illustrates geographically the location of each of the above listed plants, with respect to the major load centers of Calgary and Edmonton.

[1] Capacity information publicly available from each company's website: TransAlta – www.transalta.com, Epcor – www.epcor.com, ATCO Power – www.ATCOpower.com

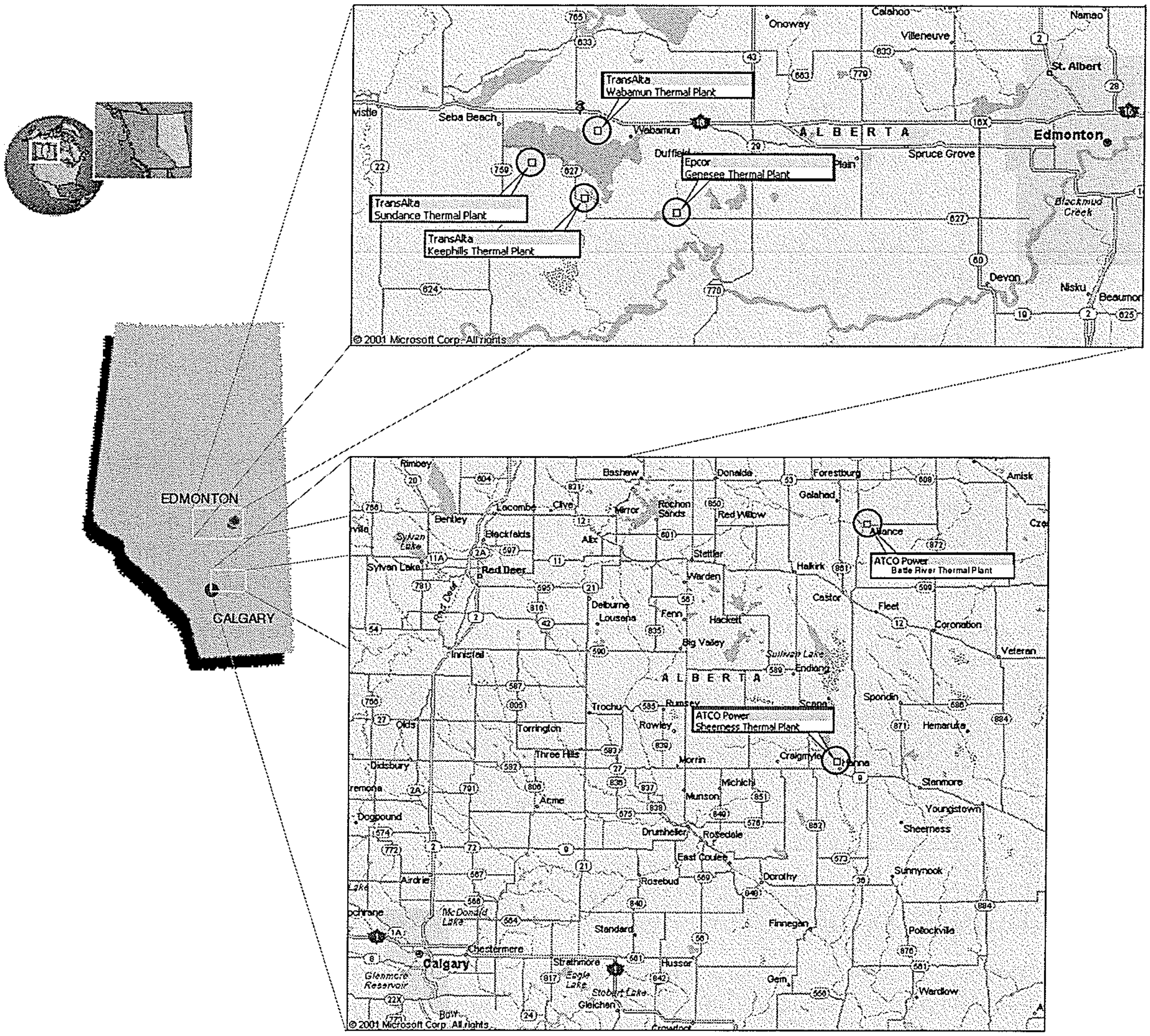


Figure 1-Coal-fired Generation in Alberta >500MW

It is visible in the above figure that the significant amount of generation located west of Edmonton requires large numbers of transmission lines in this area to move the power toward the load. This factor makes this area of the transmission system sensitive to communication and forced transmission line outages.

2.2 Gas-fired Generation

Natural gas generation is widespread in Alberta. This is due in part to the perception that it is less environmentally damaging than its rival coal. Natural gas supplies are abundant in Alberta, making the supply of raw fuel for these plants cost-effective and easy to obtain in large quantities.

The gas-fired generation process takes on several forms, and is the most common type of power plant in operation across the province. The first and simplest process uses gas-fired boilers to produce steam for electricity generation. The second type utilizes gas-fired turbines to produce electricity and waste steam for heating or industrial processes. This process is *co-generation.* Heat recovery boilers capture heat contained within the turbine's exhaust gasses. This waste heat generates steam for building heating or intermediate processes, most of which are related to the petrochemical industry. The third form of gas-fired generation appears as *combined-cycle* plants. These plants use two stages. The first is identical to the co-generation process described previously: Natural gas combustion spins a turbine generating electricity and excess heat.

The second stage uses the excess heat to create steam that generates additional electricity by passing it through a secondary steam turbine.

The following table gives a perspective of the gas-fired plants in Alberta. This list shows only those plants with capacities greater than 100 MW, as there are too many plants to list all of them.

Plant Name (Owner)	*Type*	*Installed Capacity (MW)*
Fort Saskatchewan (TransAlta)	Co-generation	120
Poplar Creek (TransAlta)	Co-generation	360
Joffre (ATCO Power)	Co-generation	480
Muskeg River (ATCO Power)	Co-generation	172
Scotford (ATCO Power)	Co-generation	150
Cloverbar (Epcor)	Natural Gas	660
Rossdale (Epcor)	Natural Gas	221
Cold Lake (Mahkeses) (Imperial Oil)	Co-generation	160
Balzac (Encana/Nexen)	Natural Gas	104
Cavalier (Encana)	Natural Gas	104
Balzac (Calpine Energy)	Natural Gas	270
City of Medicine Hat	Natural Gas	211
Total	-	3262

Table 2-Gas-fired Generators >100MW[2]

The following map of Alberta illustrates the location of the plants mentioned above.

[2] Capacity information publicly available from each company's website.

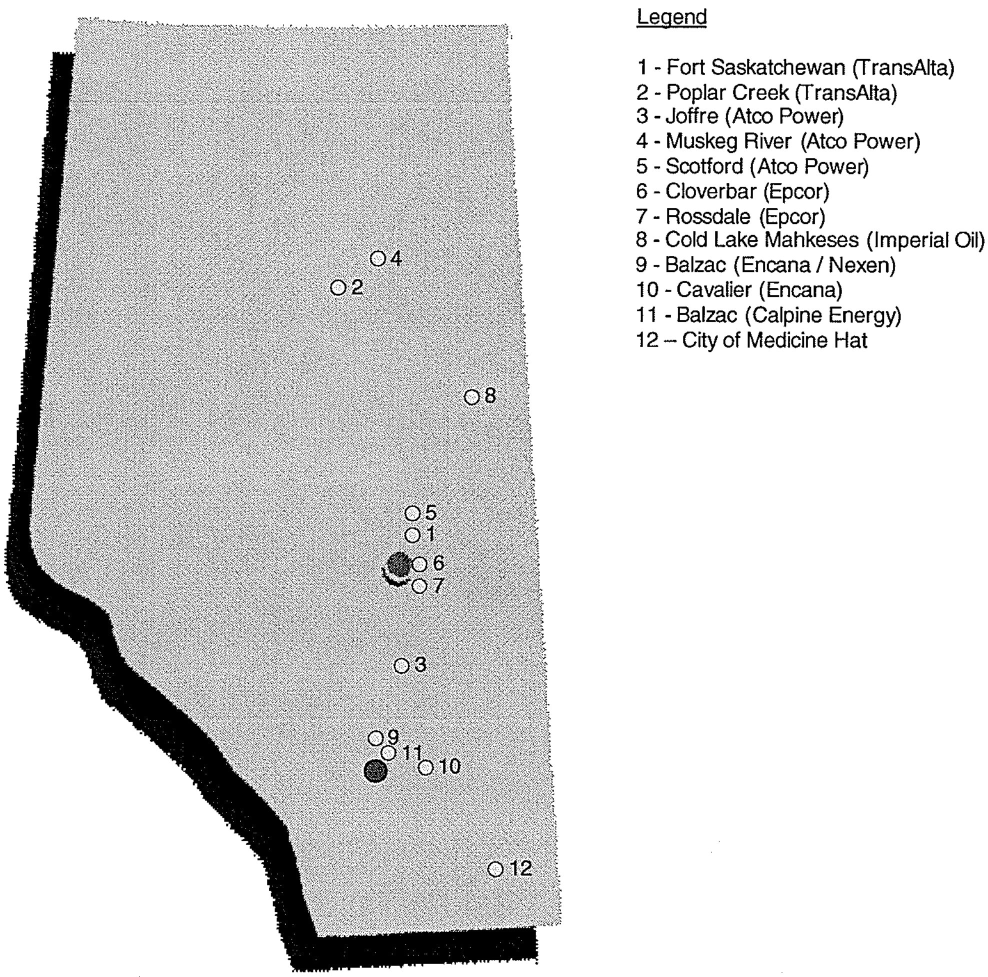


Figure 2-Gas-fired Generation in Alberta >100MW

As can be seen on the map above, gas-fired generators are not located in one specific part of the province. The diverse nature of these installations coincides with the location of major population centers and petroleum production and refining facilities. Significant transmission infrastructure is required to connect all of these sites to the common grid.

2.3 Wind Generation

Using wind to generate electricity is a new idea for Alberta. Only in the past ten years has it become a recognizable component of the total electricity generated in the province. Wind farms are located in the southwestern corner of Alberta, mostly near the town of Pincher Creek. It is there that the prevailing winds roll off the Rocky Mountains and race across the foothills creating an ideal location to construct wind turbines.

As a form of 'green' energy[3], wind turbines harness the mechanical energy of the wind and use it to spin a generator producing electricity. Unfortunately, the units cannot capture enough wind to generate substantial quantities of electricity individually. It is for this reason that many smaller units are located closely together forming a 'wind farm'.

A typical wind turbine unit generates between 600kW and 1.5MW of electricity. Construction of the turbine unit begins with the large windmill-like blades. Each blade is up to 33 meters long and weighs up to 5000 kg. Three blades connect to a central rotor capable of varying the pitch of the blades for optimal aerodynamic performance. The rotor, located atop a steel column more than 67m above ground level, connects to a power-electronic based generator capable of producing constant frequency output power with variable frequency input.

At present, there are at least four wind farm development projects either already commissioned or under construction. The following table lists these projects and their generation capacity:

Project Name	*Owner*	*Installed Capacity (MW)*
Cowley Ridge Windplant	Canadian Hydro Developers, Inc.	47
Castle River East #1	Vision Quest	29
Kettles Hill Wind Farm	Bening Energy	53
Castle Rock Ridge	Wind Power, Inc.	100
Total	-	229

Table 3-Wind Generation in Alberta >1MW

The following map of Alberta illustrates the location of the plants mentioned above.

[3] Information on each wind power project in Alberta can be found at the Climate Change Central website: http://www.climatechangecentral.com/alternative_energy/alt_alberta_actions.html

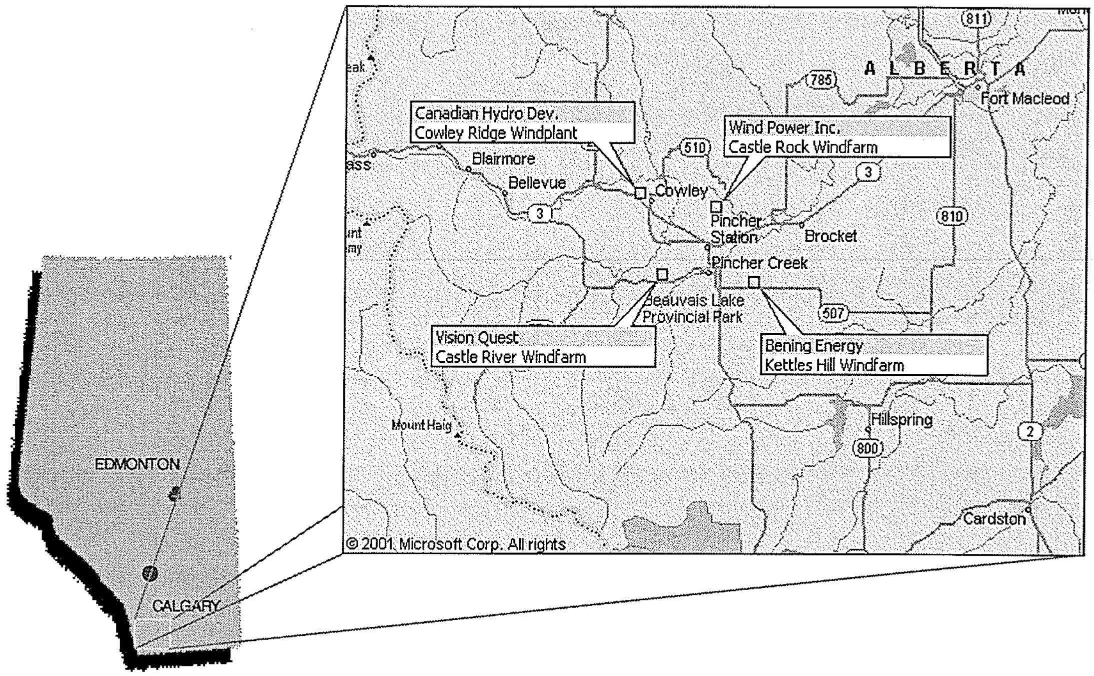


Figure 3-Wind Generation in Alberta >1MW

Although wind generation represents a small portion of the overall electricity requirements of the Province, it represents an opportunity for an emerging technology to be tested and proven economically viable. Development forecasts suggest that significant growth in the area of wind farms will be seen over the next decade [B1].

2.4 Hydro Generation

Numerous hydroelectric plants are in operation across Alberta. Construction of these plants began in the Canmore region as a new source of electricity to feed the growing city of Calgary.

At present, few companies in Alberta still operate hydroelectric facilities. TransAlta Utilities owns the majority of these sites, using them to produce electricity during peak loading hours and as emergency sources for black-start procedures. Located on the eastern edge of the Rocky Mountains, these plants harness the runoff of mountain streams and rivers producing limited amounts of electricity. This is due to small water flows and restrictions on reservoir size and headwater, as compared to larger installations such as those on Manitoba's Nelson River system or Quebec's James Bay.

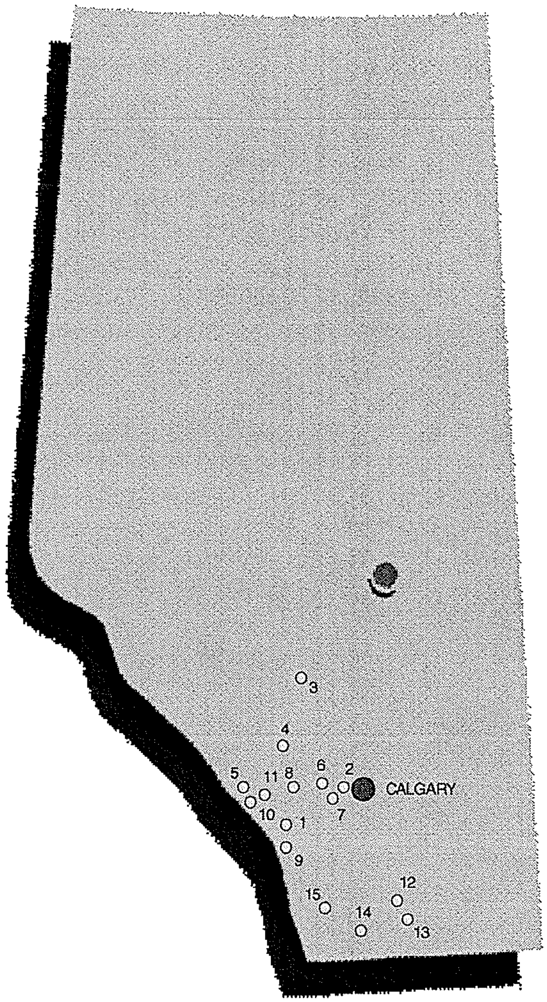
Recently, additional hydroelectric development began in the southern region of Alberta nearing the US border. ATCO Power, Epcor, and Canadian Hydro Developers are all developing projects in this area.

The following table shows hydroelectric plants with capacities greater than 10MW:

Project Name	*Owner*	*Installed Capacity (MW)*
Barrier	TransAlta Utilities	13
Bearspaw	TransAlta Utilities	17
Big Horn	TransAlta Utilities	120
Brazeau	TransAlta Utilities	355
Cascade	TransAlta Utilities	36
Ghost	TransAlta Utilities	51
Horseshoe	TransAlta Utilities	14
Kananaskis	TransAlta Utilities	19
Pocaterra	TransAlta Utilities	15
Rundle	TransAlta Utilities	50
Spray	TransAlta Utilities	103
Chin Chute	Irrican Power	11
Raymond Reservoir	Irrican Power	18
Taylor Coulee	Epcor/Can.Hydro	12.7
Old Man River	ATCO Power	32
Total	-	866.7

Table 4-Hydro Generation in Alberta >10MW

The following map shows the location of hydro plants. The next section discusses their interconnection to the Alberta transmission system.



Legend

1 - Barrier (TransAlta)
2 - Bearspaw (TransAlta)
3 - Big Horn (TransAlta)
4 - Brazeau (TransAlta)
5 - Cascade (TransAlta)
6 - Ghost (TransAlta)
7 - Horseshoe (TransAlta)
8 - Kananaskis (TransAlta)
9 - Pocaterra (TransAlta)
10 - Rundle (TransAlta)
11 - Spray (TransAlta)
12 - Chin Chute (Irrican Power)
13 - Raymond Reservoir (Irrican Power)
14 - Taylor Coulee (Epcor / Can. Hydro)
15 - Old Man River (ATCO Power)

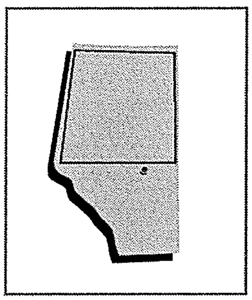
Figure 4-Hydro Generation in Alberta >10MW

2.5 High Voltage Transmission System

The Alberta transmission system is a diverse network of lines ranging in voltage from 69kV on the low side to 500kV on the high side. Lines energized at 240kV are the workhorse of the grid, carrying the bulk of electricity from one region to another. Within regions, 138kV lines form the major collector and supply lines. The use of 69kV lines for transmission is still widespread in rural areas, but for longer transmission lines, higher voltage links are used.

A regional approach to describing the transmission network throughout Alberta offers the best view of how the system is constructed. Each region has specific reasons for constructing lines the way they are, as well as individual development plans. Logically dividing the province into three sections gives the following regions: northern, central, and southern Alberta. Following regional descriptions, a brief discussion on deregulation and the challenges is creates can then be presented. The section concludes with a description of potential high capacity development and export lines.

2.5.1 Northern Alberta



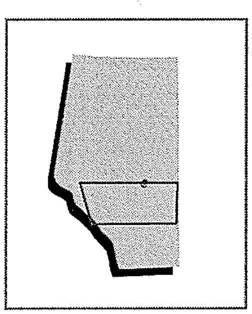
The northern region of Alberta contains the same development restrictions faced by nearly all provinces in Canada. The weather conditions are colder and the poor terrain more difficult. Population is sparse with roads and infrastructure often very isolated. Building high-capacity transmission lines to traverse this area is not economically viable without a large load or generation source to justify it. Northern Alberta has all of these scenarios.

The western half of the northern region contains small communities with limited amounts of electrical generation and industrial load. For these reasons, only 138kV and some 69kV lines are employed. Two 240kV lines link the region to the high-capacity network near Lake Wabamun to the south.

The eastern half of the region contains Fort McMurray and Cold lake oil sands development projects. These major industrial sites generate significant amounts of electricity through co-generation. At present, only two 240kV circuits exist to link each of these areas to the backbone network. Locally, 138kV infrastructure collects generation and provides connection to 240kV lines for transmission south.

Development in the area is limited with the exception of the Fort McMurray area. Due to increasing generation capacity, construction of an additional 240kV transmission line from Fort McMurray to a substation northeast of Edmonton will begin in 2004. Discussions have also begun for a new HVDC transmission line linking Fort McMurray to the Pacific Northwest area of the United States. This project known as "Northern Lights" and would allow generators to sell electricity directly into the lucrative California and Oregon/Washington markets.

2.5.2 Central Alberta



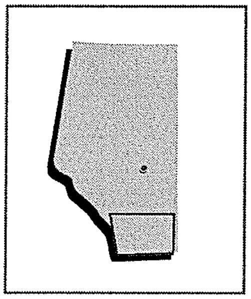
This region of Alberta is arguably the most dense and complex of the entire province. The geography of the region is more flat, and as a result more conducive to construction of transmission lines. The major urban areas of the province, Edmonton and Calgary, are large load centers and require extensive lines to provide supply. Fortunately extensive coal reserves existing west of Edmonton near Lake Wabamun, allow large thermal plants to be constructed.

Multiple 240kV circuits transport electricity from the thermal plants in all directions. Lines extend to Edmonton in the east and to Calgary via a utility corridor to the south. Lines also extend to the northwest and northeast feeding those respective areas of the province. Lines extending south terminate southeast of Calgary at Langdon substation. This substation also serves as the northern terminus of the 500kV tie line to BC Hydro.

The use of 138kV lines is extensive throughout the central region of Alberta. These lines provide power supply within the major urban areas of Calgary and Edmonton, but also supply to the concentrated refinery area northeast of Edmonton. Circuits extend across the eastern half of the central region to the Saskatchewan border. Transport lines also connect hydro generation and petrochemical plants in the western half of the region to the 240kV corridor lines in the center.

Development plans are extensive within this portion of the province. Additional 240kV lines are planned extending east from the central corridor, and to the southern area of the province due to development of wind generation. Another proposed project would increase capacity within the north-south corridor using either 500kV AC or HVDC lines.

2.5.3 Southern Alberta



The southern region of the province, while increasingly populated, lacks the population density, generation, and load to justify construction of many 240kV circuits. For this reason, predominantly 138kV circuits serve the area. The geography of the area is diverse ranging from mountainous, hilly terrain near the Rocky Mountains to the prairies and badlands regions of southeastern Alberta.

Significant urban areas like the city of Lethbridge and the major natural gas processing facilities of the Empress area are the primary sites currently served by 240kV lines. Lines connecting ATCO's Sheerness generating station and McNeil HVDC Converter station also extend into this region.

Circuits energized to 138kV form the majority of the transmission network throughout southern Alberta. Lines extend from the British Columbia border to the Saskatchewan border, supplying larger towns and cities with electricity as well as the rural distribution network.

Development in this region is limited. Plans for expansion of the Empress Gas Processing Station and the wind farms of the southwest may justify new 240kV lines extending to these areas. Also, potentially new coal and gas-fired generating stations near Brooks and Medicine Hat will spur the need for increased transmission capacity to these sites.

2.6 Deregulation and Asset Ownership

Deregulation of the power system is a complex process still under development in many ways. Problems with the implementation of deregulation were seen recently in California and Ontario, highlighting the downside of deregulation and what can happen when the system fails. Alberta has been implementing deregulation for the past several years and continues to this day. The following section is not an attempt to explain the operation of a deregulated power system, but rather a description of the challenges faced by an owner and operator of transmission infrastructure within the deregulated environment.

Within the deregulated environment, generators produce electricity and market it to buyers through energy trading contracts. This allows retail suppliers of electricity to purchase power competitively and attempt to achieve fair and just pricing. Regulated rates of return on the asset base, or *rate base*, generate revenues for the transmission system owner. This rate base is the present value of assets deemed necessary for operation of the transmission system. A rate of return equal to a percentage of the value of those assets is predetermined and fixed. The owner/operator of the asset receives revenue based on that rate of return for the duration of the expected lifetime of that asset. Developers bid on contracts to build new infrastructure, and thus the opportunity to obtain the fixed revenues guaranteed by it. This process is supposed to guarantee that the ratepayers of Alberta receive the infrastructure required, for the best price possible.

As good as all of this seems, there are difficulties in operating the transmission system that come along with it. The first, and foremost is the problem of asset ownership. When multiple parties bid on contracts to build infrastructure, ultimately the system fragments into portions owned by many different groups. This makes operation and maintenance complicated due to the additional communication and co-ordination required between asset owners to complete everyday tasks. Access to sites may be restricted because equipment resides inside another company's substation. The recordkeeping involved along with service and operational agreements make management a tedious task. In the end, the system continues to operate, but the management of the system is increasingly complicated as compared to a complete system operator such as a crown corporation.

With reference to the topic of this thesis, the communication system of a transmission utility is analogous to a service provider with only a handful of customers. The needs of your own system always come first, but other entities requiring access to the network may also request service. Cooperation between utility companies often requires that significant traffic carry through to other utilities communication networks. This limits the control of the end user to determine such critical factors as equipment type, channel latency, reroute capability, and network synchronization. As a network owner and operator, this undermines capacity planning and makes the co-ordination of system outages and maintenance more complex.

2.7 Capacity Development Projects

The province of Alberta has seen significant growth over the past decade. Fueled by higher prices for oil and natural gas, the petroleum industry has experienced a boom in construction. This factor is one of many that combined with little new development of power system infrastructure, has stressed the power system nearly to the point of failure.

To combat the problem the Alberta Electric System Operator (AESO) has planned several new system capacity upgrades. These include the North-South Corridor 500kV AC upgrade, Genesee Thermal Plant Expansion, and the Dover – Deerland 240 kV line. A private venture to develop a merchant transmission line from Fort McMurray to the Pacific Northwest is also under review.

One major project connected with these planned system upgrades is the Telecom Maintenance Replacement project. The goal of this project is to replace the existing analog-based communication infrastructure with newer, digital equipment with increased capacity. Command and control of the power system will be enhanced through the improved reliability of new equipment, combined with easier maintenance and increased future growth capacity. The following sections detail the many decisions and processes encountered when planning for a construction project of this magnitude.

3

3. Communication Requirements

The core topic of this document is to detail the processes and engineering design issues encountered when planning to construct a new, digital communication network. It is common for two paths to bring an organization to this point - replacement of an existing analog-based network, or starting new and building a network from the ground up.

Inevitably, the question arises why an electrical utility requires its own private communication network, and why should a utility invest millions of capital dollars to construct one. There are several components to the answer, the most direct of which is to facilitate command and control of the power system, carrying teleprotection between substations and scada circuits back to the system control center. Emergency response to system outages is also a requirement, using land-mobile radios to direct field crews when the conventional telephone system is unreliable. With the basis for operating a large area network established, a discussion of additional functionality can begin.

Several steps are required to justify and create the overall communication development plan. This process applies whether one is rebuilding the communication network or starting new. It begins with asking how much communication capacity is required. Answering that question leads to the next: To what reliability objective should the system be built and what latency is acceptable? A parallel question also arises at this point asking how much additional spare capacity built into the network is sufficient to accommodate future growth. Answering these three key questions permits detailed design to proceed and the incorporation of other issues such as network link planning, control points, and system restoration.

A final problem, and one often overlooked, is network synchronization. Keeping a network synchronized is paramount to operating a stable, reliable system. Addressing synchronization early is critical to avoiding problems later during system commissioning.

3.1 System Design

3.1.1 Analog versus Digital: why upgrade?

Two specific factors lead to a complete system rebuild: available bandwidth and ongoing maintenance. Either one of these can justify the need for new construction, or in the case of the AltaLink network, both at the same time.

The existing analog communication infrastructure is more than twenty years old. Costs to maintain the existing communication network are climbing, combined with increased difficulty in obtaining spare components. This puts reliable operation of the network in question, and escalates the possibility of a sustained forced outage.

Capacity, or lack of it, is also a critical factor motivating a system upgrade. As substations and communication facilities have new equipment installed, these devices require additional bandwidth for remote monitoring and control. Substation networks are becoming more common as relays are renamed Intelligent Electronic Devices (IED) for the additional functionality they contain. Extending Ethernet to the substation is rapidly becoming a requirement. It would be possible to obtain the additional bandwidth required using more analog radios, assuming one could obtain the hardware and the licenses to operate, but it makes more sense from a long-term operations perspective to make the jump to digital and embrace the advantages it brings with it.

An additional factor supporting a technology upgrade from analog to digital is the staffing component. Many technologists experienced in maintenance of the analog equipment are nearing retirement age. New graduates are trained primarily on digital platforms and do not have the skills necessary to maintain the older equipment. This adds another element of risk to keeping the analog network running.

3.1.2 System Capacity

'Circuits' are individual point-to-point connections analogous to a phone line connecting one site to another. The number of circuits operating in a network, or 'circuit count' is the common denominator for determining bandwidth quantities required.

The initial stages of a channel capacity plan involve identification of all types of circuits and their associated bandwidth. When replacing an existing network, the majority of this assessment is already complete and the circuit count can be easily be determined. The goal is to determine the circuit count and the associated bandwidth, sum the total bandwidth required, and obtain a minimum capacity value for the transport network.

Within the AltaLink network, as with most utility networks, the circuit count contains categories of circuits: teleprotection (including relay-to-relay direct communication and transfer-trip signals), supervisory SCADA, Voice off-premises extensions (OPX), mobile radio access, and operational Wide-Area-Network (WAN). Before examining the requirements of each of these circuits, a brief explanation of each is necessary.

<u>Teleprotection</u>: Circuits used to enhance reaction time of relay protection devices in response to system faults. These circuits allow relays to communicate while monitoring transmission lines. When a relay protecting one end of a transmission line senses a line fault and initiates a breaker trip sequence, the signal propagates to the relay monitoring the remote end of the line causing it to trip also. This provides benefit in fault clearing time because the remote end relay does not wait to sense the fault. Given the operation of these circuits and the assets they protect, they are the most critical in nature and uninterrupted service is a top priority. In addition, knowing that the isolation of a line fault relates directly to the time taken to send trip signals between relays, network latency is a critical factor. Additional explanation is available later in the section.

<u>Supervisory SCADA</u>: Scada or Supervisory Control and Data Acquisition channels are the basis of the system command and control structure. Remote Terminal Units or RTU's are the interface at the substation, collecting status information and providing control points to interface with substation controls. Operators monitor the power system through status information relayed to the control center via supervisory circuits. Operators can also issue control commands to remote sites using these circuits. For obvious reasons, supervisory circuits are the next highest priority on the circuit list.

<u>Voice OPX</u>: These circuits are the telephone lines located at the substation. Off-Premises Extension or 'OPX' circuits are the local telephone lines connecting the remote site to the Head Office telephone switch.

These circuits provide convenience to maintenance staff by allowing direct telephone access to the remote site. This is particularly useful during commissioning and during system modifications.

Mobile Radio Access: These circuits, also carrying voice traffic, permit communication from the central office telephone switch to a specific mobile radio repeater. They also allow for mobile radio users to access the POTS (Plain Old Telephone System) by dialing a specific code.

Operational WAN: The operational WAN portion of the network consists of an Ethernet channel branching out across the network providing remote access to substation and radio site networks. This traffic is for remote access to substation devices and is not critical in nature. For that reason, it has the lowest priority of service. In the event of system failure, Ethernet circuits will be the last ones flagged for restoration. Within the Ethernet traffic, the number of concurrent users is few, and therefore allocated bandwidth of less than 10 Mbps is typically sufficient for use.

Currently analog circuits carry each of these circuit types with the exception of the Operational WAN. When converted to a time-division multiplexing (TDM) digital platform, each circuit type requires the following digital bandwidth:

Circuit Type	***Bandwidth Required***
Teleprotection	64 kbps
Scada Supervisory	9600 bps
Voice OPX	64 kbps
Mobile Radio	64 kbps
Operational WAN	10 Mbps

Table 5-Power System Circuits and Bandwidth

The wide-area-network can utilize any amount of available bandwidth ranging from 64 kbps to in excess of 100 Mbps, depending on the transport medium employed and the circuit density carried on that medium.

Under the standards defined by the American National Standards Institute (ANSI), the digital equivalent of analog circuits is adapted to form the Asynchronous Digital Signal Hierarchy (ADH). This specification is for North America only and provides a breakdown as follows:

Circuit Type	*Equivalent Circuits*	*Bandwidth*
DS0 (Digital Signal Level 0)	1	64 kbps
DS1 (Digital Signal Level 1) = 24 x DS0 + framing bit	24	1.544 Mbps
DS2 (Digital Signal Level 2) = 4 x DS1 + control bit	96	6.312 Mbps
DS3 (Digital Signal Level 3) = 7 x DS2 + control bit	672	44.736 Mbps

Table 6-DSX Circuits and Bandwidth

The above table is a reference for future reading. Specifications of equipment or technical details of circuit routing will refer to the hierarchal levels listed above. Microwave radios capable of transmitting any number of DS1 circuits or multiple DS3s are currently available. Within the utility environment, deployment of these radios consists of major spurs or smaller capacity backbone links.

Above the DS3 level, communication platforms move to a SONET or Synchronous Optical NETwork platform. Sonet is another standard set out by Bellcore™ and ANSI for higher capacity transport links. Although Sonet had its beginnings with optical fiber links, several microwave radio manufacturers have products that now meet the Sonet interface requirements. For further background information, the following table describes the layers of Sonet capacities and their equivalent number of analog circuits. Note that OC-N (Optical Carrier level N) and STS-N (Synchronous Transport Signal level N) are equivalent capacities, differing only in the medium to which they transmit. Optical fiber is designated OC-N whereas copper wires are given the STS-N designation. For simplicity, only the optical carrier levels are listed:

Sonet Capacity	*Equivalent Circuits*	*Bandwidth*
OC-1 (Optical Carrier Level 1)	672	51.84 Mbps
OC-3 (Optical Carrier Level 3)	2016	155.52 Mbps
OC-12 (Optical Carrier Level 12)	8064	622.08 Mbps
OC-48 (Optical Carrier Level 48)	32256	2488.32 Mbps

Table 7-OC-n Circuits and Bandwidth

Microwave radio links of Sonet OC-3 capacity are available today with deployment typically reserved for the network core, or backbone of the system.

3.1.3 An Examination of the AltaLink Network

Beginning to plan for a system upgrade requires assessment of the number of circuits currently in operation. This involves examining the current hardware and summing the total circuits carrying actual traffic and those reserved for spare capacity. The replacement digital network must be able to carry at least this number of circuits.

Examining the existing network topology dictates how circuit concentration will take place, and gives a good idea of where higher capacity transport radios are required. In the AltaLink scenario, the network is broken into three constituent components: the backbone, the major spur, and the last mile. The following sections present each scenario, and describe the capacities required.

To begin, the following figure shows the existing AltaLink network. It can be seen that the backbone of the network is in the form of a loop extending from Calgary in the south to north of Edmonton. These links red in color are the OC3 capacity. The major spurs connecting into the backbone loop are multi-DS1 in capacity and are blue in color. These links make up the majority of the microwave hops installed in the network. Finally, the green links indicate last mile, or 2-DS1 or less capacity links. In an effort to keep the figure legible, only a representative few of these hops are visible on the figure. This is because there are simply too many to include them all. The objective of the figure is to display the top-down nature of capacity planning and present an example of how this is accomplished in actual practice.

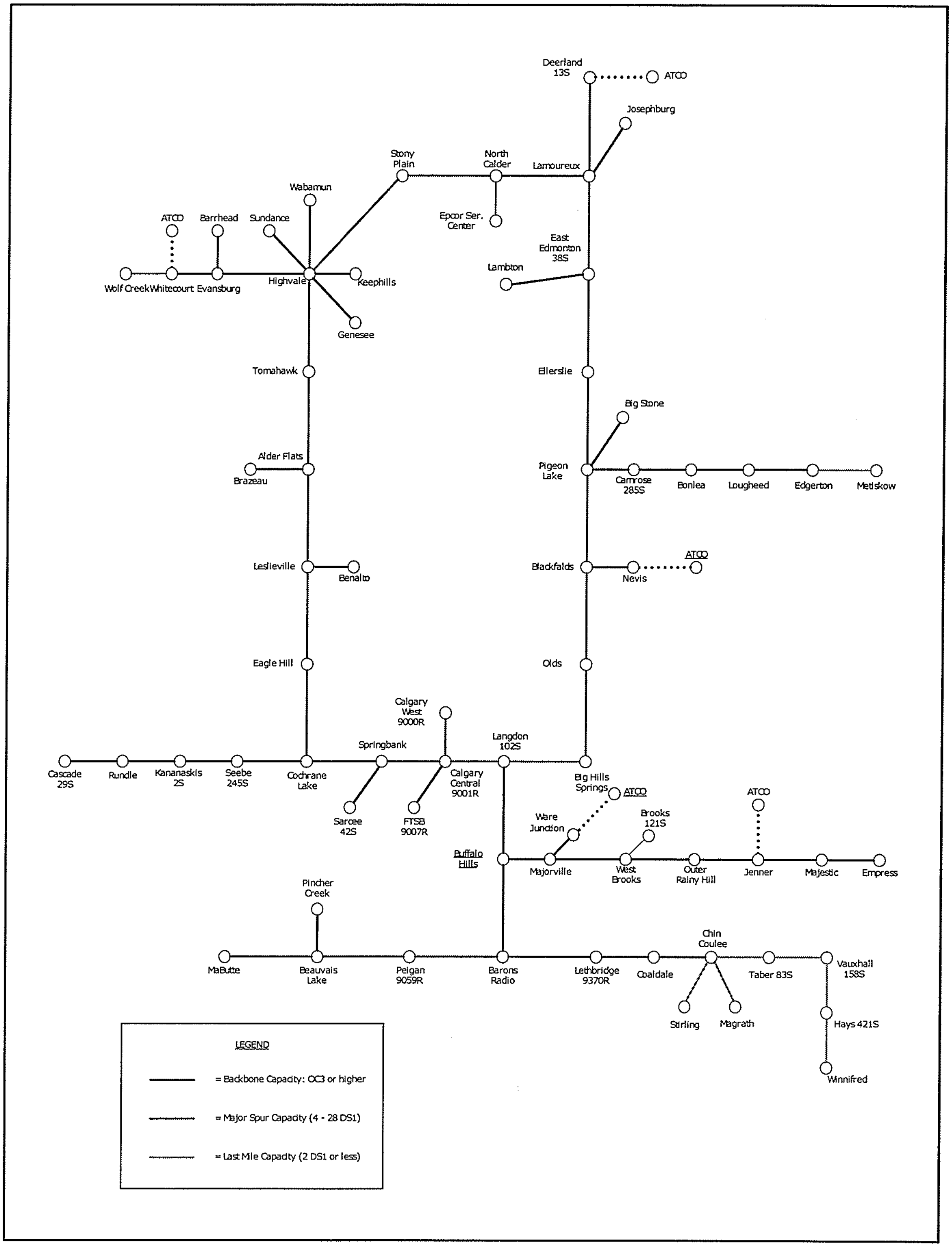


Figure 5-AltaLink Network Capacity

The Backbone

Knowing that the backbone of the network transports the highest number of circuits, examination begins there. The backbone acts as the concentrator of the system, collecting circuits originating on spurs and transporting them to other substations or the system control center. The current AltaLink backbone contains 600-channel capacity, of which nearly all is in active service. This number of circuits is equivalent to one DS-3 or an OC-1 circuit, with minimal spare capacity. Knowing that a DS-3 is already in use, future growth combined with rapidly expanding demand for Ethernet services will insist on installation of more than OC-1 capacity. The next commonly available capacity is OC-3.

The backbone of the AltaLink network is in the form of a ring. What this implies is that route diversity is also a requirement, assuming that the desire is to achieve the same or better level of redundancy using the new digital equipment. This assumption will play a critical role as it affects spare capacity calculations and necessitates a more complicated network design.

The location of the system control center and critical power stations are also potential problems, because constructing direct links with sufficient capacity to the communication backbone may be difficult if not considered during route planning. In the AltaLink network, these sites are specified for a minimum of 28-DS1 transport links.

Another factor that complicates backbone capacity planning is requirement to carry communication traffic for other utilities. In the regulated power system environment that AltaLink operates, utilities often co-operate and share excess capacity where available. Doing this allows network construction to be simplified and is more efficient since it prevents duplication of infrastructure. Consultation with other entities must take place while in the planning stage, to ensure other capacity requirements and assumptions not overlooked.

The Spur

Spurs act as tributaries to the network backbone, transporting circuits for further transportation to remote substations or the system control center. Since the backbone network eventually carries these circuits, it is obvious that they should have fewer circuits than the chosen capacity of the backbone network. In AltaLink's network, this restricts capacities to 28 DS-1 or less. Typical capacities chosen are 4-DS1, 16-DS1, and 28-DS1.

Choosing capacities for spur communication links is easier than backbone links because they typically carry traffic in only one direction – upstream towards the backbone. Excess capacity for Ethernet traffic can be included, along with spare DS1 capacity for other utility use. As well, traffic can be separated based on DS1, providing for easier capacity planning and interfacing to the backbone network.

Consideration of path length and frequency must also be included in spur route planning. While 7-GHz radios are typically reserved for backbone paths due to the larger bandwidth capabilities and longer hop length, they will be used where the 7-GHz path performance is significantly better than that of any other option, such as 5.8-GHz spread-spectrum or 15-GHz.

The Last-Mile

Last mile links are slightly more complicated than spur links because the number of options is greater, making cost a more significant factor in determination of capacity. The desire is to install as much capacity as can be justified, so that additions to the network such as Ethernet can be incorporated later more easily. Multiplexer requirements are also a factor because requiring a multiplexer to interface to a DS1 capacity radio adds significant cost over the single-channel, direct-interface option.

Typical capacities available for last mile links are single-channel (1-circuit), 1-DS1, 2-DS1, and DS1+Ethernet. For the AltaLink network, an array of these options will be deployed, depending on the number of circuits required at the site and the significance of the site to the power system.

3.1.4 System Reliability

Determining system reliability for a power system communication network is a complicated task. Due to the potential liabilities for power system outage caused by a communication failure, the reliability of the network must be as high as reasonably possible. Complicating the issue are factors that vary depending on the equipment used, geographical location, and the weather. Ultimately, the only solution is to design the network mitigating as many risks as possible, and preparing emergency response plans for all others.

Assessing the risk and reliability of a communication network begins with a top down approach, similar to capacity planning discussed earlier. The backbone of the network requires the highest reliability because it carries the largest number of circuits, and is where a forced outage would cause the most harm. Included with the backbone are the system control center and the major generating stations and substations. Network spurs are next, followed by individual last-mile links. In AltaLink's system, this means the backbone followed by the spurs connecting to that backbone, and finally the individual links to the substations.

How does a utility assess reliability and ensure that the design of a new communication network addresses all of the potential risks? To begin, a reliable network has a number of contributing factors. These are as follows:

- High-reliability microwave path calculations
- Length of microwave radio hops.
- Equipment protection
- Uninterruptible power supplies and stand-by power generation.
- Private land-mobile radio for emergency restoration.

The foremost item determining the reliability of a communication link is the radio path calculation. This calculation takes into account the effects of the terrain on the path, and allows the design engineer to observe the effects of different configurations on the expected reliability of a given path. Software tools available today make performing these calculations simpler, and are the first step in the path design procedure. Section 4 of this document presents a detailed inspection of a radio path calculation.

Further to the path design calculations described previously, keeping the radio path lengths short - less than 50 km - helps to ensure higher reliability. Microwave radio signals attenuate over longer distances, and as a result shorter path lengths correlate to higher received signal strengths. The downside to shorter path lengths is an increase in the number of communication sites required. Consideration of this cost is imperative when planning repeater sites – sites that simply capture an incoming signal, amplify, and rebroadcast it. The additional cost of repeater sites may in fact justify the installation of a long-haul fiber link in its place.

Within the radio facility, choice of equipment and protection options directly influences overall link reliability. Manufacturers today offer radios designed for operation in one of four protection modes: frequency-diversity, space diversity, hybrid diversity, and quad diversity. The use of each protection option varies depending on the path calculation and the region of operation. Section 4 describes protection options and those selected for use on the AltaLink network.

Uninterruptible power supplies or UPS are the emergency back-up power sources allowing a communication network to function when station service has been lost. They are a requirement of all high-reliability communication sites. The UPS consists of a battery charger and a battery bank. Station AC service powers battery chargers that keep station batteries charged and power the communication radios and multiplexers. When a station AC service interruption occurs, the communication infrastructure is unaffected because it can continue to operate using the battery backup. Battery standby time is a design issue with minimum standby time in excess of 8 hours. The addition of a standby generator provides extra security by extending backup AC service. The quantity of fuel stored on site limits the operation time of the generator, but operational periods in excess of three days are typical.

Private Land Mobile Radio is a secondary communication system available during times of system outage and congestion on the cellular phone networks. Owned and operated privately by the utility, this system operates on top of the microwave communication infrastructure and is available exclusively for their use. The primary benefit to operating a mobile radio network is that system restoration time is reduced and an alternate mode of communication is available when public networks cannot be relied upon. Command and control structures can more efficiently direct emergency crews to repair the network, and in return, outage time decreases.

3.2 Future Planning

3.2.1 Installed Capacity

The objective of this section is to present the high-level decision making process used when selecting hardware and attempting to accommodate all future communication requirements for the next ten to fifteen years. This is not an easy topic to describe for all situations as other unforeseen factors such as new substations may influence the decision process.

When rebuilding a communication network, there are motivating factors that determine how much capacity is required and how much will be actually installed. The obvious minimum is sufficient capacity to carry all existing circuits. What is not obvious is how much spare capacity will be required to accommodate all new circuit requirements for the duration of the expected lifetime of the asset. Further complicating the issue are the type of potential circuits required and how much bandwidth is assignable to any one particular circuit. Available hardware also plays a role in this decision, as the availability of hardware by the manufacturing industry will influence the type and capacity installed. A final consideration, and likely the biggest one, is overall cost.

To begin, selection of the operating frequency must be complete. The path analysis calculation determines which frequency bands meet the reliability objectives and which equipment platforms are acceptable options. Once the equipment options are available, the engineer responsible for network planning must determine how much capacity is acceptable.

A guideline used by AltaLink is to install a minimum of twice the network bandwidth of the installed system. For example, on the AltaLink backbone the existing system has a capacity of 600 channels (DS3). The guideline requires installation of a minimum of 1344 (2 x OC1) channels to replace it. When compared to equipment available in the industry, the only acceptable option that meets or exceeds the requirement is OC3 capacity. This is deemed to be acceptable because a) OC3 bandwidth is an industry standard and there are many multiplexer equipment options available, b) the new types of circuits expected in future installations, primarily Ethernet, demand significantly more overall bandwidth, and c) the cost is deemed acceptable when compared to the minimum requirement option.

Also affecting the capacity installation, and in particular on spur hops, is the ability to upgrade hardware to higher bandwidth capabilities later. In the case of the AltaLink network, spur radio hops are specified with the ability to carry 28-DS1 circuits although they are only populated with interface cards to a capacity of 16 DS1 circuits. What this does is eliminate the need to replace the platform when additional capacity is required, up to a maximum of 28 DS1 circuits. Only additional interface modules are required to add capacity. An incremental cost earlier reduces larger replacement cost later.

Multiplexer selection follows the radio selection process. Multiplexers act as the equipment interface to the communication network and are critical to the functionality of the overall system. Most telecom manufacturers offer equipment that is very flexible and expansion can be accomplished with minimal effort. Consideration of these issues when selecting multiplexer equipment will prevent the scenario where additional circuits are required but no space is available on the multiplexer. In an attempt to eliminate this potential problem, AltaLink's network design requires a minimum of two free interface module slots in all new multiplexer installations.

The following flowchart describes the design process:

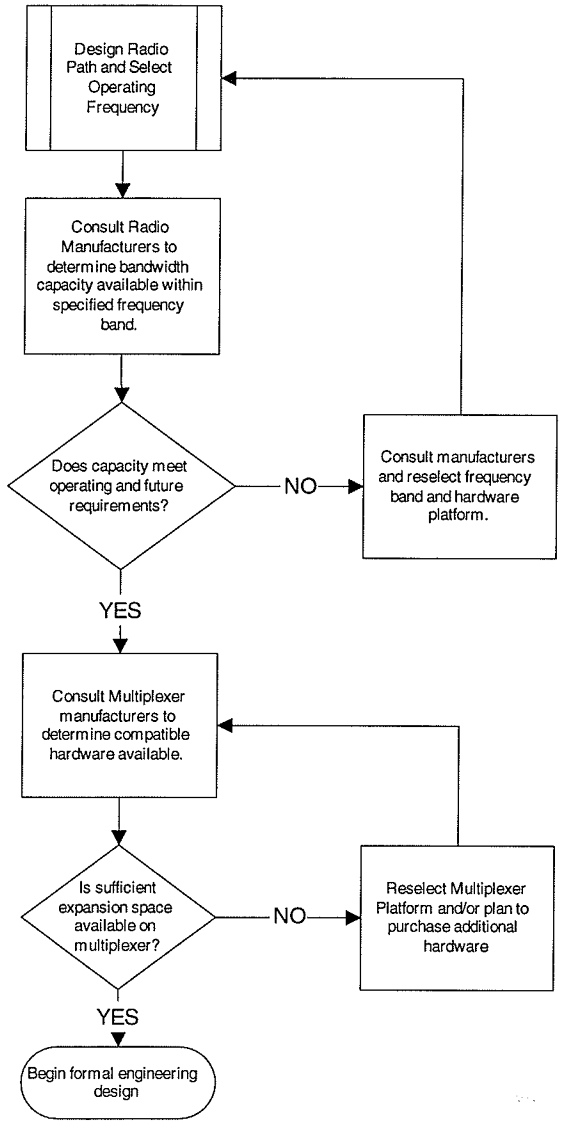


Figure 6-Capacity Planning Flowchart

3.2.2 Expected Growth

Expected growth is always a difficult question because system growth in a deregulated environment is dynamic. New generators or large industrial loads may plan to build in one area only to change their mind and relocate somewhere else. This makes the role of the planning engineer difficult at best.

For AltaLink utility, the province of Alberta has a Transmission Administrator overseeing the transmission system environment and publishing a 10-year development report [B1]. This document permits long-term planning to take place with a marginally improved forecast of new system growth requirements.

As a rule, significant space for expansion is included in any new link design. As per the Transmission Administrator of Alberta's interconnection guidelines [B4], any new generator or load exceeding 10MW in capacity requires fewer than five new circuits to accomplish all critical system communication requirements. These are scada, OPX telephone, substation WAN, and two channels of teleprotection. Sources or loads less than 10 MW in capacity do not require any circuits, but may have scada circuits to monitor connection status.

For those sites requiring multi-channel communications, new radios are not installed with less than one DS1 (24 circuits) of capacity. This leaves at least twenty spare channels available for future use. For those sites where teleprotection channels are required, installation consists of a minimum of four DS1 channels.

Expected growth, while difficult to predict accurately, is incorporated into an overall network design. Installing communication links with excess capacity ensures that new requirements can be accommodated without significant added cost and effort.

3.3 Network Security and Restoration

3.3.1 Security Planning – Loop Design

The reliability of communicating with a remote substation is not entirely secure because most facilities have only one path linking them to the network. When that link fails, communications to that site are lost unless an alternate route is available. This is where 'mesh' or 'loop' design can improve the reliability of communicating with a given site. The following figure displays a typical mesh design plan:

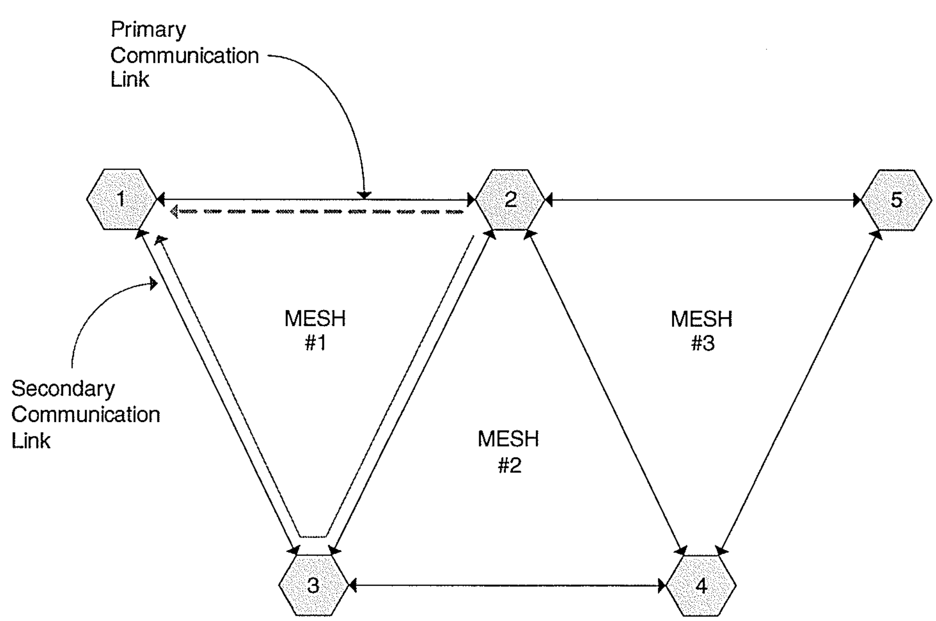


Figure 7-An Example of Mesh Network Design

Loop design implies that communication links to a site arrive from differing directions – otherwise known as route diversity. The links to that site, when displayed on paper, form a mesh or 'loop', and hence the term. Loop design improves the reliability of communicating with a given site but only if certain criteria can be achieved. These are:

- Ability to monitor communications to a site and switch routes as required.

- Diverse communications path does not follow a similar route as original path. Specifically, this requires a separate radio link to an alternate point in the network.

Another factor is cost. Sites where one communication link would normally suffice require two links to be part of a loop. This doubles the cost of communications to the site. Only the network planner can determine if the added expense is justified. For the AltaLink network, only those sites deemed critical – major backbone sites – have loop diversity in their planned operation.

3.3.2 Alternate Control Points

Monitoring and controlling a communication network carrying teleprotection traffic is fundamental to system reliability. System operators need to know when communications to an area have failed and are in need of repair. Without this flow of information, communication system operation cannot be monitored and reliable operation not guaranteed. In addition, because the communication network carries power system scada information, reliable operation of the power system is at risk when communications fail. It is for these reasons that alternate or backup control sites are necessary.

When planning a communication network, the ability to monitor and control from several sites is mandatory for the reasons described previously. If a primary site fails then the others are available as backup. Operation from the secondary site activates until restoration of the primary site is complete.

The ability to change control sites and evaluation of a Network Management System (NMS) to operate correctly when communication to the network is lost, is critical to the reliable operation of the network.

In AltaLink's network, construction of the command and control network is in layers. These layers have their own levels of redundancy and alternate methods of control. A description of these is next:

<u>Site Configuration and Control</u>

At each communication facility, the base level of command and control is available. Field technicians are equipped with software that allows them to connect with each multiplexing node and radio locally. This is necessary for on-site verification of configurations and troubleshooting.

In a worst-case scenario where all other means of communicating with a facility have been lost, this method of system restoration will be utilized. Dispatching of field technicians begins from an emergency command and control facility. Sites are systematically restored, beginning with the highest priority sites and working towards the lowest priority.

Field technicians communicate with each other using a secondary means of communication, likely two-way portable radio, to co-ordinate system restoration. If the public-switched telephone network (PSTN) is available, cell phones may also be used.

<u>Network Management System (NMS)</u>

The network management system is an overlaying layer used to monitor, configure, and restore the network. Located along side the main power-system control infrastructure, the NMS operates in a primary and secondary configuration. When the primary configuration cannot communicate with the active network any longer, or is disabled, the secondary system automatically takes over. For increased reliability, the locations of the primary and secondary systems are physically separate.

The use of primary and secondary systems is paramount to the reliability improvement offered by a network management system. The NMS is the only command and control device that maintains an active display of functional communication paths. Because of this, it is the device responsible for automatically rerouting communications circuits within the asynchronous transfer mode (ATM) and controlled-TDM domains.

Scada Redundancy

The power-system control network, or scada system, controls the flow of electricity across the provincial grid. Its operation is only as reliable as the communication network responsible for transporting scada information to the control center. The scada network operates using primary and secondary servers, similar to that of the communication network NMS. For that reason, primary and secondary servers with operator interfaces at each location are a requirement. Redundant communication paths between the servers also help to ensure the highest reliability possible of the overall system.

3.3 System Restoration

A restoration plan for a communication network is a major component of any utility's overall emergency response plan. The plan provides guidance during a time of system disturbance or outage and sets the direction for restoration of service. Since the communication network is essentially the eyes and ears of the power system operator, it is critical to providing real-time information to those departments that ultimately control the delivery of electricity to customers.

The restoration process consists of several sequential stages beginning with an initial assessment of the severity of the disturbance. Following the assessment, the next step is to formulate a plan of attack that will bring the system back to normal operation. Once complete, field operation staff acts on the plan. Once the system is restored, a debrief takes place analyzing the effectiveness of the plan and identifying any weaknesses found.

3.3.1 Assessment

As described previously, the communication network is broken down into three categories of service and capacity. These are backbone, spur, and last-mile links. Obviously, the outage of a backbone link takes higher priority than that of a spur link, and a spur link higher than a last-mile link. The effect of the outage on the ability to command and control the network factors into the priority assignment process. For instance, a spur link connecting a major substation to the network would take higher priority than that of a simple backbone repeater site. Consideration for the consequences of the communication outage to the operation of the power system is critical.

The ability to reroute traffic around a link outage factors into the assessment process as it permits allocation of resources to other sites where rerouting is not possible. This is where the technology employed within the communication system proves its usefulness. Asynchronous Transfer Mode and Ethernet systems, when used in conjunction with an intelligent network management system and loop-based network topology, provide additional time to develop a restoration plan. These systems will autonomously reroute traffic through alternate routes to restore service faster than a system requiring human intervention.

Determining the extent of the damage or failure causing the system outage is important when assessing the severity of the outage and attempting to determine restoration time. Management staff must be aware of what caused the outage before estimating how long it will take to repair. Often information is sporadic at best and a best-guess estimate is all that can be determined. An example illustrating this involves the failure of a communication tower and the loss of a microwave radio dish. To the network operator, the radio path is no longer functional. Without knowing what has caused the failure, it is difficult to determine how long the link will take to restore. Replacing a failed component within a radio with one from an emergency stores inventory is faster than that requiring potentially more labor and equipment.

3.3.2 Plan of Attack

With the assessment of the fault condition underway, a plan of attack begins to be constructed that will return the system to operation. Within the plan, three key components influence restoration time. The first is which staff to dispatch to which sites. Field operations staff members each have varying levels of experience and it is often prudent to send the most experienced staff to those sites deemed the most critical. The physical location and expected travel time of field staff may also determine which people travel to what sites.

The availability of spare parts greatly influences repair time as it allows swapping of modular components in the field. Utilities maintain only limited numbers of spare components and therefore the plan of attack must include allocation of components to the most critical sites. Emergency ordering of additional components from vendors may also begin at this time.

Contact with vendors and supporting utilities during development of a plan of attack allows the availability of additional resources to factor into deployment decisions for staff, equipment, and materials. Supporting utilities may have access to experienced staff and additional spare components on hand that can assist in system restoration. Vendors can expedite orders for replacement components to shorten delivery times.

3.3.3 Execution

Execution of the plan of attack begins with communicating the plan to field operations staff. This ensures that staff members receive instruction on the nature of the outage and allows them to prepare for the required work in the field. Field staff can often make preliminary assessments as to the cause of an outage simply by knowing which alarms the outage raised. This permits them to prepare for repair by taking along any specific test equipment or spare parts likely required.

Actual assessment of the extent of the damage and feedback to the utility command center is imperative as it allows management staff to better estimate the time required for return to service. This is especially important in scenarios where critical infrastructure such as a communication towers are in need of repair. The relay of information from the field happens through a variety of means: private land mobile radio, off-premises telephone extensions, and even cellular networks.

Private Land Mobile Radio (PLMR) networks, although expensive to operate and maintain, often permit communication to field staff when all other forms of communication are inoperable. The public switched telephone networks (PSTN) and cellular network can become overloaded during times of crisis and restrict communication via conventional means. As mentioned earlier, PLMR systems permit field staff to relay update information to the command center that can assist the restoration process.

Execution of the restoration plan involves instruction of field staff as to where to direct their efforts to restore the system. Once an initial site is secure, communication with the command center allows redirection of field staff to further affected sites within the outage area. In addition, problems requiring specific assistance from third-party contractors or other utilities can be addressed and additional staff mobilized.

3.3.4 Follow-up

After repairing a system outage and restoring service, a debriefing should take place. This allows crisis management staff to assess the performance of the emergency response plan and gauge its effectiveness. Modifications to the plan can then take place such that the same mistakes do not happen again.

Sparing levels must be examined following the completion of any extensive repair work. This is due to depleted levels of spare inventory and the fact that the utility is essentially operating at a higher risk of extended outage until sparing levels can be restored. In addition, a spares location assessment must take place to determine if sufficient materials are available for a given operating region.

Throughout the duration of the system outage, the monitoring of time-to-repair must take place. This allows crisis management staff to better estimate how long future failures may take to repair. It also allows field operations staff to improve their troubleshooting skills by better recognizing the signatures associated with certain types of failures and better preparing them for troubleshooting and field restoration work.

3.4 Network Synchronization

Network synchronization is an important and commonly overlooked design issue with digital communication networks. Improper synchronization can cause performance degradation and outages that can be very difficult to troubleshoot and repair. One question often asked is why synchronization equipment is required at all. Following that, the next logical question is how a network planner synchronizes the network.

Before leaping into the synchronization process, it is necessary to describe why synchronization is required. Within the AltaLink network, two communication systems are in use or planned for construction: ATM multiplexing over Sonet, and DS1 multiplexing. Each system involves the transmission of data frames containing header information and payload. Each device in the hardware chain contains an internal oscillator providing a reference clock that both sending and receiving ends use to stream data. Since it is impossible to have reference clocks in each device built identical, frequency differences occur. This causes two possible scenarios: the transmitter sends data faster than the receiver can accept it, or the transmitter sends data slower than the receiver expects it. In either case, over time the sender or receiver become too far out of synchronization that they must realign themselves and start over. This is known as a 'slip'.

To further describe the terminology, reference clocks are categorized based on the number of expected slips in a given time period. As described by S.V. Kartalopoulos in [B3], these categories are Stratum Levels. Stratum level 1 is the best performance level and has a slip frequency of less than one slip in $1x10^{10}$ periods. This high level of accuracy is achieved using cesium or rubidium oscillators, and is improved further by combining the reference clock signal with that received from Global Positioning System (GPS) satellites. This type of clock acts as a primary reference source clock or 'PRS' for short.

Subsequent stratum levels are next, in the following table:

Stratum Level	*Minimum Accuracy*	*Slip Rate*
1	$1x10^{-10}$	2.523/year
2	$1.6x10^{-8}$	11.06/day
3	$4.6x10^{-6}$	132.48/hour
4	$3.2x10^{-5}$	15.36/minute

Table 8-Stratum Levels and slip rates

Planning to synchronize the AltaLink network is achieved through a combination of the *Bits* timing model and *Loop* timing model, as described in [B3]. The Bits timing model uses a PRS GPS clock to provide a Stratum 1 reference clock to all devices within a site. All tributary channels originating from that site synchronize to the PRS clock. The Loop timing model uses incoming bit streams to derive a synchronization signal. Tributary channels synchronize to the derived timing signal, propagating the timing signal downstream.

As per manufacturer recommendations and guidelines described in the ITU-R G.811 document, no more than 20 network sites may be connected in sequence without another PRS clock. A new synchronization supply unit (SSU) is recommended after a maximum of 20 network elements to help filter signal jitter and wander.

The network synchronization design specified for AltaLink's network is based on that described in [B5] Spectracom Prototype Network Synchronization plan. Beginning with the location of primary reference sources, strategic sites with many radios, higher circuit concentrations, or varying brands of equipment are chosen to have primary reference source clocks. For AltaLink's backbone loop, this equates to a primary reference clock at each of the 17-sites comprising the backbone network loop. This is because the nature of the loop transport medium is Sonet, and by definition is a synchronous network. To achieve optimum performance, a synchronization source is installed at each node, eliminating the requirement for transporting a primary synchronization signal across any portion of the backbone loop.

As a backup, a synchronization T1 channel (1.544 Mb/s) is transported to one adjacent node via an overhead T1 link available on the microwave radio. Transportation of synchronization timing via a tributary channel within an ATM / Sonet-based payload is not recommended due to synchronization pointer adjustments experienced by Sonet frames. The T1 timing channel from the adjacent node is connected to an auxiliary input port on the GPS clock where it is retimed for distribution. Retiming uses the local GPS signal and internal oscillator to correct for jitter and wander within the timing signal such that the source can be accepted as an alternate source for synchronization timing.

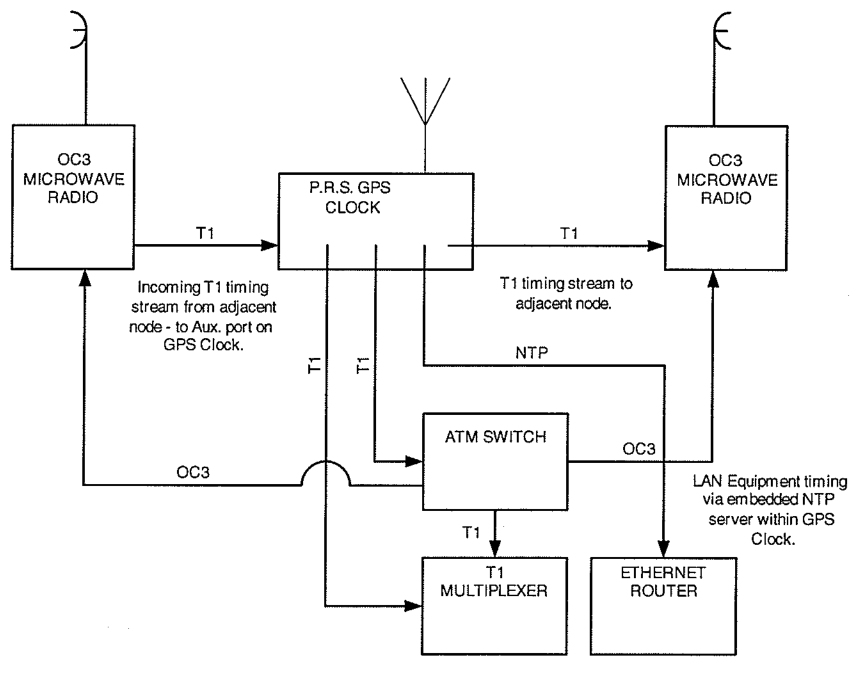


Figure 8-GPS Synchronization Connection Block Diagram

A further consideration when using this planning methodology is to prevent the formation of timing loops. A timing loop is when timing source paths can be traced back to originate from themselves. To prevent this, specific radio links are demarcation zones. Primary or secondary timing source paths do not cross these links. In the event of a source path failure, the communication equipment - i.e. the ATM multiplexer

– determines which source to synchronize under until the primary sync path is restored. This may include a secondary link towards a different reference source, or use of the holdover clock within the multiplexer itself.

Until this point, the focus for synchronization has been AltaLink's Sonet backbone loop. A Sonet backbone is a more intelligent synchronization scheme due to the synchronization performance monitoring capabilities of the ATM multiplexer. This is not always the case on radial DS1 spurs derived from the core loop.

At sites without PRS clocks, a synchronization signal is derived using loop timing and based on the upstream link connecting in the direction of the nearest reference source clock. This link is the primary reference source connection. If that link should fail, the local site would remain in a holdover state and continue to supply synchronization timing to all links downstream from the failure. Additional clocks are installed at other sites where the hop count from the backbone loop exceeds six hops, or interfaces to other utilities are made.

For radial spurs where add-drop DS1 multiplexing occurs, secondary sources of synchronization rarely exist. To develop a secondary source at each site would require a reference clock of some type at each site, and is cost-prohibitive. As a result, DS1 multiplexers resort to 'holdover' mode and depend on internal oscillators to provide a reference source clock. These internal clocks have accuracies approaching that of Stratum-1 reference sources for short durations only. After the initial period, timing performance begins to degrade causing an increased number of slips on the system. The risk caused by this happening is that extended resynchronization time may be required for nodes downstream from the original synchronization disruption. Each time a resynchronization of the chain is required, the furthest nodes cannot resynchronize until each successive unit between it and the new source are synchronized. The only way to mitigate this risk is to either install more reference source clocks or attempt to keep network spurs as short as possible.

The synchronization-planning diagram is included in Appendix A. The area of AltaLink's network south of Calgary is an example of where the synchronization problems previously described may occur. Multiplexer chains are longer i.e. 6 to 10 hops, and as a result accurate source timing is required. This is especially important for DS1 channels that cross-connect to other DS1 channels not timed from the same source. To mitigate the risk, a GPS-based, Stratum-1 primary reference source clock is installed at Calgary, the terminus of all DS1 channels connecting sites in AltaLink's southern Alberta region.

4

4. Radio Communication Link

The radio communication link is the workhorse of the utility communication network. It provides real-time communication to and from remote facilities delivering information required to operate the power system safely and efficiently. Planning a radio communication network requires several different types of radio, based on the bandwidth required and the type of communication traffic carried. Selecting standard hardware for each application is one of the key job requirements of the utility telecommunication engineer, and the topic of this next section.

Prior to examining the three categories of radio link selected for the AltaLink network, a description of basic radio link design is necessary. This includes presenting several radio configurations where deploying these depends on the reliability and performance objectives of the radio link.

The previous section describes the three main types of utility radio communication. These are a) the backbone link, b) the major spur link, and c) the last mile link. Each of these has their own requirements for reliability, performance, bandwidth capacity and latency. In evaluating the hardware planned for use in each of these categories, there are many different factors for consideration. The requirements for each type are shown within each category including details of typical design and installations.

After viewing the standard radio links chosen to meet the needs of the AltaLink power system, the reader can examine the standards developed for AltaLink and compare those to the standards developed within other electric utilities.

4.1 Radio Path Design

Within the AltaLink network, path engineering is crucial to creating a reliable microwave communication infrastructure. Path engineering is a complex area of communication link planning and as a result, there are many factors and decisions influencing the path analysis calculation. It should also be understood that this section is written to highlight the design process and illustrate the research and calculation required in planning a microwave link. The research presented in this section is based on that used for telecommunication carriers. A wealth of research is available to provide guidance, but as the utility communication engineer, I must decide which components are applicable to the needs of the utility communication network. This section outlines the process taken for planning and constructing the new AltaLink digital network.

4.1.1 Microwave Path Objectives

Based on the microwave path design criteria presented in Harris' path engineering course notes [B35], the primary objectives in planning a radio path are to accomplish the following:

- Minimize short-term outage
- Eliminate long-term outage
- Comply with all regulatory guidelines for safe, efficient, and non-interfering operation.

Path design begins with identifying the desired radio path and selecting the desired bandwidth capacity. A description of these options can be found later in this section. Because microwave radio required a clear line-of-sight, selecting sites with higher elevation is a good place to begin.

GPS (Global Positioning System) coordinates identify potential radio transmitter sites. These are used as inputs to the path analysis to generate a path profile. Overhead topographical maps and satellite photos may then be referenced to complete preliminary obstruction checks. If existing radio sites are to be connected, the heights of towers and possible microwave dish elevations must be known in advance.

4.1.2 Microwave Path Frequency

Selecting a radio for this application begins with the operating frequency and bandwidth. Industry Canada administers the licensing of frequencies, and recommends frequencies for utility communication use. Industry Canada document SRSP-307.1 [B8] explains the 7-GHz frequency allocation plan. Industry Canada document SRSP-314.5 [B10] explains the 15-GHz frequency allocation plan. Radio frequencies recommended for power utilities in Canada are as follows, and consist of two 30MHz channels within the 7-GHz band. These channels are located at the lower end of frequency allocation sub-plan 1 and sub-plan 2.

Frequency Pair	*F1 (MHz)*	*F2 (MHz)*
1	7140	7315
2	7440	7590

Table 9-Industry Canada Utility Microwave Frequencies

Use of these reserved frequencies is preferred because they are typically available to the radio path designer. Manufacturers targeting the Canadian utility communication market design their equipment for use in these bands. For example, radios providing OC3 or 155.52 Mbps of capacity require a dedicated 30 MHz channel. Radios providing 28-DS1 capacity require a 10 MHz channel that can be allocated within the 30MHz band reserved by Industry Canada.

As part of the frequency planning process, utility communication links within Canada often employ frequency diversity. What this means is that two frequency pairs, carrying the same information, operate simultaneously on the radio link. Selecting radio equipment that is available in this configuration permits an extra level of protection against radio frequency interference and path fading. It should be noted that use of frequency diversity is not required by Industry Canada, but available should the designer choose to employ it.

Following frequency selection, a frequency search of the Industry Canada database locates any other utilities also operating on the reserved bands. The frequency search displays all other licensed microwave radios within a specified radius, typically 100km, of the radio installation site. If any other utilities are operating with similar frequencies within the suggested radius of 100km, Industry Canada requires all other utilities receive a letter explaining the planned operation of the new radio link. This ensures that all parties potentially affected by the new radio link receive notification and avoids potential operational interference. Confirmation by the other parties is required as proof of notification before an official radio license will be issued.

After receiving tentative approval for planned frequency assignment, a radio path engineering study must take place. The radio path consists of the geographical line connecting the transmitting and receiving ends of the link. Microwave radio frequencies require a clear line-of-sight in order for the link to operate properly. Assuming that a clear line-of-sight exists, the path analysis calculation determines the expected reliability of the link. Portions of the path engineering calculation results are also required to be submitted to Industry Canada for review prior to issuance of an official radio frequency license.

4.2 The Backbone Radio Link

The backbone radio link is critical to any communication network because it carries the majority of the communication traffic. As a result, performance and reliability objectives for this type of radio link are the most stringent.

The previous section describes the frequency bands available to the designer. Selecting equipment begins with determining the bandwidth required to meet the capacity requirements of the backbone radio link. In AltaLink's case, the bandwidth selected is OC3 capacity, or 155.52 Mbps. Examining the radio frequency bandwidth used by a radio of this capacity shows that 30 MHz of bandwidth is required. This permits frequency selection within those reserved for utility use in Industry Canada SRSP-307.1 as shown in the previous section.

Industry Canada regulations specify that radio links operating within the 7 GHz band utilizing 10 – 30 MHz of bandwidth must not exceed 1W of output power. AltaLink point-to-point radio links are licensed for a maximum of 27.5 dBm, or 0.5623W RF output power. To meet AltaLink requirements, any radio equipment must be capable of operating at the maximum level permitted by Industry Canada license.

Planning a radio link within this category requires that selection criteria be determined such that the product installed meets the reliability and performance objectives expected. To detail these, AltaLink standards require that a backbone communication link have the following features and performance levels:

<u>Operating Protection</u>

Protection of the radio link can appear in several, commonly used forms. These are space diversity, frequency diversity, and hybrid diversity. Hardware protection is also available as monitored hot-standby configuration. Harris Corporation's Microwave Engineering Seminar [B9] describes the following protection options.

Space Diversity consists of radios with two antennae located at differing heights above ground level. Fading of microwave signals can occur at various heights above ground level and spacing between radio dishes makes fading at both heights of radio dish less likely. The second receiving microwave dish helps to ensure that at least one dish receives a usable signal.

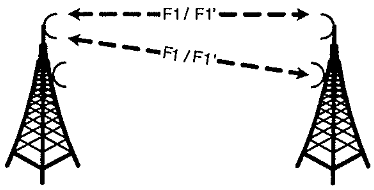


Figure 9 – Space Diversity Block Diagram

Frequency diversity uses only one microwave dish at the sending and receiving ends of the microwave link. Frequency diversity protection involves transmitting and receiving on two frequencies simultaneously via the same microwave dish. Path fading typically only affects one frequency at a time and therefore one frequency remains less affected and usable.

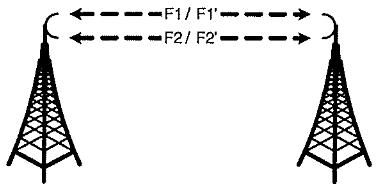


Figure 10 – Frequency Diversity Block Diagram

Hybrid diversity adds the most protection to microwave radio links of the three diversity types listed here, adding frequency diversity protection to a radio hop with space diversity. One end of the radio link employs two receive dishes with the transmitter communicating on two carrier frequencies.

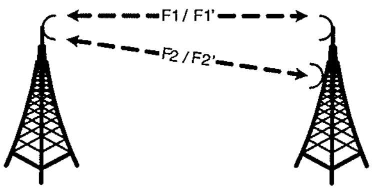


Figure 11 – Hybrid Diversity Block Diagram

To meet AltaLink's protection requirements, the frequency diversity option is used. This leverages the allowance by Industry Canada to employ this type of protection and transmit on two frequencies. For radio hops where frequency diversity does not offer sufficient protection, hybrid diversity is used.

Hardware Redundancy

Sufficient hardware redundancy is a design criterion because it offers two benefits. The first being one-for-one protection of all critical components within the radio. This means that for each major component of the radio, there is a standby unit ready to take over in the event of failure. The second benefit is that it permits operations staff to conduct maintenance on radio components without requiring communication outages.

For AltaLink, this is a factor when selecting hardware for any proposed backbone radio link. All components and interfaces must have hardware redundancy. Further to this, receiver switching between operating frequencies must be hitless, meaning that data stream experiences no errors when a receiver switch takes place.

Performance Level Expectation

The operational performance level, as often specified by the vendor, is a target rather than a guarantee. This is due to the variable nature of the radio link and the unpredictable nature of the atmosphere between the transmitting and receiving stations. Knowing that this is the case, it is required that all AltaLink backbone radio links design for a minimum of 5 – 9's reliability (99.999% availability and carrying error-free data).

Overall, and with reference to ITU (International Telecommunications Union) and AltaLink radio frequency design guidelines [B11], the reliability objective for an AltaLink backbone or heavy route radio link is summarized as follows:

Definition - backbone, loop, major spur, long hop (> 40 Km), in excess of four T1's or two TPR channels.
Reliability - in excess of 99.999% at a composite fade margin of 30 db.

Composite Fade margin is defined as thermal or flat fade margin + interference fade margin + dispersive fade margin. Based on the ITU two-way availability objective for a 2500 km / 1500 mile system is 99.7%. This translates to a single hop objective of 99.995%. AltaLink uses 99.999% reliability as its performance target that exceeds the ITU objective.

This performance level should be observable when monitoring the overall performance of the radio link over the course of any given year. Component redundancy and frequency switching features should equate to no more than 315.36 seconds of operational downtime in any given year.

AltaLink's Standard Backbone Radio Link

AltaLink's standard configuration for a backbone radio is shown below:

Radio Manufacturer: Harris Microwave Communications Corp.
Radio Model: Constellation OC3
Operating Frequency: As per SRSP 307.1 – Primarily 7GHz, Industry Canada Approved.
Transmitter Power: 0.5623W or 27.5dBm
Modulation: 128 TCM w/FEC
Protection Options: Frequency, Space or Hybrid Diversity
Interfaces: Redundant Sonet OC3, multimode fiber
Power Supply: Redundant -48VDC
Microwave Dish: High-Performance, 6' diameter minimum, 10' diameter maximum.
Waveguide: Nitrogen-pressurized elliptical

4.3 The Spur Radio Link

Spur radio links act as the collectors for last-mile connections to remote end-user sites – in this case electrical substations. They do not contain as much capacity as a backbone radio link, but require nearly the same levels of protection. Performance level expectations are similar to backbone links, but with more tolerance for short duration outages.

Equipment selection within this category involves two types of radios, each used in different scenarios. The first spur radio is a 7GHz, 28-DS1 capacity radio. The second is a 15GHz, 16-DS1 radio. Spur radio links do not require as much bandwidth as backbone radios, but still more than those of the last-mile do. This network topology is similar to that of a tree – the trunk is the backbone, the spur a heavy branch, and the last mile a small twig.

The 7GHz, 28-DS1 capacity radio offers the same protection features of the backbone radio without the high capacity. The 15GHz, 16-DS1 radios offer larger bandwidth than a last-mile radio but with additional hardware protection. In AltaLink's case, these radios are employable interchangeably depending on the path analysis and the critical nature of the circuits transported.

Industry Canada regulations specify that radio links operating within the 7 GHz band must not exceed 1W of output power. For AltaLink, the 7 GHz, 28 DS1 point-to-point radios are licensed as specified in the previous section with a maximum output power of 27.5 dBm, or 0.5623W RF output power. For those radio links operating in the 15GHz band, the maximum allowable output power is 2-5W, depending on the bandwidth used. AltaLink licenses specify a maximum output power of 16.98 dBm, or 0.05W RF output power. To meet AltaLink requirements, any radio equipment must be capable of operating at the maximum level permitted by Industry Canada license.

As in the previous section, a radio link within this category requires criteria such that the product installed meets the reliability and performance objectives expected. To detail these, AltaLink standards require that a spur communication link have the following features and performance levels:

Operating Protection

Industry Canada permits frequency diversity protection to be employed by utilities on point-to-point radio links operating within the 7 GHz band only. This is the same as backbone radio links and will be used within the AltaLink network wherever possible. Radios operating in the 7 GHz band must also have the same redundant components as backbone radio links.

Because of the restriction on frequency diversity protection and the lack of equipment capable of this form of protection, 15 GHz radio links must employ monitored hot-standby protection.

Monitored Hot-Standby Protection (MHSB): This mode of hardware protection uses two, separate but identically configured radios installed at each end of the link. A central controlling unit monitors the health of the primary, or 'A' side equipment and switches to the redundant, or 'B' side in the event of failure. This form of protection increases reliability of the radio link, but switching between primary and redundant radios causes short-term outages on all traffic carried by the link.

Monitored Hot-Standby involves no protection against frequency-affecting atmospheric events, but does protect against hardware failure. A primary and secondary radio configuration is used.

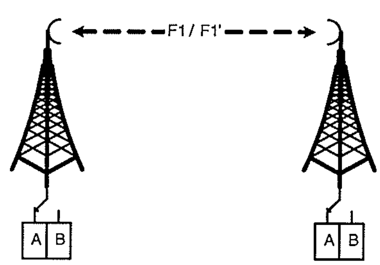


Figure 12 – Monitored Hot-Standby Block Diagram

Performance Level Expectation

As described previously, the operational performance level is more of a target than a guarantee. Knowing that this is the case, AltaLink requires that all spur radio links design for a minimum of 5 – 9's reliability (99.999% availability and carrying error-free data). A key point within this category is that the reliability objective may be achieved by any means possible. Radio links outside of the 7GHz band may require additional analysis and review of planned radio path and hardware to ensure this.

Definition – spur hop, (< 40 Km), up to four T1's or two TPR channels.
Reliability - in excess of 99.999% at a composite fade margin of 30 db.

This performance level should be observable when monitoring the overall performance of the radio link over the course of any given year. Component redundancy and frequency switching features should equate to no more than 5.256 minutes of operational downtime in any given year.

AltaLink's Standard Spur Radio Link

AltaLink's standard configuration for a spur radio is shown below:

Model 1 – 28-DS1 Capacity

Radio Manufacturer: Harris Microwave Communications Corp.
Radio Model: Constellation 28-DS1
Operating Frequency: As per SRSP 307.1 – Primarily 7GHz, Industry Canada Approved.
Transmitter Power: 0.5623W or 27.5dBm
Modulation: 64QAM w/FEC
Protection Options: Frequency, Space or Hybrid Diversity
Interfaces: DS1 breakout, connectorized copper connection
Power Supply: Redundant -48VDC
Microwave Dish: High-Performance, 6' diameter minimum, 10' diameter maximum.
Waveguide: Nitrogen-pressurized elliptical

Model 2 – 16-DS1 Capacity

Radio Manufacturer: Harris Microwave Communications Corp.
Radio Model: MicroStar M/H 15 GHz
Operating Frequency: As per SRSP 314.5 – 15GHz, Industry Canada Approved.
Transmitter Power: 0.05W or 16.98dBm
Modulation: QPSK or 16QAM
Protection Options: Monitored Hot Standby
Interfaces: DS1 breakout, connectorized copper connection
Power Supply: Redundant -48VDC
Microwave Dish: High-Performance, 2'-6' diameter, low-profile where available
Waveguide: Andrew LMR-400 co-axial cable or equivalent

4.4 The Last Mile Radio Link

Last mile radio links form the final link in the radio system chain. These links tie the individual substations and facilities to the network and are typically of lower capacity than the spur or backbone radio links. This equipment does not employ protection and performance requirements are the lowest of the radio categories.

As with the spur radio links, there are two types of radios employed within this category. The first radio is the 5.8GHz spread-spectrum radio. This radio transports one DS1 of bandwidth, and provides a LAN (local area network) bridge for 10Base-T Ethernet access. The second radio is a single channel 400MHz radio transporting one RS-232 protocol data connection at up to 9600bps. Both radios have specific application criteria. The 5.8 GHz spread-spectrum radios are deployed where multiple channels are required and where a possible microwave path exists. The single-channel radios are deployed where no other service is required other than for real-time scada interconnection.

Because each of these radio links connect as individual links to remote sites, it is accepted that a failure of the radio can be repaired with no significant impact on the power system. This is also because teleprotection channels are not permitted to be carried by these types of radios. Only spur or backbone quality radios can carry teleprotection circuits because of their built-in protection systems.

One concern is the use of spread-spectrum radios. Because these radios are unlicensed by Industry Canada, frequency coordination with other users of spread-spectrum equipment is not required. There is an elevated risk that interference may occur on any given radio link. The decision to deploy these radios is based upon the location of the link – rural areas have fewer radio links operating, and therefore the risk of interference is lower. Within AltaLink, these radios are not to be installed within the city limits of any urban area. The benefit of these radios is that they offer increased bandwidth at little incremental cost.

The single channel 400MHz radios are easier to design because they do not require communication towers and microwave dishes. These radios may have their antennae installed on poles because lateral deflections or sway in the pole does not affect the operation of the radio. Industry Canada licenses these radios within their respective bands and provides protection against interference. This is done in accordance with SRSP-501 [B12]. The only drawback to these radios is that they are limited in capacity to one low speed data channel of 9600 bps.

As in the previous sections, a radio link within this category requires criteria such that the product installed meets the reliability and performance objectives expected. To detail these, AltaLink standards require that a last-mile communication link have the following features and performance levels:

Operating Protection

Last-mile radio links, either 5.8 GHz spread-spectrum or 400MHz single-channel are not commercially available with protection. This is accepted and the risk mediated by having direct replacement spares on hand in equipment stores.

Performance Level Expectation

As with any radio link, the expected performance level is more of a target than a guarantee. Last mile radio links within the AltaLink network design for a minimum of 4 – 9's reliability (99.99% availability and carrying error-free data).

Definition – last mile hop, (< 40 Km), up to 2 T1's, or 1-T1 and Ethernet bridge, No TPR permitted.
Reliability - in excess of 99.99% at a composite fade margin of 30 db.

This performance level should be observable when monitoring the overall performance of the radio link over the course of any given year. Component redundancy and frequency switching features should equate to no more than 8.76 hours of operational downtime in any given year.

AltaLink's Standard Last Mile Radio Link

AltaLink's standard configuration for a last mile radio is shown below:

Model 1 – 2-T1 Capacity

Radio Manufacturer: Harris Microwave Communications Corp.
Radio Model: Aurora 5800
Operating Frequency: 5.8 GHz spread-spectrum.
Transmitter Power: 0.0707W or 18.5dBm
Modulation: DQPSK
Protection Options: None
Interfaces: DS1 breakout, connectorized copper connection (RJ-48C)
Ethernet, 10Base-T via RJ-45
Power Supply: -48VDC
Microwave Dish: 2' to 6' diameter
Waveguide: Co-axial cable, 5/8' LDF foam-dielectric

Model 2 – Single-channel Capacity

Radio Manufacturer: Microwave Data Systems (MDS)
Radio Model: MDS 4790 (Master) and MDS 4710 (Remote)
Operating Frequency: As per SRSP 501 – 400MHz, Industry Canada Licensed.

Transmitter Power: 5W or 36.98dBm
Modulation: Digital CPFSK
Protection Options: None
Interfaces: DB-9 Connector, RS-232
Power Supply: -48VDC
Antenna: Yagi or dipole depending on application.
Waveguide: Co-axial cable (LMR-400 or equivalent)

4.5 Equipment Selection

4.5.1 Antenna Selection

Selecting the antenna for use on a utility microwave link involves selecting an antenna to match the operating frequency of the radio. As per Industry Canada regulation, within the 7 GHz band, only high-performance solid parabolic dishes may be used. To maintain consistency throughout the equipment selection process, this requirement is extended across all microwave operating frequencies, where available from the manufacturer.

Size selection depends on the radio path in question, but for 7 GHz frequencies, the minimum size requirement is 6 feet (1.8m). The size of the dish is one variable that may be modified to meet the overall reliability objectives described in section 4.6.

The purpose of the antenna is to direct the transmitted signal is a given direction as opposed to radiating in all directions. On the receive side of the link, the antenna acts to concentrate the received signal. Both of these uses appear as signal gain in the overall path loss calculation. The general equation for calculating antenna gain is:

$$Gain\ (G)\ [dB] = 7.5 + 20\log_{10} f + 20\log_{10} d \qquad \text{(Equation 1)}$$

Where: Gain (G) is the antenna gain in dB
f is the frequency in GHz
d is the diameter of the antenna in feet

Preference is for using antenna emitting a vertical-polarity signal. This is to minimize the effect of rain cells passing through the path. Dishes may be selected with either single or dual polarity capability, but typically only single is required.

4.5.2 Waveguide Selection

Waveguide is selected to connect the radio to the antenna with the smallest amount of signal loss possible. Different types of waveguide, or transmission line as it is also called, are used depending on the frequency selected. For the frequencies most commonly used in the utility network, 7 GHz and 15 GHz, elliptical waveguide and foam-dielectric coaxial cable are used.

For higher power radio equipment with indoor RF amplifiers, elliptical waveguide is selected to interface directly to the antenna. EWP-64 (Andrew™) waveguide or equivalent is the standard transmission line selected for 7 GHz radio links. Attenuation for this line is specified at 4.78dB per 100m. It is clear that the height of the antenna must be included in ERP (effective radiated power) calculations.

For higher frequency radio links such as 15 GHz, the actual carrier frequency transmitters and receivers are mounted on the tower behind the microwave dish. A co-axial cable may be used to carry the IF (intermediate frequency) signal between the indoor and outdoor units. For this application, LDF-4.5-50 (Andrew) or equivalent is used. The attenuation of this cable is 3.57 dB per 100m.

4.5.3 Communication Towers

It is obvious to the communication engineer that taller towers cost more money. For this reason, it is desired to keep tower heights as short as possible. This factor is particularly evident when constructing self-supporting towers due to the additional constructing steel required for this type of tower. Self-supporting towers are only constructed when sufficient land area is not available to construct a guyed-type tower. The majority of the towers within the AltaLink network are guyed structures.

Tower loading is also a concern due to the weight and wind-loading additional dishes add to the tower. Proper analysis of the structure, including average and extreme wind speeds must be completed to ensure tower integrity is not compromised whenever modifications to the tower are made.

4.6 Time Classification

Classifying how a radio link will operate depends on the nature of the outage. A breakdown of the time classifications is described in Harris' Path Engineering course notes [B36]. A synopsis of the classifications described in Harris is presented here.

An examination of the overall *availability* of the radio indicates that a radio link must be available for operation at least 99.995% out of 100% total availability. This assumes that outages in the radio link due to human error, equipment failure, or very severe fades in signal strength occur only 0.005% of all time.

Within the 99.995% of all time that the radio is operational, it is specified that the radio path shall be available to carry traffic at less than a 10^{-3} Bit-Error Rate (BER), at least 99.999% of the time. This is the path reliability guideline as required by Backbone and Spur radio links within the utility network. The portion of time where the BER exceeds 10^{-3}, short term outages may result.

Of the 99.999% of time where the radio is available and operating at a BER less that 10^{-3}, the radio should be carrying data traffic at a rate of 99.99% error-free-seconds. This means that for 99.99% of normal operating time free of signal fade or outage, data will be transported across the link error-free.

Within the total error-free operating time, the bit-error rate shall be below 10^{-6} with dribbling (random) errors occurring as a Residual Bit Error Rate (RBER) of less than 10^{-10}. This error rate is a quality characteristic of the radio and typically specified by the radio manufacturer.

4.7 Rain Attenuation

For frequencies above 10 GHz, a general guideline is that rain attenuation of microwave signals must be examined and the probability of a rain induced fade outage calculated. This is due to the short wavelength of microwave signals and their size in comparison to rain droplets. Below 10 GHz, the wavelength is significantly large such that the probability of an outage due to rain is considered negligible.

For the North American continent, two models are available to calculate the minimum required path fade margin to protect against rain fade outages. They are ITU-R Rec. P.530 and Crane. These models are based on the average rain rates of a given region, and the percentage of time that the rain attenuation exceeds the resulting fade margin. For the purposes of rain attenuation calculation in Canada, the Crane model is typically used. For this reason, only the Crane model is presented. The reader is referred to the ITU-R Rec. P.530 for more information on the ITU model.

Both models use coefficients corresponding to the operating frequency and polarization. These coefficients can be found in [B35].

The Crane Model:

$$A(dB) = \alpha R_P^{\ \beta}\left(\frac{e^{\mu\beta d} - 1}{\mu \cdot \beta} - \frac{b^{\beta} e^{c\beta d}}{c \cdot \beta} + \frac{b^{\beta} e^{c\beta D}}{c \cdot \beta}\right) \quad for\ d \le D \le 22.5\ km \qquad \text{(Equation 2)}$$

$$A(dB) = \alpha R_P^{\ \beta}\left(\frac{e^{\mu\beta D} - 1}{\mu \cdot \beta}\right) \quad for\ D < d \qquad \text{(Equation 3)}$$

$$\mu = \frac{\ln\left(b\, e^{cd}\right)}{d}$$

$$b = 2.3 R_P^{\ -0.17}$$

$$c = 0.026 - 0.03\ln(R_P)$$

$$d = 3.8 - 0.6\ln(R_P)$$

Where: R_p is the rain rate in millimeters per hour.
D is the path length in kilometers.
α, β are regression coefficients available in [B35], based on frequency and polarization.

Selecting the coefficients requires interpolation of the exact frequencies planned for use. The calculation to interpolate α, β regression coefficients is presented in [B36].

For the AltaLink network, the Crane model permits rain rate coefficient selection based on the annual percentage of time the rain fade outage will exceed the resulting fade margin. For Alberta, the rain rate is based on 99.999% availability. This corresponds to a rain rate of 0.001%.

The outcome of the Crane model provides a minimum fade margin required for the planned radio link. This fade margin can then be factored back into the original path planning calculation to determine if sufficient fade margin is available.

4.8 Equipment Availability

It is desired to have a radio link available 100% of the time, but this is not a realistic objective. Failures will occur and will cause outages exceeding ten consecutive severely errored seconds (CSES). For utilities, hardware availability is desired to be greater than 99.999%.

Looking at the Harris radio planned for the AltaLink network, the mean-time-before-failure (MTBF) is specified as 120888 hours of continuous service. This equates to 13.8 years, which is approximately the expected service life of the radio. From Equation 4 below, the availability time is 99.99338%.

Using this MTBF specification and the expected Mean-Time-To-Repair for one hop of backbone or spur radio within the AltaLink network of 8 hours, the equipment availability is calculated:

$$T_{Avail}(Non - protected)(\%) = \left(\frac{MTBF}{MTBF + MTTR}\right) \cdot 100\% \qquad \text{(Equation 4)}$$

Where: MTBF is the Mean Time Before Failure of the equipment.

MTTR is the Mean Time to Repair of the radio, including obtaining spare components, travel time to site, and actual restoration of the equipment.

If hardware protection such as Frequency Diversity is employed, a completely redundant radio will switch to this redundant hardware limiting the outage due to hardware failure to milliseconds. Continuing the example described earlier, the Harris Constellation radio switches to redundant hardware in 60 milliseconds.

The improvement factor is based upon the fact that when hardware protection is deployed, two components must fail to cause a forced outage. The improvement in overall reliability is a combination of the two outages, as described in [B6]. The new reliability assumes that only one failure will occur at any given time. This availability time is also cumulative based upon multiple radio links carrying traffic in a multi-link system.

$$T_{Avail}(Freq.Diversity)(\%) = \sqrt{\left(\frac{MTBF}{MTBF + MTTS}\right)_{Primary} \times \left(\frac{MTBF}{MTBF + MTTS}\right)_{Secondary}} \cdot 100\% \qquad \text{(Equation 5)}$$

Where: MTBF is the Mean Time Before Failure of the equipment.
MTTS is the Mean Time to Switch between Primary and Secondary hardware.

Calculating the improved reliability by using Frequency Diversity and Equation 5, the new availability time of the Constellation radio is 99.99999%.

4.9 Path Reliability Calculation

The process to calculate the overall reliability of a radio path involves a sequence of steps. Equipment availability and rain attenuation factor into this process, influencing the equipment selected for a required availability time and the overall path fade margin required. Beginning with selection of the radio sites, the process is based on that used by the Pathloss™ software program. Typically software is used to perform the path analysis calculations, but for the purpose of illustrating the theory behind basic path analysis it is explained here. Explanation of Fresnel zones and diffraction theory, although briefly mentioned in the path analysis theory, are beyond the scope of this document. The reader is referred to [B6], [B35], and [B36] for a more detailed explanation of those topics.

Formulation of the Standard Path Model

A basic model for the standard radio path is presented. A typical path consists of transmitting station A, emitting a radio signal that is received by receiving station B. At each location, a radio, waveguide, and microwave dish are used. The microwave signal is transmitted across free space that attenuates the signal based on the Free Space Loss (FSL) equation. By identifying the various gains and losses in the transmission path, the overall expected receive signal level can be estimated. This value is then compared to the characteristics of the radio, providing the necessary fade margins to calculate expected path reliability.

Location

The location for each end of the link must be determined and known in GPS co-ordinates. These are typically based on the NAD27 GPS coordinate system (North American Datum 1927), although other systems may be used.

To illustrate, AltaLink's Springbank to Cochrane Lake path is used as an example:

	Springbank Radio	Cochrane Lake Radio
Elevation (m)	1219	1343
Latitude (Deg. Min. Sec.):	51 02 40.00 N	51 16 37.00 N
Longitude (Deg. Min. Sec.):	114 11 55.00 W	114 29 44.00 W
Azimuth (degrees):	321.5	141.12
Vertical Angle (degrees):	0.12	-0.34

Antenna and Waveguide

The antenna and waveguide selected for use provide gain and loss values required for the overall path gain / loss summation. These values are dependant upon the equipment selected and are provided as specifications from the manufacturer.

Antenna Model	HP6-71GF	HP6-71GF
Antenna Height (m)	77.72	86.87
Antenna Gain (dBi)	40.00	40.00
Transmission Line Type:	EWP64	EWP64
Transmission Line Length (m)	86.87	96.01
Tx Line Loss (dB/100m):	4.83	4.83
Tx line Loss (dB):	4.20	4.64

Antenna gain is given in dBi (Decibels Isotropic). This is the gain improvement over an equivalent antenna emitting uniformly in all directions similar to a point source emitter.

Frequency Selection

Assignment of frequencies occurs within the desired band based on bandwidth required and specific license permissions for utilities. Industry Canada issues licenses for these frequencies. Polarization is set to vertical in most cases to avoid unnecessary rain attenuation. Path length is determined from the GPS co-ordinates described earlier. The Free Space Loss calculation is based upon the following equation:

$$Free\ Space\ Loss\,(dB) = 92.4 + 20\log d_{km} + 20\log f_{GHz} \qquad \text{(Equation 6)}$$

Where: d is the path length in kilometers.
f is the frequency in GigaHertz.

Additional atmospheric losses due to Oxygen and Water Vapor are estimated using values of 0.014 dB/km and 0.002 dB/km respectively at frequencies of 7.5 GHz. Due to their small value, these values are typically negligible.
Using the values described under location, antenna and waveguide selection, and frequency selection, the net path loss can be calculated. To illustrate the net path loss, a radio link block diagram is shown next:

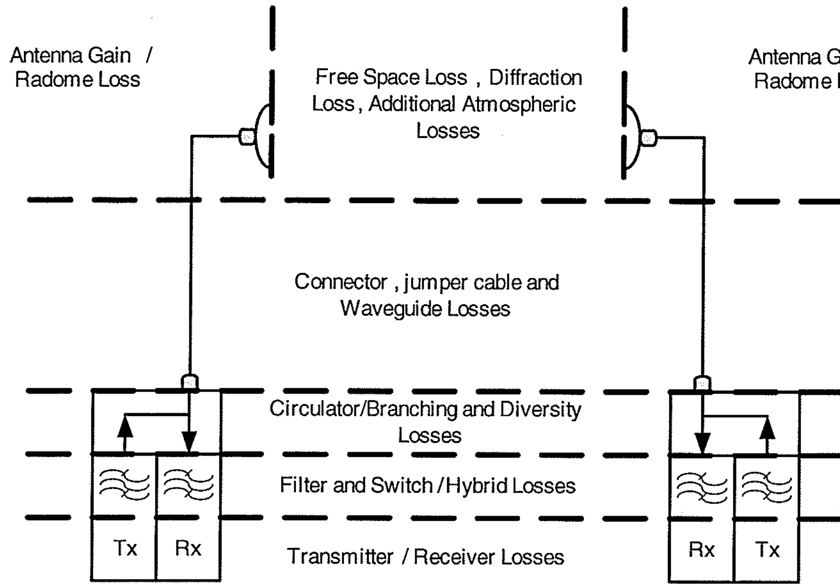


Figure 13 – Net Path Loss – Radio Link Block Diagram

Adding up the basic equipment losses, the following data sheet can be created:

Frequency (MHz)		7475.00	
Polarization		Vertical	
Path Length (km)		33.17	
Free Space Loss (dB)		140.36	
Atmospheric Absorption Loss (dB)		0.33	
Net Path Loss (dB)	69.52		69.52

Diffraction losses due to signals arriving from alternate paths has not been included in this calculation. Diffraction losses occur when signals outside of the main microwave beam are received out-of-phase with the main signal. These diffracted signals serve to degrade the main signal by subtracting from it. Typically path analysis software will approximate the diffraction loss and add it to the overall loss equation. For the purposes of illustrating the path analysis process, this has not been included. More information on diffraction losses may be found in [B6].

Radio Selection

Having already selected the frequency band for desired use, the model of radio must also already be known. Using the data sheets for the radio supplied by the manufacturer, the following data is required:
Radio Model, Transmit Power in watts, Transmit Power in dBm, the EIRP (dBm), the Receive Threshold Criteria, and the associated Receive Threshold Level. These are summarized in the following table:

Radio Model	Constellation	Constellation
Transmitter Power (Watts)	0.54	0.54
Transmitter Power (dBm)	27.30	27.30
EIRP (dBm)	63.10	62.66
Receive Threshold Criteria	10-3 BER	10-3 BER
Receive Threshold Level (dBm)	-69.50	-69.50

The transmitter power in watts, dBm, and EIRP are used to determine compliance with Industry Canada regulation. The receiver threshold criteria is selected to determine the receiver threshold level corresponding to a specific bit error rate. These values are used in upcoming calculations to determine reliability.

Receive Signal and Margin Calculation

Knowing the net path loss and the radio transmit level, the net receive signal level can be calculated. In addition to this the thermal fade margin, dispersive fade margin, and effective (composite) fade margin may be calculated. The equations used to determine thermal fade margin and composite fade margin are shown. The Dispersive fade margin is a characteristic of the radio and determined from the equipment data sheets. For Altalink's network, this is the Harris Constellation radio [B37].

Rx Signal Level (dBm)	-42.22		-42.22
Thermal Fade Margin (dB)	27.28		27.28
Dispersive Fade Margin (dB)	48.00		48.00
Dispersive Fade Occurrence Factor		3.00	
Effective Fade Margin (dB)	27.17		27.17

Where:

$$RSL\left(dBm\right)= Transmitter\ Power - Net\ Path\ Loss\ \left(dBm\right) \qquad \text{(Equation 7)}$$

$$Thermal\ Fade\ Margin\ (dB) = Rx\ Signal\ Level - Receive\ Threshold\ Level\ (dBm) \qquad \text{(Equation 8)}$$

Dispersive Fade Occurrence Factor is a measure of weighting for the effect of dispersive fades on the path. For average paths, the weighting factor is selected to be 3. Additional values may be found in [B36].

The effective fade margin is a composite fade margin calculation consisting of the logarithmic addition of the individual fade margins. Also included but not shown is the interference fade margin, or the fading due to interference required to reach the 10^{-3} BER threshold.

$$EFM\left(dB\right)=-10\cdot\log\left(10^{-\frac{A_T}{10}}+10^{-\frac{A_I}{10}}+10^{-\frac{A_D}{10}}\right) \qquad \text{(Equation 9)}$$

Where: A_T = Thermal Fade Margin (dB)
A_I = Interference Fade Margin (dB)
A_D = Dispersive Fade Margin (dB)

The effective fade margin is required for path reliability calculations detailed next:

Environmental Factors

Environmental factors are accommodated in the path reliability calculation, and therefore must be selected. The *Vigants – Barnett* path reliability model uses the following factors:

Climatic factor (C) – a factor corresponding to the type of terrain found on the radio path under study. This variable takes into account the c-factor (c) described below, and the terrain roughness (S).

Terrain Roughness (S) – is a calculation based on the roughness of the terrain between transmitting and receiving stations. Samples of elevation are taken across the path profile, and the standard deviation calculated. This may be done using statistical methods but typically, software calculates the solution. The resulting terrain roughness factor is expressed in meters (m).

C-factor, climate-terrain factor (c) – is a variable selected from maps provided as part of the Vigants-Barnett model. This variable represents the climatic-terrain for North America, and is selected from a list available in [B36]. For Alberta the value is 1, for average propagation conditions – average terrain and climatic conditions.

Average temperature (°C) – available from local weather offices, this is a historical statistic for average temperature. In southern Alberta, this value is 4°C.

Climatic factor	1.00
Terrain roughness (m)	42.67
C factor	0.26
Average Annual Temperature (°C)	4.00

Reliability Calculations

The *Vigants-Barnett* model is used to estimate the probability of outage based on path fading activity on a given radio link. The calculation is based on a non-protected radio link and must be adjusted to account for frequency diversity protection used by utilities. The frequency diversity improvement factor is given by: [B35] and [B36]

$$I_{fd} = 80.5 \cdot \frac{\Delta f}{f^2 \cdot d} \cdot 10^{\frac{A}{10}} \qquad \text{(Equation 10)}$$

Where: Δf = effective frequency spacing in GHz
f = frequency in GHz
d = path length in km
A = Effective Fade Margin in dB

The *Vigants-Barnett* model for fade probability is given by: [B35] [B36]

$$P = 6.0 \cdot 10^{-7} \cdot C \cdot f \cdot d^3 \cdot 10^{-\frac{A}{10}} \qquad \text{(Equation 11)}$$

Where: Δf = effective frequency spacing in GHz
f = frequency in GHz
d = path length in km
A = Effective Fade Margin in dB

The result of the fade probability equation is the severely errored seconds ratio for the given radio hop. This ratio, P, is used to forecast the worst-month unavailability as a percentage of operating time. These values are the basis for estimating reliability for the link, as mentioned previously in this section. For utilities, the desired reliability for critical links is 99.999%.

As presented in [B36],

Worst month unavailability (%) = 100·P
Worst month availability (%) = 100·(1-P)
Worst Month outage time (seconds) = P·(seconds/month)

Using this result, and recognizing that fading typically occurs for only a fraction of the year, it is common to use a 3-month fading season as an estimation of fade probability for the year. The annual unavailability calculation is computed using 25% (3 of 12 months) of the worst month unavailability, P.

Annual unavailability (%) = 100·P·0.25
Annual availability (%) = 100·(1-0.25P)
Annual outage time (seconds) = 0.25·P·(seconds/year)
To further estimate the annual one-way performance of the radio link, multipath fading is related to the average annual temperature of the region. The duration of fades expressed as a fraction of the year is related by:

$$T_o = 0.25 \cdot \left(\frac{t}{50}\right) \qquad \text{(Equation 11)}$$

Where: t = average annual temperature in °F

This factor, T_o, is then applied to the annual availability calculations to determine the desired, overall one-way expected availability for the radio link.

Annual unavailability (%) = $100 \cdot T_o P$
Annual availability (%) = $100 \cdot (1 - T_o P)$
Annual outage time (seconds) = $T_o \cdot P \cdot$(seconds/year)

The overall path availability is a combination of the two, one-way path availability calculations. This is calculated by multiplying the resultant one-way probabilities together.

Using this result, the performance of the radio link is estimated for the period of one year. Depending on this result, the components comprising the radio link may have to be adjusted to ensure targets are met. This may be accomplished in several ways, mainly changing the size of the antenna and increasing the output power of the radio, if licensing permits. A summary table of the resulting availability calculation is presented next:

Effective Frequency Spacing (MHz)	300.00	275.00
FD Improvement Factor	6.79	6.22
Worst-month - multipath (%)	99.99879	99.99868
(seconds)	31.86	34.76
Annual - multipath (%)	99.99975	99.99973
(seconds)	78.38	85.51
Combined two-way (% - sec)	99.99948 - 163.90	

Examining the overall communication reliability to a specific site, specifically a substation or remote radio site, the path reliability is the defining factor governing the expectation of reliable communication to that site at any one time. The mean-time-between-failure statistics of equipment are sufficiently high that the path availability calculation is the dominant factor influencing whether communications will be available. For this reason, the path reliability calculation is used as an estimate of overall reliability.

4.10 Radio Design Conclusions

Radio network design and for a loop-topology in particular, require significant frequency planning. Industry Canada licenses radios for use and regulates output signal strength. Obtaining licenses for operation is the first step to beginning radio deployment. Protection options are deployed to improve the expected performance of the radio link. AltaLink, as with most Canadian utilities, uses frequency diversity. Path engineering for utility radio links requires classification of links to fix reliability targets. In AltaLink's case, these classifications are backbone, spur, and last-mile. The actual radios used by AltaLink for each of these classifications are presented. To complete the section, an overview of the radio path engineering calculation is examined.

5

5. Teleprotection (TPR) and the Communication Network

5.1 Maximum Operating Latency

One of the critical uses of the utility communication network is for the application of Teleprotection. This is important to a utility communication network designer as the technical requirements for the application of teleprotection influence the design of the communication network. For this reason, I feel that a brief explanation of the protections systems employed by AltaLink is prudent.

Teleprotection, or TPR as it often called, is the coordinated tripping of transmission line breakers at each end of the transmission line in the event of a system fault. The signal used to command the relays at the remote end of the transmission line to trip their breakers open, is a transfer-trip signal [B14]. This signal originates from the relay first sensing that a fault is underway; fault detection occurs within either the first or the second zone of operation (zone 1 or zone 2). The signal travels via the communication network and when received by the remote end relays causes them to trip their breakers upon sensing the fault at their end of the line. This is faster than if the relay were to wait for the standard time delays imposed on a zone-2 line fault. The process of communication between the relays at each end of the line shortens the time required to isolate the system fault and as a result lessens the disturbance to the power system. Shortening the time that substation equipment is subject to the stresses caused by the system fault increases the potential life of the equipment and may prevent damage from occurring.

Block diagrams of the standard protection schemes employed by AltaLink [B15], are included in the Appendix.

Within the AltaLink transmission network, employing protective relaying schemes provides protection against damage caused by system faults as described in the previous paragraph. The schemes consist primarily of permissive over-reaching and under-reaching transfer trips as well as direct transfer trips and blocking signals. They require a reliable communication network to communicate protection and control signals from one end of the line to the other.

Because teleprotection directly affects the performance of the line protection scheme, ground rules are necessary such that the constraints imposed by the communication network are acceptable to the protection design. These criterion, although somewhat controversial, are listed as follows and are limits to which any new AltaLink communication-aided protection design must conform. Within the context of this thesis document, whenever the telecommunication network is modified, the latencies of teleprotection circuits must be verified to ensure that they still meet or exceed the original requirements. That is the discussion of this section.

For protection of transmission lines, the duration of the line fault is directly proportional to the disturbance felt by the power system. For this reason, it is reasonable to expect that faults on higher voltage lines must clear faster than lower voltage lines. In AltaLink's network, the guideline provided for clearing time requirements on high voltage transmission lines is as follows:

Line Voltage (kV)	*Breaker Clearing Time (60Hz cycles)*	*Overall Fault Clearing Time (60Hz cycles)*
500	2	5
240	3	6
138	5	9

Table 10-Clearing time requirements, measured in 60Hz cycles, for 500kV, 240kV, and 138kV transmission lines.

The protection engineer designs coordinated protection schemes to fit within these time constraints. As a result, it is imperative that the communication engineer be involved in any new planned teleprotection system so that the time allowed for communication system latency can be determined. To illustrate the process, a new 500kV line protection scheme provides an example:

Voltage Class: 500kV

Breaker Clearing Time: 2 cycles = 2 x 16.666 ms = 33.333 ms.

Required overall clearing time from Table 10: 5 cycles = 5 x 16.666 ms = 83.333 ms.

If newer, advanced relays are employed that specify operation at or below one cycle, relay operation can be deducted from the overall time budget. At some point in the electrical controls of the breaker, at least one physical relay will be employed. This is due to the high currents required to operate the trip coils of some breakers. Physical relay contacts take an average of 5ms to close upon energization of the coil. To be safe, if one assumes that two relays are installed in the control schematic connecting the relay to the breaker, an additional 10 ms of delay can be expected.

The time allocation remaining after all pre-requisite delays are accounted:

Overall clearing time requirement:	83.333 ms.
Less breaker clearing time:	-33.333 ms.
Less relay operate time:	-16.666 ms.
Less physical relay operate time (x2):	-10.000 ms.

Time remaining for communication delay: 23.333 ms.

This figure indicates the maximum time permitted to send a contact closure signal from one end of a transmission line to the other, including all possible delays.

If one assumes that the breaker and relay operate times are approximate, it is prudent to design the communication network such that latency is minimized. This will ensure that communication of protection signals occurs in the fastest way possible.

With the upgrade to AltaLink's communication network, new issues arise. It is an assumption that the digital equipment has a lower latency then that of its predecessor – analog teleprotection. This is generally the case because of two scenarios: where physical relay contact interfaces are required, digital teleprotection shelves using solid-state (semiconductor) relays have pass-through delays of less than 3 ms. This is faster than analog teleprotection schemes requiring frequency-shifting techniques (guard and trip tones) to transmit a protection signal and having back-to-back latencies of greater than 10 milliseconds. A block diagram of a digital TPR scheme is shown below:

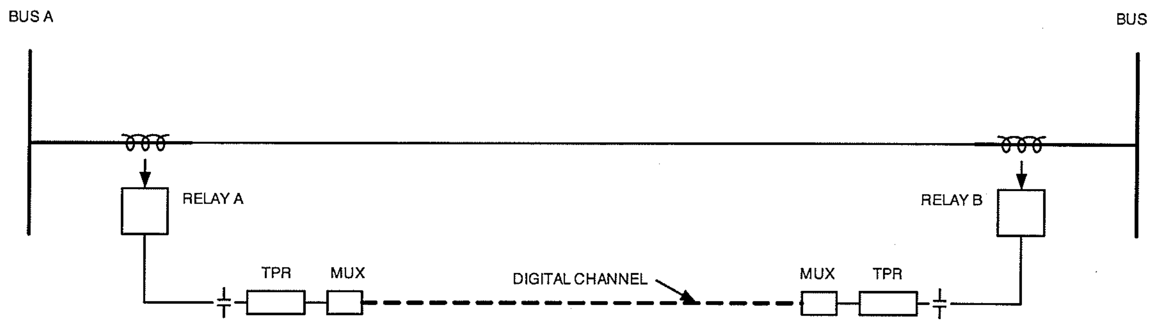


Figure 14-Digital Teleprotection Block Diagram with TPR equipment

The second scenario is one that is still emerging within the protective relaying industry. This scenario uses direct, digital communication links to connect relays together. The elimination of TPR equipment is possible because the relays can communicate directly with each other. The removal of the TPR equipment also eliminates the delay associated with the equipment and shortens the overall communication latency. Delays remain within the protective relays in order to maintain security and dependability standards. A relay-to-relay direct communication scheme block diagram is shown next:

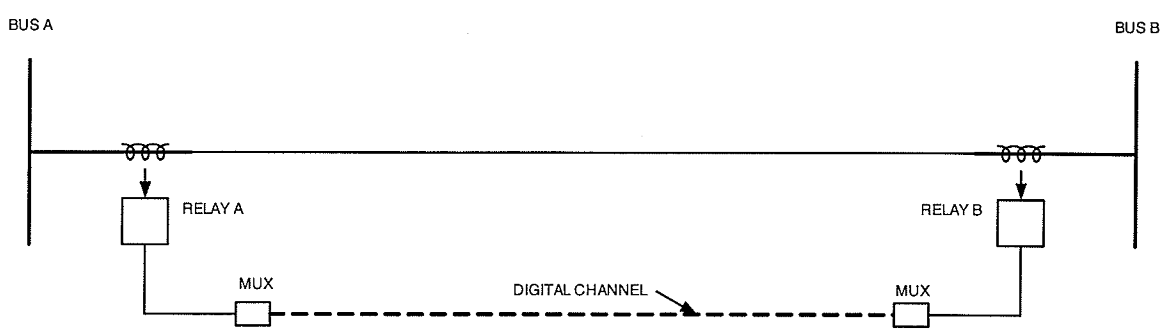


Figure 15-Digital Teleprotection Block Diagram with direct relay-to-relay communication

The elimination of the digital TPR equipment shortens delays but also permits deployment of additional protection schemes within the communication network. An example of this is ATM (Asynchronous Transfer Mode) multiplexing and path diversity. AltaLink's new digital network will use ATM to manage the core delivery of communication circuits from one point to another. ATM adds circuit routing intelligence and bandwidth quality-of-service to the system. In doing this, some delay is added as hardware is now expected to monitor communication circuits and ensure delivery of data should a primary path fail. Consideration of this delay is important when designing teleprotection links. More detail on this is provided because the operating time of a protection scheme depends upon the network topology carrying the TPR signal.

A third possible scenario is relays connected directly to each other using fiber-optic cable. In this case, the multiplexer, ATM, and radio delays are removed from the equation. This scenario is the simplest to design and plan, although rarely used in a province-wide utility due to the lack of available fiber. Having said that, new transmission lines are being built with OPGW (OPtical Ground Wire) that can provide direct fiber links between substations. This scenario is included in possible TPR scenarios.

Based on the design criteria provided by the utility protection and control engineer, the following table describes the maximum operating times expected for the most common 500kV and 240kV TPR scenarios within the AltaLink network. Lower voltage class 138kV lines are not shown due to the similar application of relay protection schemes as those used on 240kV lines. The clearing time requirement is sufficiently long that the variance in microwave communication latency is a small portion of the overall timeframe, and not considered as critical as for 240kV and 500kV transmission lines.

Teleprotection timing diagram

breaker	relay	teleprotection shelf	3600 Multiplex shelf	ATM (combine T1's to ATM cells)	radio equipment (1 hop)	ATM shelf (no drop)	radio equipment (1 hop)	total propagation delay (90km)	3600 Multiplex shelf	ATM (recover T1's from cells)	teleprotection shelf	Relay signal processing time	Close output contacts on relay	breaker	time(ms)	cycles	Maximum time allowed in ms	Maximum time allowed in cycles
Case 1: 500kV (2 cycle breakers) with TPR shelves																		
	1 cycle 16.7	1.5	0.6	0.5	0.21	0.04	0.21	0.3	0.6	0.5	1.5	1/2 cycle 8.33	1/2 cycle 8.33	2 cycles 33.33	72.65	4.35	83.3	5
Case 2: 500kV (2 cycle breakers) with Relay connected directly to 3600 mux																		
	1 cycle 16.7	n/a 0	0.6	0.5	0.21	0.04	0.21	0.3	0.6	0.5	n/a 0	1/2 cycle 8.33	1/2 cycle 8.33	2 cycles 33.33	69.65	4.17	83.3	5
Case 3: 500kV (2 cycle breakers) with relays connected directly via fibre																		
	1 cycle 16.7	n/a 0	n/a 0	n/a 0	n/a 0	n/a 0	n/a 0	0.43	n/a 0	n/a 0	n/a 0	1/2 cycle 8.33	1/2 cycle 8.33	2 cycles 33.33	67.12	4.02	83.3	5
Case 4: 240kV (3 cycle breakers) with TPR shelves																		
	1 cycle 16.7	1.5	0.6	0.5	0.21	0.04	0.21	0.3	0.6	0.5	1.5	1/2 cycle 8.33	1/2 cycle 8.33	3 cycles 50	89.32	5.35	100	6
Case 5: 240kV (3 cycle breakers) with relays connected directly to 3600 mux																		
	1 cycle 16.7	n/a 0	0.6	0.5	0.21	0.04	0.21	0.3	0.6	0.5	n/a 0	1/2 cycle 8.33	1/2 cycle 8.33	3 cycles 50	86.32	5.17	100	6
Case 6: 240kV (3 cycle breakers) with relays connected directly via fibre																		
	1 cycle 16.7	n/a 0	n/a 0	n/a 0	n/a 0	n/a 0	n/a 0	0.43	n/a 0	n/a 0	n/a 0	1/2 cycle 8.33	1/2 cycle 8.33	3 cycles 50	83.79	5.02	100	6

Table 11-Clearing time estimate for teleprotection configurations on 500kV and 240kV lines using TPR equipment, relay-to-relay over microwave, and relay-to-relay over fiber optic cable.

The above table presents expected time delays for each component of the communication link between the sending and receiving station relays. The time delays presented here are as determined from manufacturer specifications.

T1 multiplexer delay adapting DS0 circuit to T1 frame: 600μsec.

This is the delay within the multiplexer when adapting the 64kbps data stream to the outgoing T1 circuit. Delays are in the form of buffering, sampling, and insertion within the T1 extended superframe (ESF).

T1 link transmission delay to second T1 multiplexer: 370μsec.

This delay is experienced only with back-to-back T1 multiplexers. The delay is in the form of transmitting the T1, receiving it at the remote-end unit, and de-multiplexing the circuits from the T1 frame.

T1 circuit adaptation to ATM via T1 circuit emulation port: 500μsec minimum.

The interface and migration from T1 data frames to ATM Adaptation Layer 1 (AAL1) cells for transmission across the ATM network also has a time delay associated with it. This value is represented by the 500-microsecond delay added for ATM adaptation. This delay is variable depending upon settings within the ATM switch itself. For the purposes of this calculation, the 'K' factor variable (cell fill ratio) is assumed set to its lowest possible latency value. A more complete explanation of the 'K' value and adaptation within the ATM layer will be presented in Section 6.

T1 Multiplexer frame examination and pass-through: 70μsec.

This delay is the frame examination within the T1 multiplexer for buffering, cross-connecting, and retransmission.

ATM packet examination and relay: 70μsec.

This delay is similar to that of the T1 multiplexer. Cells are examined for delivery and either buffered for demultiplexing, or cross-connected and retransmitted to the next node.

OC3 Radio transmit/receive delay: 119μsec/terminal.

This delay is the buffering and processing time necessary to convert data to a modulated radio frequency (RF), receive it at the remote end, and reassemble the data for delivery.

28-DS1 Radio transmit/receive delay: 78μsec.

Same explanation as for the OC3 radio, with the difference being the RF modulation scheme and the format of the data interfaces.

Radio frequency propagation delay: (determined by path length)

This is the delay experienced by the radio-frequency wavefront as it is transmitted across free-space to the receiving antenna.

A block diagram summary explains the above delay calculation spreadsheet and adds the expected delays through relays and breaker control interfaces.

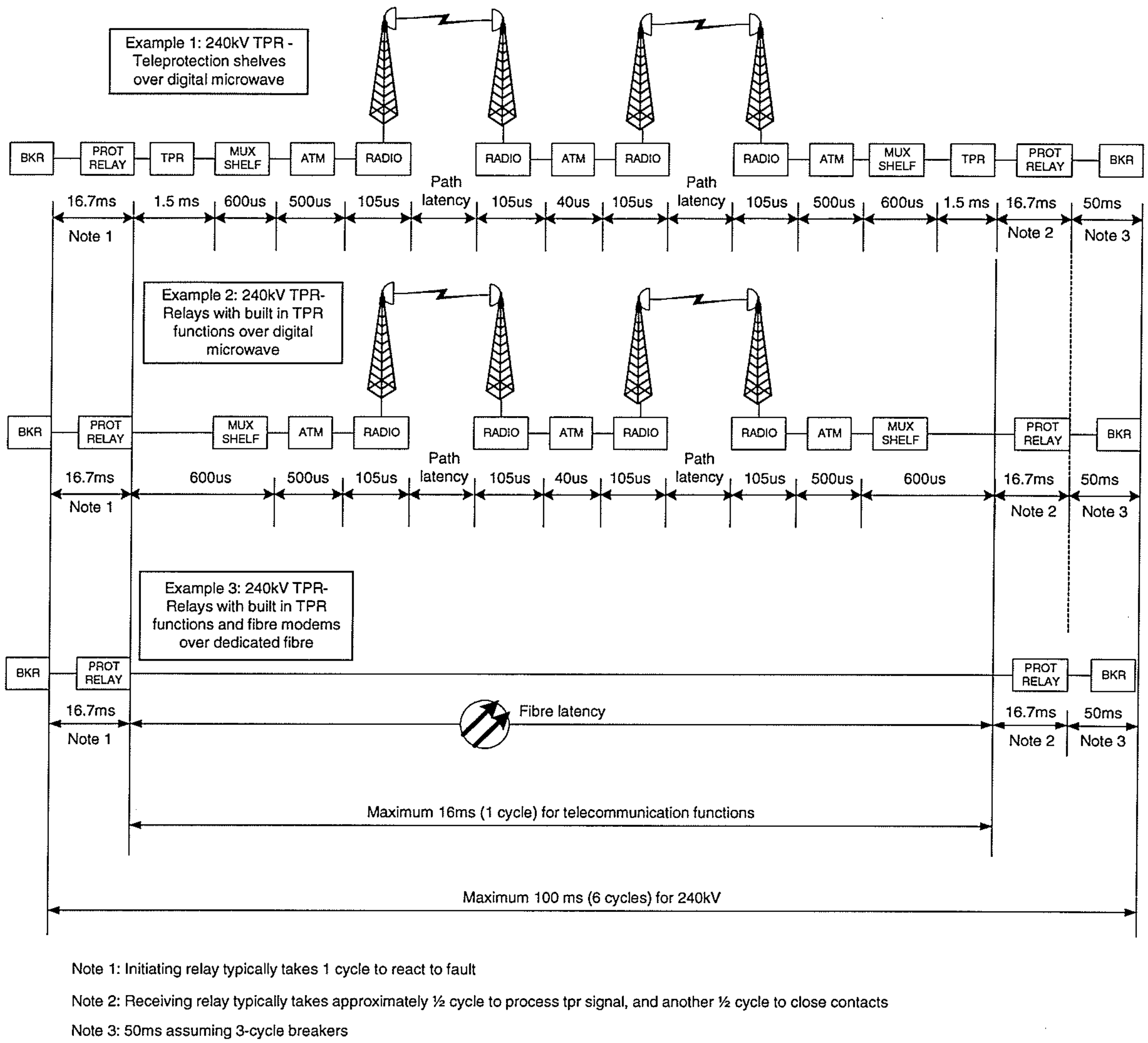


Figure 16-Teleprotection Delay Calculation Block Diagram

The calculations presented in Figure 11 can be used to calculate overall expected path latency. The ingress and egress portions of the calculation remain the same with the radio hop and ATM pass-through delay multiplied to match the number of hops in the circuit path under review.

5.2 Redundant Route Additional Delay

One consideration of the AltaLink network is that there is a core communication loop. This loop provides an alternate path for communications to route around a failed link. Because of this loop, it is clearly visible that if one path is shorter, the alternate route is longer. Each communication hop adds delay and the additional delay of the reroute path must also comply with the maximum time delays expected by the protection designers. The following figure illustrates the increase in delay when using an alternate path:

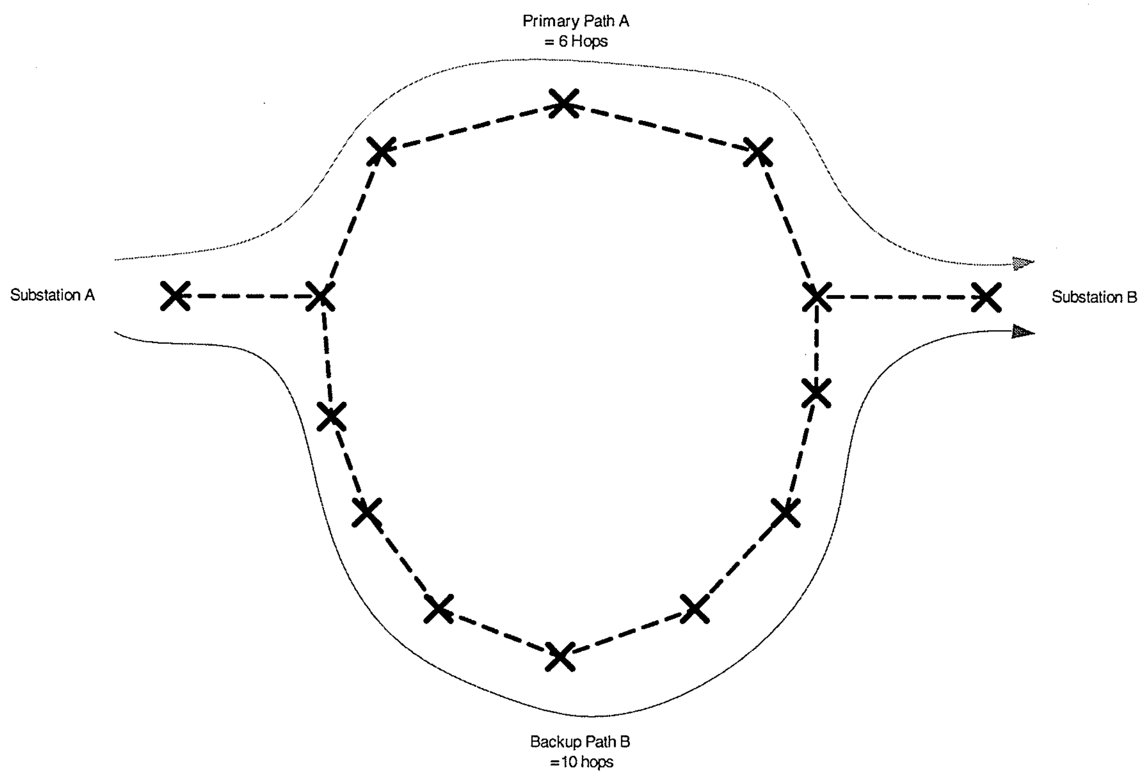


Figure 17-Generic block diagram of primary path route versus backup path route

The communication network designer must consider both the primary and protection routes when determining acceptance of communication latency. For AltaLink, the communication latency has a limit of one 60Hz cycle or 16.666 ms. This time differs from that shown previously due to the inclusion of the buffer factor for miscellaneous relays and unforeseen delays. To verify that the ATM system will meet the time delay restrictions, a complete estimation has to be prepared assuming the worst-case scenario. This is the AltaLink scenario where a TPR circuit enters the 17-hop loop at one site and exits at an adjacent node. The primary path length is one hop while the alternate route is seventeen hops. Refer to Figure 18 for more information.

To begin, it is assumed that a 64kb/sec data channel is used for the communication channel. This is the base communication channel and the standard means of communication for TPR and direct relay-to-relay communications.

There is a propagation time delay introduced because the electromagnetic wave has to travel from the sending antenna to the receiving antenna. The wave-front propagation velocity is assumed the same as the speed of light in a vacuum: 3×10^8 metres/second. The propagation delay can then be calculated knowing the velocity and the distance traveled. For the AltaLink backbone loop, the following table presents the minimum path delays due to wave-front propagation. These values do not include additional delay due to the difference in propagation velocity of the wave through waveguide (considered negligible).

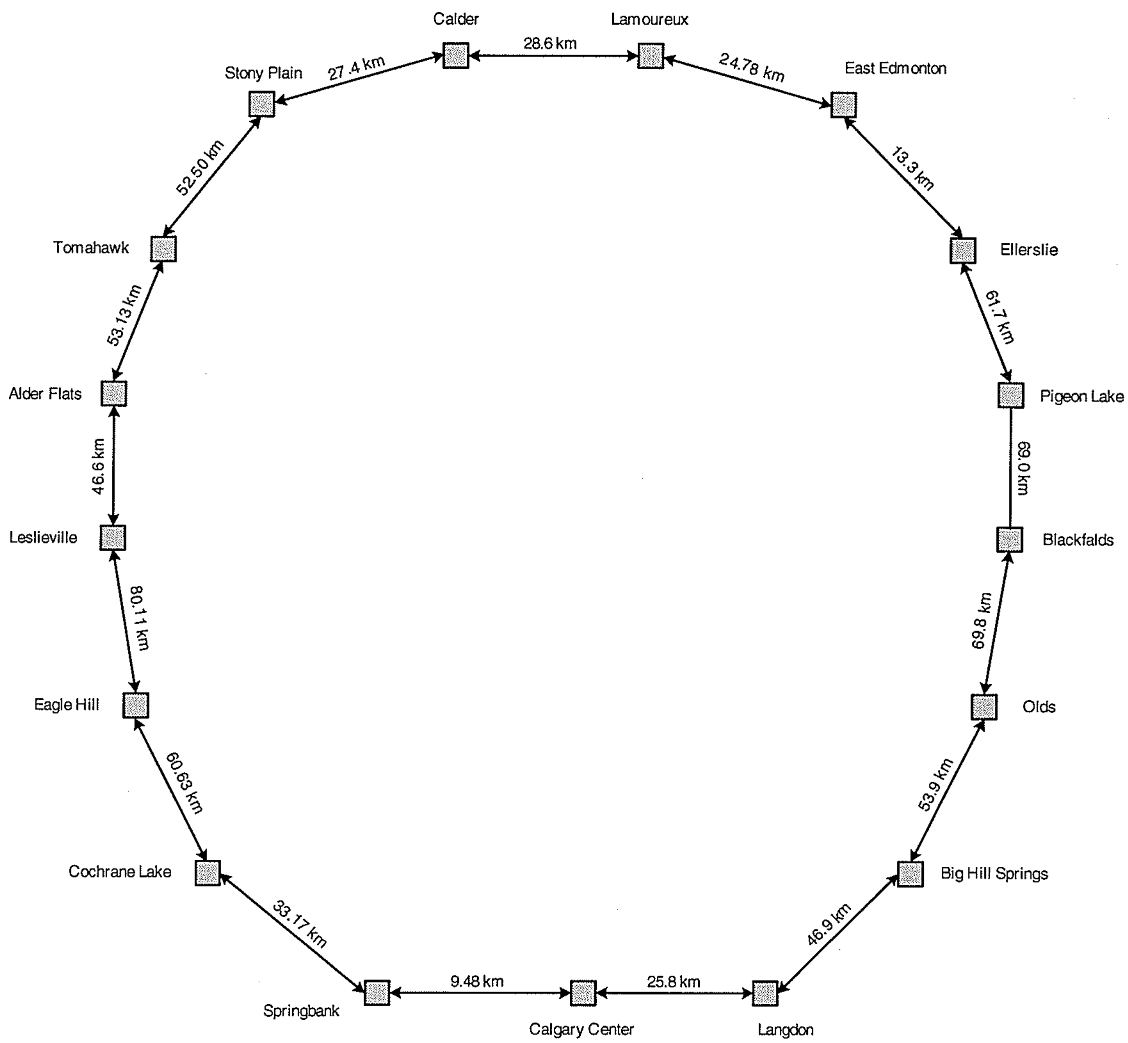


Figure 18-Block diagram of AltaLink's core communication loop.

Loop Path Distances			
Site 1	Site 2	Path Distance (Km)	Propagation Delay (usec)
Tomahawk	Stony Plain	52.50	175.00
Stony Plain	Calder	27.40	91.33
Calder	Lamoureux	28.60	95.33
Lamoureux	East Edmonton	24.78	82.60
East Edmonton	Ellerslie	13.30	44.33
Ellerslie	Pigeon Lake	61.70	205.67
Pigeon Lake	Blackfalds	69.00	230.00
Blackfalds	Olds	69.80	232.67
Olds	Big Hill Springs	53.90	179.67
Big Hill Springs	Langdon	46.90	156.33
Tomahawk	Alder Flats	53.13	177.10
Alder Flats	Leslieville	46.60	155.33
Eagle Hill	Leslieville	80.11	267.03
Cochrane Lake	Eagle Hill	60.63	202.10
Springbank	Cochrane Lake	33.17	110.57
Calgary Radio	Springbank	9.48	31.60
Calgary Radio	Langdon	25.80	86.00
		Total Time Delay (usec):	2522.67

Table 12-Propagation delay calculation for AltaLink's core communication loop.

A comparison calculation shows the best-case delay through one hop of communications versus the worst-case delay through a total of seventeen hops. The interface to the core communication loop for traffic ingress and egress is the same in both scenarios.

<u>Case 1 – Shortest possible route (1 hop)</u>

The low speed data channel originating at a protective relay transmits via a standard, 64kb/second serial data channel. This signal is then interfaced to a T1 multiplexer and combined with other channels to form a T1 multi-circuit link. Once the T1 link has been formed, it is then interfaced to a Sonet OC3 ATM multiplexer for communication across the loop backbone.

At the destination site on the backbone loop, the circuit is de-multiplexed from the Sonet OC3 ATM multiplexer and shaped into an outgoing T1 circuit. Transmission of the T1 circuit to a T1 multiplexer occurs and further de-multiplexes the DS0 channel. The 64 kb/second DS0 channel is then interfaced to a remote-end relay and the communication link established.

To illustrate the previous two paragraphs, a block diagram indicating the associated delay with each segment in the chain can be seen next in Figure 19:

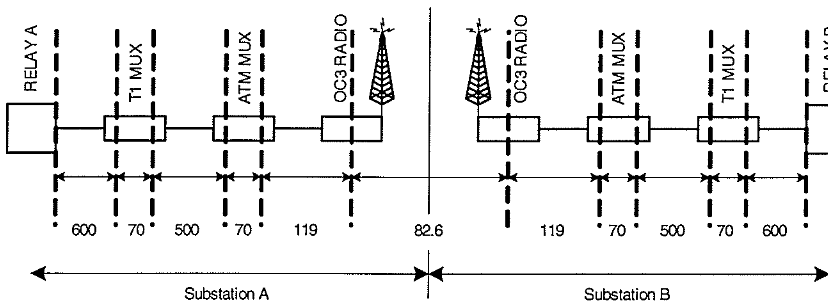


Figure 19-Single-hop OC3 loop communication latency estimate (all values are microseconds).

As can be seen in Figure 12, the total estimated latency for a 64kb/second serial data channel across one hop of the AltaLink OC3 backbone loop is 2.8006 ms (minimum). This complies with the AltaLink specification requiring communication latencies to be below 1-60Hz cycle, or 16.666ms. It does not include the additional delay of the station-end relays and physical contact closure to initiate a breaker trip.

Case 2 – Longest possible route (16 hops)

The longest case scenario assumes that the primary, or shortest, communication path has failed. The ATM layer within the core communication loop redirects communication channels to reroute around the backbone loop and arrive at the destination via an alternate path. Unfortunately, the alternate path crosses a total of 16 hops of communications and an additional 732.02 km of distance. The additional ATM latency and radio frequency (RF) propagation delay are calculated to ensure that the alternate route delay is still within acceptable limits.

Using the example presented above, the ingress and egress latencies to the ATM core backbone loop remain the same. That is the portion where the low-speed serial data channel is multiplexed within a T1 circuit and then adapted to the ATM network layer. The addition of fifteen repeaters adds a significant amount of delay to the system.

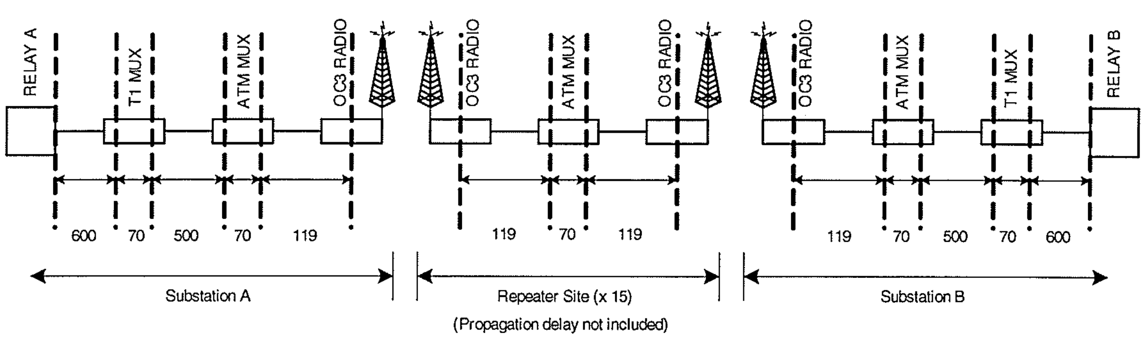


Figure 20-Block diagram of alternate route communication path for latency estimate (All values are microseconds).

The total delay estimate is calculated within a spreadsheet. The results are presented next:

Alternate Path Delay Estimate	Time (usec)
Ingress to Loop Delay at Lamoureux:	1359.00
Lamoureux to Calder Propagation delay:	95.33
Calder Repeater	308.00
Calder to Stony Plain Propagation delay:	91.33
Stony Plain Repeater	308.00
Stony Plain to Tomahawk Propagation delay:	175.00
Tomahawk Repeater	308.00
Tomahawk to Alder Flats Propagation delay:	177.10
Alder Flats Repeater	308.00
Alder Flats to Leslieville Propagation delay:	155.33
Leslieville Repeater	308.00
Leslieville to Eagle Hill Propagation delay:	267.03
Eagle Hill Repeater	308.00
Eagle Hill to Cochrane Lake Propagation delay:	202.10
Cochrane Lake Repeater	308.00
Cochrane Lake to Springbank Propagation delay:	110.57
Springbank Repeater	308.00
Springbank to Calgary Centre Propagation delay:	31.60
Calgary Centre Repeater	308.00
Calgary Centre to Langdon Propagation delay:	86.00
Langdon Repeater	308.00
Langdon to Big Hill Springs Propagation delay:	156.33
Big Hill Springs Repeater	308.00
Big Hill Springs to Olds Propagation delay:	179.67
Olds Repeater	308.00
Olds to Blackfalds Propagation delay:	232.67
Blackfalds Repeater	308.00
Blackfalds to Pigeon Lake Propagation delay:	230.00
Pigeon Lake Repeater	308.00
Pigeon Lake to Ellerslie Propagation delay	205.67
Ellerslie Repeater	308.00
Ellerslie to East Edmonton Propagation delay:	44.33
Egress from Loop delay at East Edmonton:	1359.00
Total Time Delay (microseconds)	9778.06

Table 13-Propagation delay calculation including equipment delay.

It is clear that the time delay calculated above, 9.778 milliseconds is below the maximum of 23.333 milliseconds described earlier, and below the 16.666-millisecond (1-cycle) AltaLink guideline. This does not include time delays for TPR gear or internal delays of intelligent electronic relays for the purposes of security and dependability. A reasonable assumption is that a minimum of 3 milliseconds must be added to account for these delays. If physical interposing relays are necessary to interface with breaker controls, an additional 5 milliseconds must be added. This is a common practice, and therefore a reasonable assumption because typically TPR communication gear using solid-state relays is not rated for the high currents drawn by breaker trip coils.

It should be noted that in actual practice within the AltaLink network, there are few circuits that would experience the 'worst-case' scenario compared above. Nearly all will have a longer primary route and hence a shorter alternate route. This scenario is better due to the reduction in the additional delay presented by the alternate route.

5.3 Hardware Redundancy

The application of communication hardware redundancy is dependant on the risk to the power system in the event of a communication failure occurring at the same instant in time when communication is required to assist in the clearing of a power system fault. Within the AltaLink network, the following criteria shall apply:

<u>500 kV Teleprotection</u>

- Redundant teleprotection channels A & B (either relay-to-relay direct or teleprotection relay units).
- Redundant multiplexer processor cards, backplanes and power supplies.
- Teleprotection circuits separated to be carried on redundant communication equipment – i.e. separate multiplexer interface modules, T1 links, and radio modules, T1 circuit-emulation cards within ATM multiplexers.

<u>240 kV Teleprotection</u>

- Redundant teleprotection channels A & B (either relay-to-relay direct or teleprotection relay units).
- Redundant multiplexer processor cards, backplanes and power supplies.
- Teleprotection circuits separated to be carried on redundant communication equipment – i.e. separate multiplexer interface modules, T1 links, and radio modules, T1 circuit-emulation cards within ATM multiplexers.

<u>138 kV and below Teleprotection</u>

- Redundant teleprotection channels A & B (either relay-to-relay direct or teleprotection relay units).
- Redundant multiplexer processor cards and power supplies.
- Single backplanes permitted.
- Teleprotection circuits separated to be carried on redundant communication equipment – i.e. separate multiplexer interface modules, T1 links, and radio modules, T1 circuit-emulation cards within ATM multiplexers.

5.4 Conclusions

To conclude, it has been shown that the use of an intelligent communication layer such as Asynchronous Transfer Mode can be applied to the stringent requirements of teleprotection and utility communications. The best case and worst-case scenarios for delay within the AltaLink backbone loop have been presented. The expected delays are acceptable and within the guidelines specified by AltaLink protection and control engineers. A standard for hardware redundancy has been created to apply additional hardware protection where sensitive teleprotection circuits and potential risk to system security requires it.

6

6. TDM Multiplexers

6.1 Utility Time Division Multiplexers (Utility TDM)

Multiplexers are critically important to utility communication networks because they are the concentrators of data. They make it possible for management of one, higher capacity data link instead of many individual ones. The also permit the aggregation of data transmitted at differing data rates using several different protocols into one common transport medium.

Selecting a multiplexer for utility communication is not as simple as it would initially appear. Consideration must be shown for the types of circuits being carried, and the level of operational protection employed to ensure their delivery. In addition, the environment that the equipment is expected to operate in must be considered. Utility substations are not hospitable places to be installing sensitive electronic equipment. Communication equipment may be subjected to extreme temperatures, EMI surges, and ground potential rise.

The ability of the multiplexer to provide flexibility in its application is a key contributor to use in the utility environment. Utilities have many sites in their networks with specific types of voice and data traffic being transported. Not all sites are connected with high bandwidth links. For this reason, the ability of the multiplexer to concentrate data and also provide channel cross-connect capability, offers the best possible solution.

An examination of the hardware selected for the AltaLink network will show the how one utility evaluates communication equipment and deploys them within their network. The decision to employ ATM within the core will be examined and the results presented. Overall, it is desired that this section will provide a background of the engineering and planning involved with designing and selecting TDM multiplexers for a utility communication network. It is not a straightforward decision process.

6.1.1 Flexible Time Division Multiplexers

Selecting a multiplexer begins with an explanation of what a multiplexer is expected to do. The basic T1 multiplexer is a *flexible T1 multiplexer*. It has multiple card-slot interfaces and concentrates up to 24 time-slot inputs into one T1 circuit. As mentioned previously in this document, a T1 circuit is comprised of data from 24 input channels plus one frame bit per data frame. Using 64 kb/second input channels, a standard

DS-0, and sampling one byte from each channel per frame, gives a combined data rate of: 8 bits/channel x 24 channels + 1 framing bit = 193 bits. Transmitting this data at a rate consistent with the 64 kb/second inputs requires transmission in 125μsec (8000 frames per second). This corresponds to a combined data rate of 1.544 Mb/second. Derivation of the term Time Division Multiplexer is from the splitting of time into slots allocated to data from different channels.

The T1 circuits leaving the T1 multiplexer may connect to a DS-1 compatible radio for transmission directly, or to higher-order multiplexer such as ATM for further multiplexing into a transport link such as Sonet.

Multiplexers need to interface with many different types of equipment. SCADA systems utilize *DNP* (Distributed Network Protocol) via low-speed serial channels. Protection relays use a variety of protocols such as RS-232, G.703, RS-422, and Ethernet. Some multiplexers offer *DTT* (Direct Transfer Trip) cards for transmission of teleprotection relay contact closures. Substation voice communications are carried using *OPX* (Off-premises Extension) channels and extend private voice-line access to remote locations. The multiplexer may also extend wide-area network connections to the substation for remote access to *IED's* (Intelligent Electronic Devices). All of these different types of data need access to the multiplexer for communication out of the substation. The following block diagram illustrates the process:

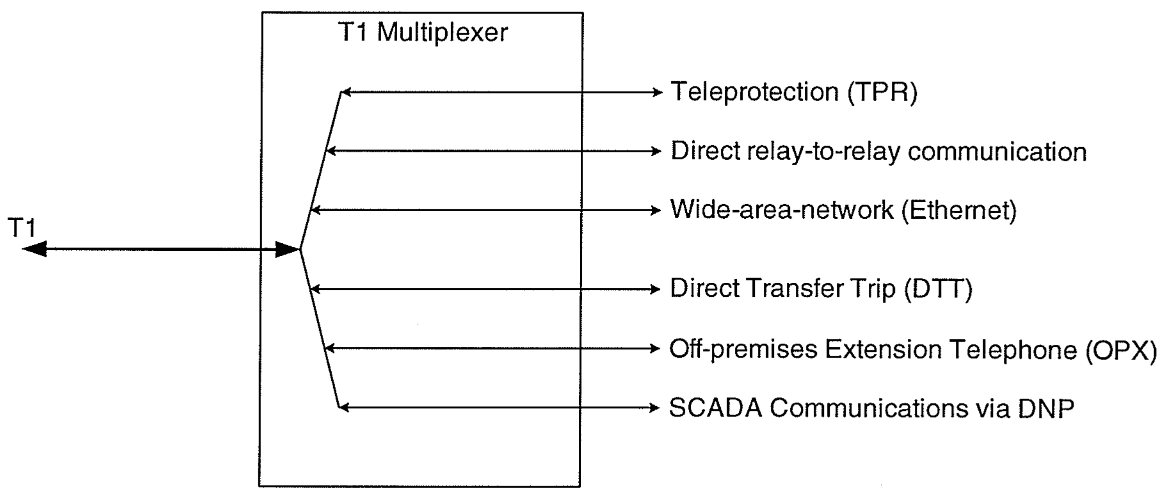


Figure 21-Block diagram of flexible T1 multiplexer operation.

Installing a multiplexer within a substation requires access to substation power supplies and battery banks. These DC power supplies are higher than -48VDC power supplies commonly available on telecom equipment. Common substation control voltages are about 125VDC to 250VDC. DC-DC converters are required to make them usable.

Environmental conditions are important to the utility communication designer because even the best-engineered system may fail if subjected to extreme temperatures outside the specified range of equipment operation. The equipment temperature rating must be examined before installation in the substation, and also the heating and air-conditioning of the building.

6.1.2 Networking Time Division Multiplexers

Networking Time Division Multiplexers have the same capabilities as the Flexible Time Division Multiplexer with one exception: they have the ability to interface to additional T1 links and to cross-connect time slots within them. This feature is known as *DACS* or digital access and cross-connect system. It is useful for utility communications because it is possible to make more efficient use of available time slots within the T1 circuit. Individual circuits from several locations may be combined into one T1 circuit without requiring back-to-back multiplexers to join them. It also eliminates the requirement to backhaul circuits to the nearest DACS unit to cross-connect circuits. This may be done at any node, making overall links shorter and delays smaller in the process.

The same application notes and design criteria apply to this type of multiplexer as that of the Flexible TDM multiplexer. The following block diagram shows the addition of the cross-connect switch to the flexible TDM multiplexer.

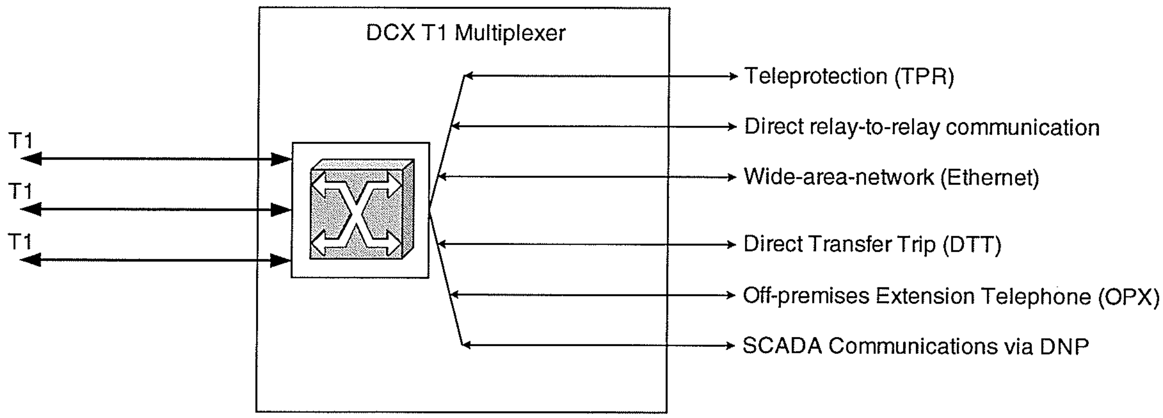


Figure 22-Block diagram of Flexible T1 Multiplexer operation.

6.2 Multiplexer Evaluation

When evaluating a multiplexer for application in a utility environment, several factors need to be reviewed. These factors apply to both Flexible and Networking TDM multiplexers. A detailed examination of each is presented in subsequent sections.

- T1 circuit capacity and expansion
- Available interfaces consistent with those required by substation devices.
- Voice communication.
- Ethernet communication capability.
- Fiber-optic cable interfaces.
- Power supply options.
- Cross-connect capability.
- Interfacing to existing multiplexer equipment.

The evaluation of products based on the above criteria permits the network designer to narrow his/her options very quickly. Not all products are designed for the utility application, nor do all options have every feature listed above. For the AltaLink network, products from two vendors are selected for use. They are the IMUX 2000 Intelligent Multiplexer and the Alcatel 3600 Multiservice Bandwidth Manager.

6.2.1 T1 Circuit Capacity and Expansion

Multiplexers are available in two capacities – single T1 units and multiple-T1 units. This capability, described earlier, is one of the differences between flexible and networking multiplexers. The Imux 2000 multiplexer is capable of multiplexing within one T1 circuit only; the Alcatel 3600 multiplexer is capable of multiple T1 interfaces. The objective of this section is to show which interfaces are required by a utility for specific application within their network.

Application of the two units selected for the AltaLink network is dependant upon the traffic carried. The Imux 2000, single-T1 units require additional multiplexer shelves to be added whenever the capacity required exceeds one T1, or when Teleprotection circuits require hardware diversity in the form of separate multiplexers carrying primary and secondary teleprotection circuits.

The Alcatel 3600 multiplexer is capable of multiple-T1 circuits and can have additional T1 interface modules added when required. Circuit processing allows circuits to cross-connect between any T1 circuits interfacing to the unit. Hardware diversity is added in the form of a second T1 interface module or a second multiplexer directly connected to the first.

In summary, the Alcatel 3600 multiplexer offers more capacity and expandability due to the ability to add additional T1 interfaces as required. The Imux 2000 multiplexer can only offer additional capacity and expandability in the form of additional multiplexer units.

6.2.2 Available Interfaces

The availability of interfaces on either the Imux 2000 or Alcatel 3600 multiplexer is driven based on the expected application of the multiplexer. The Imux 2000 multiplexer design is for use specifically within utility networks, whereas the Alcatel 3600 multiplexer design is for primarily telecommunication service provider use. Many different interfaces are available to the utility designer, but only those specifically used within the AltaLink telecommunications network will be described.

To evaluate, the Imux 2000 multiplexer has the following interfaces: [B22]

- T1 Interface module, configurable for either Terminal or Drop & Insert function.
- Dual-channel PCM (Pulse Code Modulated) 4-wire E&M Voice Frequency module.
- Single-channel PCM 4-wire Voice Frequency module.
- Single/Dual channel 2-wire Foreign Exchange Office End (FXO) module.
- Single/Dual channel 2-wire Foreign Exchange Station End (FXS) module.
- Dual-port Asynchronous Data polling module.
- Four-port Asynchronous Data polling module.
- Single-port Synchronous Data module.

- Wideband Synchronous Data module (Ethernet Bridge).
- Modular Teleprotection System.
- SNMP Access Gateway module.

The Alcatel 3600 multiplexer has the following interfaces: [B23]

- Single/Dual T1 Interface module, completely cross-connect capable.
- Common-carrier module capable of installation with any combination of four, single-channel modules.
- Single-channel PCM (Pulse Code Modulated) 4-wire E&M Voice Frequency module.
- Single-channel PCM 4-wire Voice Frequency module.
- Single-channel 2-wire Foreign Exchange Office End (FXO) module.
- Single-channel 2-wire Foreign Exchange Station End (FXS) module.
- 6-port Asynchronous Data polling module.
- Single-port Synchronous Data module.

Four-wire interfaces use a separate pair of wires to transmit data in both the sending and receiving directions, thus requiring a total of four wires. *Two-wire* communication combines the transmitting and receiving wire pairs into a single pair of wires using a hybrid, hence the term two-wire.

These modules are applied within the TDM network to interface to specific substation equipment and perform certain functions. Their application is described in the following sections.

6.2.3 Voice-Frequency Communication

Voice communication is broken down into two categories: actual voice communication, and voice-frequency communication for data transfer.

Voice communication is a requirement of substations such that each site has a private-line communication link back to the central office. It is an existing standard requirement for substations in Alberta that three modes of communication be available for emergency access. These are 1) Telco service provider, 2) Private Line (OPX) and cellular telephone / mobile radio. The FXO/FXS modules provide the proper interfaces so that dedicated OPX phone lines can be interfaced directly with the central office PBX (*Private Branch Exchange*) switch.

Voice-frequency communication modules are required to interface to legacy equipment capable of low-speed data communication via analog modem only. Rather than attempt to modify existing hardware to complete end-to-end digital communications, it is simpler to provide the necessary VF interface to the digital multiplexer. Many teleprotection units and RTUs fall into this category. In some instances, analog telemetry is also communicated using voice-frequency channels.

Both models of multiplexer, flexible and networking, have interfaces capable of providing this function.

6.2.4 Ethernet Communication Capability

Ethernet interfaces are a new concept to existing digital multiplexers. The required function is to provide an Ethernet-bridge between two points across a T1 data link. The desire is to provide as much bandwidth as possible using varying numbers of assigned DS0 circuits. This feature facilitates the deployment of Ethernet to the substation improves network access to intelligent substation devices.

No routing function is required, only bridging of Ethernet networks with a standard RJ-45 or fiber-optic interface. Routing is performed within the network routers themselves (OSI Model Layer 3).

Of the product selection I have made for AltaLink, only the IMUX 2000 brand of flexible multiplexer has this capability. The Alcatel 3600 multiplexer does not have a high-speed Ethernet bridge module. Low-speed connections may be constructed using a router and V.35 interfaces, but this is the least desirable option.

As a result, the modules available allow for extension of the Ethernet network in two ways: where Ethernet bridge modules are available, they will be used. Where they are not available, Ethernet will be extended to the substation using network gear with direct T1 interfaces. This may be via direct router-to-router connection over T1 or via Frame Relay links over T1. This application is explained in more detail in section 8.

6.2.5 Fiber-optic Interfaces

Fiber optic interfaces are required for those substations physically separated from the radio communication facility and linked by fiber optic cable, and for those communication links within the substation located more than 3m away from the multiplexer. Both single-mode and multi-mode fiber optic cables are used. Multi-mode operation uses 850 – 1300 nm wavelengths. Single-mode operation is primarily between 1300 and 1550 nm wavelengths.

Fiber optics is the medium of choice for communications within the substation environment due to its non-conductive properties and resistance to electromagnetic interference (*EMI).* New protection relays and IEDs are being offered with fiber-optic communication ports. Communication with these devices directly using a fiber-optic cable is the most desirable option due to its simplicity. Where possible, all substation equipment with communications capability should be ordered with fiber optic communication interfaces.

For those devices capable of communication using copper cables only, fiber optic media access units (*MAU)* are employed for the copper-to-fiber signal conversion. These units are external to the IED or multiplexer and are commonly available from a variety of manufacturers. The downside to using these devices is that they often require low voltage DC to power them, complicating their installation.

Direct fiber optic interfaces are available on only the Imux 2000 flexible multiplexer. The Alcatel 3600 multiplexer does not have any fiber optic capability, resulting in the use of fiber optic MAUs.

A specific instance differing from those described above is if fiber-optic cable is used as the transport medium between two facilities. In this case, a fiber-optic multiplexer is used. This device uses redundant fiber pairs and transports up to 12-T1 circuits and up to 100Mbps of Ethernet traffic between the source and destinations. Individual flexible and networking multiplexers are then used to breakout the T1 circuits into their respective interfaces. T1 and Ethernet connections are made using standard copper connections.

6.2.6 Power Supply Options

The voltage interface capability of multiplexer power supplies directly affects how the device will be installed within the substation environment. Substations always have some form of battery bank for operation and control of substation equipment. Most IEDs within the substation are powered using this supply. Therefore, it is also desirable to have communication equipment that can also utilize the same power supply systems.

Connecting communication equipment to the substation DC battery bank may not always be required. Critical substations may have dedicated telecom battery banks that supply -48VDC. The option of both 130VDC or -48VDC power supplies makes the multiplexer flexible for installation in either case.

Multiplexers designed for substation use, such as the Imux 2000, have 130VDC power supplies available as an option. They also have -48VDC telecom power supplies available. This selection makes this multiplexer flexible for installation in both substations and radio facilities. It eliminates the need for external DC-DC converters or stand-alone -48VDC battery banks.

The Alcatel 3600 multiplexer is designed for the telecom environment first, substation second. It does not have 130VDC power supplies available as an option. To use this product inside a substation, as mentioned previously, requires the use of either a 130VDC/-48VDC DC-DC converter or a -48VDC battery bank.

In AltaLink's network, all 240kV and above substations are considered critical infrastructure and equipped with -48VDC battery banks for the purpose of communications. All 138kV and below substations may either interface to the substation 130VDC battery bank directly, or install DC-DC converters with N+1 redundancy on the converter modules.

6.2.7 Cross-connect Capability

At the beginning of the section, the difference between flexible and networking multiplexers is the ability to cross-connect timeslots within T1 data links. This ability is beneficial for two reasons: it allows for the reallocation of used timeslots within T1 channels to maximize use of T1 circuits and keep channel allocation as efficient as possible. Second, it permits cross-connection at any node in the T1 chain. This has the potential to shorten overall circuit lengths and reduce circuit latency because circuits do not have to be delivered to a DACS unit to be reassigned. The only alternative to a networking multiplexer is to install DACS units at all locations. This is cost-prohibitive in most cases and complicates the channel plan.

The Imux 2000 multiplexer cannot accept more than a single T1 input. Because of this, its cross-connect capability is non-existent. To obtain cross-connect capability an external DACS unit must be deployed around the network. All DS1 circuits must be brought to that unit in order to have circuits traverse from one T1 circuit to another. This creates a more complicated series of lengthy circuits and adds, in some instances, prohibitive delay to the channel.

The Alcatel 3600 multiplexer has the processor capability to accept up to 8, dual-T1 cards per universal card shelf. This makes the unit completely capable of cross-connecting between a maximum total of 16 x 24 = 384 circuit inputs or timeslots, assuming that no DS0 circuits were externally connected. For this reason, the Alcatel 3600 multiplexer is preferred over the Imux 2000 multiplexer.

The ability to cross-connect also factors into planning initiatives currently underway within the utility communication industry. The initiative involves adding route diversity to critical installations, either by constructing the alternate route within a utility's own network, or by obtaining capacity from an outside source. The goal is to add an additional layer of protection to the communication network by adding an alternate route to the site. Cross-connecting multiplexers facilitate this initiative by permitting connecting links between multiplexers to take diverse paths. In the event of a link failure, network management systems monitor the link status and can dynamically reroute traffic on to the surviving link. Without the ability to switch traffic between channels, this option would be more complex, if even possible at all.

6.2.8 Multiplexer Redundancy for Teleprotection Circuits

Hardware redundancy is of specific concern to the utility communication planner. Teleprotection circuits help to protect transmission and substation assets and are critical to the safe, efficient operation of the power system. For this reason, ensuring their successful delivery is of paramount importance.

To ensure communication takes place from the sender to the receiver, all efforts are made to ensure that there are no single points of failure. A single point-of-failure is simply a device or link in the communication chain for which there is no backup. If the device or link fails, so does the overall communication channel. One of these links in the chain for example, is the multiplexer. It has the potential to cause the failure of both the 'A' and 'B' teleprotection channels commonly installed to protect a transmission line.

To eliminate the risk as much as reasonably possible, multiplexers are designed to have redundant capability. This is in the form of redundant power supplies and processor cards. These offer operational protection to communication circuits assuming that no physical damage takes place to the link between the interface card in the multiplexer and the processor card. The only way to obtain that level of redundancy is to use completely separate redundant multiplexers for A and B circuits. For critical circuits, this separation is a requirement. The Western Systems Coordinating Council (now WECC) has published several useful documents describing the application of redundancy within teleprotection channels. The reader is referred to [B27] and [B28] for more information.

In the AltaLink network, teleprotection circuits for 138kV and below may be carried on the same T1 within the same multiplexer. This application lends itself to using flexible multiplexers such as the Imux 2000. The multiplexer must still have redundant power supplies and control cards in all cases. For 240kV and above teleprotection, redundant multiplexers are used. This means that 'A' and 'B' teleprotection circuits are carried across physically separate units and on separate T1 links. The only single point of failure is the microwave radio link that carries both T1 circuits. In the case of the Alcatel multiplexer, connection between redundant multiplexer shelves is possible. This permits the processors on one shelf to assume completely the switching function of both shelves in the event that one shelf experiences a catastrophic processor failure.

From the utility point of view, redundancy and diversity equate to higher reliability. Having the capability of backup power supplies and processor cards assist in achieving that goal. The design of teleprotection circuits is also a factor that must be considered. For critical circuits, separation of redundant channels is a requirement to avoid having channels both fail simultaneously.

6.3 Final Multiplexer Selection

To conclude this section, there are applications within the utility environment where both the flexible and networking multiplexer have a role. AltaLink has chosen to deploy both of these units depending on the location within the network.

Aside from the using additional Imux 2000 units where units already exist in the network, the Imux 2000 flexible multiplexer has better substation hardening and more options for direct fiber-optic interfaces. This makes it more applicable to the low circuit count communications of last-mile links to substations. The Alcatel networking multiplexer has more bandwidth capability and increased intelligence and circuit visibility through network management. This unit is deployed closer to the network core (ATM) and where higher circuit concentrations exist within substations.

7

7. ATM Multiplexers

Historically utilities have used analog or digital microwave communication systems in conjunction with channel banks for transport of teleprotection and scada circuits. Communication channels have been dedicated links between sending and receiving stations with little, if any switching intelligence. Asynchronous Transfer Mode or ATM is an emerging technology for this application, developed initially for the telecom service provider market. Only recently has it been adopted for installation in microwave radio-based, province-wide utility communication networks.

ATM is a logical progression in communication network development. Firstly, it offers a bridge between older, legacy transport mechanisms and the newer transports such as Ethernet and Sonet. This is accomplished by adapting various inputs to a common stream of 53-byte transport cells. Existing hardware such as T1 multiplexers can interface to ATM units and benefit from the increased intelligence and monitoring of ATM's core fast-switching and multiplexing abilities.

ATM also offers more efficient use of bandwidth due to the dynamic nature of ATM's cell relay services. This allows for better use of invested capital in terms of radio and fiber transports used for utility-only command and control infrastructure. Bandwidth is flexible and assigned only when data is available to transmit. Circuits are monitored in real-time and may be rerouted in the event of failure – even across alternate links available from other service providers. More on the decision to migrate utility telecom to ATM-over-Sonet will be explained in this section.

The technology behind ATM must be understood to see how it differs from that deployed in utility telecom systems today. The types of services for voice and data differ in how they are treated by the ATM switch. Quality of Service (QoS) is a feature of ATM allowing priority of service to be assigned to circuits ranging from constant-bit-rate (CBR) traffic to unspecified bit rate (UBR).

How traffic flows through the network must also be described. ATM assigns or directs traffic flow at a virtual level, meaning that physical links such as microwave radio are used to create virtual bandwidth 'pipes' to which ATM moves and allocates traffic as required by the circuit configuration parameters. A Switched Permanent Virtual Circuit (SPVC) is created as a virtual link from source to destination. This circuit is designated a virtual path identifier (VPI) and virtual circuit identifier (VCI) as addressing for cells to move from node to node along their delivery path.

ATM switches are built using components similar to that of the T1 multiplexer and as a result, must be protected in a similar manner. Interface modules are added to the ATM shelf depending on the traffic carried. Management and visibility of the ATM network is accomplished through an NMS (Network Management System). These have not been deployed within the AltaLink network until now, and offer a wealth of real-time monitoring and control capability.

In short, ATM offers a new realm of flexibility to utility network operation, and is one option available in the goal to replace aging communication networks. Its application in the transport of critical teleprotection and scada circuits is new to the utility industry and requires examination if deployment is to succeed.

7.1 Basic ATM Operation

Telecom service providers are the primary users of ATM equipment, primarily for public telephone call routing and data communication. The technology was developed in the early 1990's and is mature. This is what makes it applicable to utility communications – nearly all bugs have been fixed. Utilities do not want technology that is on the leading edge – they want platforms that have been tried, tested, and proven for reliable communication.

The core of ATM operation is its ability to transport data using cells of fixed length – 53 bytes long. These cells consist of 5 bytes header information and 48 bytes of payload. Cells are transported synchronously so that delays are kept at as constant as possible. Without this ability, delays would vary with the length of the data frame and the amount of bandwidth in use at any given time on the network. In addition, because the data cells are a fixed size (53 bytes), switching can be done on a hardware level and not in software. This makes switching very fast.

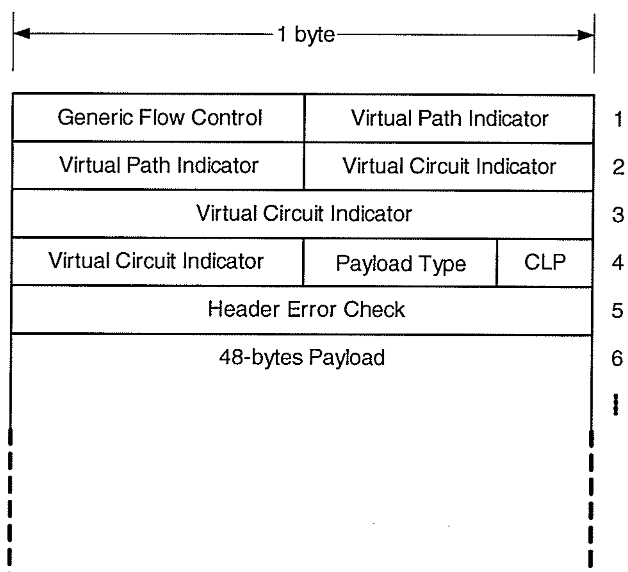


Figure 23-ATM Cell Header Structure

Within the ATM processing layer, cells are transported using virtual paths and circuits. The virtual circuit is better described as routes through network nodes. When a virtual circuit connecting two points in the network is requested, the ingress node begins by configuring the necessary bandwidth and settings between it and the adjacent node. It also requests via an overhead management link that the adjacent node do the same and ask for bandwidth from its adjacent node. This process continues until the circuit is successfully created from ingress point to egress point on the network. Data flow begins with each cell traveling the same route and arriving in sequential order. The circuit constructed may remain configured indefinitely or be automatically torn down when the requirement for it is removed.

Data cells are relayed from node to node based upon routing information stored within each node at the time of circuit creation. This is known as Virtual Circuit Switching (VCS). Allocation of raw bandwidth between two nodes forms a virtual 'pipe' or path. Multiple circuits may be carried within a virtual path such that they aggregate to form a larger bundle that may be routed and managed as if it was itself a separate unit. This is known as Virtual Path Switching (VPS). ATM switches are capable of doing both VCS and VPS. A diagram explains the virtual path and virtual circuit:

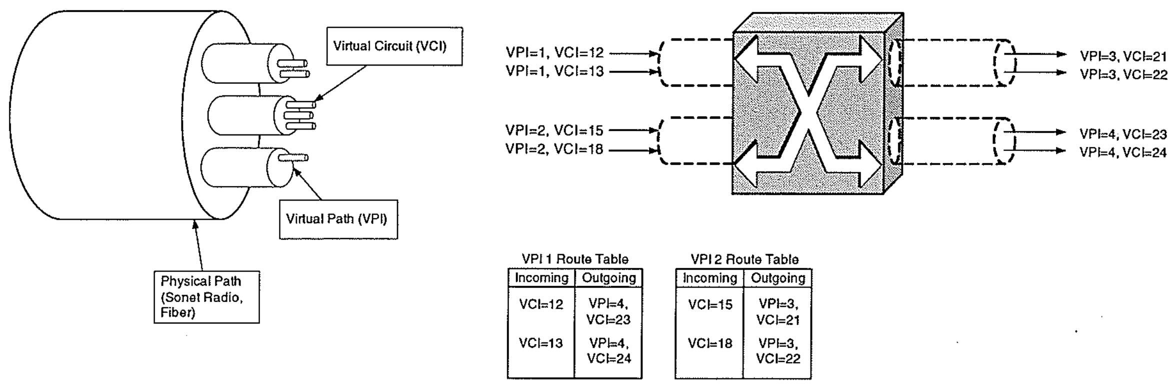


Figure 24-ATM Block Diagram and Switching Operation

The above left figure illustrates the idea of virtual paths and virtual circuits. The physical transport links may carry many different virtual paths, each containing many virtual circuits. The figure on the right shows how paths and circuits are handled through the ATM switch. Data enters the switch on virtual paths and virtual circuits. The routing table then determines which outgoing port the data should be routed, depending on the incoming data link. Switching takes place on a local level only, without each switch in the network having to know the global addressing and routing of each circuit. This permits switching to take place very quickly and with consistent delay and jitter.

Further to the idea of virtual circuits, those circuits that are constructed and remain constructed, are referred to as Permanent Virtual Circuits (PVC). Virtual circuits are created and torn down as required by the end devices. Due to the static nature of critical utility communication (teleprotection and scada), PVC's are the circuits that will carry all critical utility traffic. With PNNI (Private Network to Network Interface) communication, nodes communicate between themselves to determine active and available routes. In the event that a communication link fails, PNNI routing permits the PVC to be rerouted via alternate communication channels. PVC's with this rerouting option are known as Switched Permanent Virtual Circuits or SPVC for short. Rerouting takes place at the hardware level and as a result is very fast. All circuits may be rerouted around a link failure, providing alternate paths exist, in a matter of hundreds of milliseconds. All non-critical utility ATM traffic will use this option to maximize reliability.

Knowing the very basic ideas and terminology of ATM allows explanation of more specific feature of ATM such as the several different types of circuits and QoS, and ATM Adaptation Layers (AAL). Specific features used by the utility environment are also presented next. For additional, specific information on ATM operation, the reader is referred to the following reference texts: [B2] [B3] [B7] [B24] [B25].

7.2 ATM Quality of Service and Adaptation Layers

ATM is known for its Quality of Service (QoS) and ability to carry several different types of data traffic. To understand better how ATM will be applied to the utility communication network environment, it is necessary to present the options available and which of them will be deployed. To begin, there are five different levels of QoS. Further to that, there are five ATM Adaptation Layers (AAL) used to interface data streams and convert them to ATM cells. This subsection begins with a discussion of QoS, followed by AAL.

The five levels of QoS define how the ATM layer will handle each type of circuit and prioritize it for delivery. These levels are:

- **Constant Bit Rate (CBR)** – used for time sensitive traffic needing constant cell delay and highest priority. Time-division multiplexed circuits require this class of service. Specifically, these are utility teleprotection, scada, and all voice circuits.

- **Variable Bit-Rate–Real Time** – used to transmit data streams requiring bandwidth that varies with time. Cell delay variation is minimized. Commonly used for video streams – utility application for video surveillance.

- **Variable Bit-Rate-Non-Real Time** – Used to transmit data where cell delay is permitted and synchronism is not maintained between sender and receiver. Used for reliable data transfer – utility application for transmission of wide-area IP network traffic.

- **Available Bit Rate** – Only a minimum data rate is guaranteed. Other bandwidth may be used when available. End equipment must reduce bandwidth usage when requested or risk having cells dropped. Used for simple data transfer. Utilities will not use this, favoring VBR-nrt instead.

- **Unspecified Bit Rate** – This is best-effort service given the lowest priority of all. Utilities will not use this except in rare circumstances with non-critical data.

As mentioned within each description, AltaLink has plans to deploy only CBR, VBR-rt, and VBR-nrt classifications of data traffic.

Constant bit-rate traffic makes up the majority of utility traffic. This is because it originates on TDM data streams that are sensitive to time delay and cell arrival times. Payload data must arrive at the destination on time and in-order so that successful transfer takes place. Teleprotection (RS-232, G.703, Voice), Scada (RS-232), and voice-frequency circuits all fall under this category.

Variable bit-rate, real-time circuits are seldom used in the utility environment. These links can accept variable bit rates due to traffic bursts, but also maintain cell arrival times for synchronization. Delay is reduced and cell arrival order maintained. These circuits would be used by utilities to transport video surveillance data streams. AltaLink does not have any plans to deploy this type of circuit in the near future.

Variable bit-rate, non-real time circuits permit cell delay variation (CDV) and can accommodate variable bit-rate data streams. This is a perfect classification for reliable transport of Ethernet packets across the ATM layer, and will be employed by AltaLink. Utilities should use this type of circuit for all Ethernet transport links.

In addition to the five classifications of ATM circuit, there are also five classifications of ATM adaptation grouped into four categories. These are known as AAL1 through AAL5.

- **AAL1** – For mapping of time-sensitive data into CBR data streams. Adaptation adds cell sequence number for proper ordering, clock recovery data, and no error control bits (if errors exist in the real-time data, there is no opportunity to resend them). Used to adapt T1 and Frame Relay links to ATM cells.

- **AAL2** – Mapping of video data into ATM. Cells sequence is maintained and error control is added. Synchronization is not maintained due to variable bit rates. These would potentially be used by utilities for remote video surveillance applications, but it is expected that lower-bandwidth digital IP cameras will surpass this requirement.

- **AAL3/4** – Used to adapt VBR-nrt data packets to ATM cells. Adaptation includes error-checking, and cell sequencing. AAL3 is used for connection-based service, AAL4 for connectionless service. Both are being replaced with AAL5 due to improved reliability of data links.

- **AAL5** – Used to carry data traffic such as IP across ATM networks. Error-checking is added to the total data packet, not each ATM cell. This creates a simple adaptation of data to ATM requiring little ATM overhead. This will be used by the utility industry as part of its IP network deployment.

AAL Layers are an underlying component of the ATM design. The overall delay added to account for the conversion process must be considered when planning and calculating the expected delay of the TPR circuit. As was presented in the teleprotection section (5), delays of 500μs to 5ms are possible. In addition, the cell-fill ratio must be examined on a per-circuit basis to determine the expected latency. The cell fill ratio describes how much of each ATM cell must be full before being sent to the destination. If data is buffered until a sufficient cell fill-level is reached, the end-to-end delay experienced by the circuit will be longer. The benefit of this is that bandwidth is used more efficiently. If the converse is true, more bit-stuffing takes place and latencies are shorter. This occurs at the expense of efficiency. CBR traffic will experience a fixed delay – not elimination of delay – by adjusting this value.

To review, there are concepts that describe the conversion of structured data to the ATM layer. Virtual circuits and paths carry data through the network based on routing information. Different classes of circuit exist for different types of traffic. These include corresponding adaptation functions. All of these add up to a networking layer deemed to be capable of carrying critical utility communications.

7.3 AltaLink's ATM Deployment

Making the migration to an ATM-based network is made easier because the network is constructed from the ground up. ATM equipment can be selected and installed as required at each node in the network to meet the need. The AltaLink deployment of ATM includes descriptions of the Alcatel 7270 and 7470 ATM switch. While it is preferred not to reference specific manufacturers in the overall design of the network, the design plans described here could apply to many other manufacturers of ATM equipment. A description of the specific products is necessary to show actual system design.

Design of the network includes several components: hardware design, interconnection to radio site equipment, performance expectations and operational benefit received.

The basic hardware is based on two products. The Alcatel 7270 is a smaller network-edge device capable of nearly everything its larger brother the Alcatel 7470 switch is capable of doing. The difference lies in the types of cards available for each switch and the number of card slots useable in each device.

The following table lists those interface cards used in the AltaLink network that are available for each unit:

Interface Type	7270 ATM	7470 ATM
-48VDC Power Supplies	X	X
Backplane w/ Redundant Bus Controllers	X	X
Redundant CPU w/ PNNI	X	X
Sonet OC3 Fiber	X	X
T1 Circuit Emulation	X	X
Frame Relay	X	X
Ethernet Access	X	X
ISC Router		X

Table 14-ATM Interfaces used on the AltaLink network.

7.3.1 Core ATM Components

To begin, the ATM backplane chassis is selected in one of two possible forms:

The 7270 switch is a mid-plane architecture capable of housing redundant control cards (2) plus 6 interface modules. Redundant bus controllers are installed in the rear of the unit and a corresponding six wiring interface modules – one for each interface card - installed alongside. Interface processing cards are installed in the front of the chassis. Power supply modules are installed at the base of the unit with a redundant configuration of up to five independent modules.

The 7470 switch backplane chassis is a full-card design capable of housing redundant bus controllers (2), redundant control cards (2) and 10 interface cards. Power supply modules are included on each individual card, requiring only redundant DC power feeds to the shelf. Each card is powered independently.

These designs are favorable to the utility demands for complete redundancy and no single points of failure. With the exception of the backplane itself, all shelves have redundant backplane bus controllers, control cards, and power supplies.

Bus Controller cards control communication between the interface cards and manage all switching and multiplexing functions of the shelf. They also manage buffering and cell filtering.

Control cards are similar in function between both models of ATM shelf. The control card controls circuit processing, PNNI and data spooling functions. Furthermore, the cards perform all network management, statistics collection, and network synchronization (Stratum-3 minimum). They maintain the routing database and collect alarms for the entire shelf.

7.3.2 ATM Interface Components

Interface cards are described beginning with the SONET backbone connections. These are single port interface cards capable of communicating using SONET frames at a bandwidth of STM-1, or OC3 as described previously in the document. Overall bandwidth is 155.52 Mbps. OC12 cards are also available, but due to bandwidth restrictions on the microwave radio links, are not used. Connection to the physical port on this card is made using SC-type multimode fiber (MMF) cables. The jumper is then connected to the microwave radio. In AltaLink's network, two of these cards are installed in every shelf on the backbone loop. One connection is made to the east-facing radio and the other to the west-facing radio.

T1CE or T1 Circuit Emulation cards provide the channelized TDM access ports to the ATM switch. Cards are installed with eight ports on each card, and are physically wired out on the back of the unit. These are the most common card in the AltaLink ATM network providing T1 access to local multiplexers and direct cable connection to 28-T1 radios. A minimum of two cards is installed in every shelf for redundancy. More may be installed depending on the T1 port count requirements. Critical circuits such as teleprotection A and B channels are physically split across separate ports on separate cards. This provides an additional layer of protection to these circuits in case of a T1CE card failure. This also requires a minimum of two T1 circuits be connected to the ATM shelf from every TDM multiplexer.

T1 Frame Relay cards allow for connection of up to four channelized frame relay connections per card. Physical transport of frame relay data is via T1. Use of these cards within the AltaLink network is for distribution of wide-area-network connections carrying Ethernet IP traffic. More on the network design using these cards is described in the next section. Several of these cards are deployed within the AltaLink core loop primarily at sites interfacing to multi-T1 spurs where substation Ethernet access is required. They are installed as single units within the ATM shelves and are not configured for any form of redundancy.

EN100T cards allow direct IP to ATM access at the ATM switch. The 4-port 10/100Base-T Ethernet cards perform the adaptation of Ethernet frames to ATM using the AAL5 adaptation function described earlier. They are installed in a non-redundant form (single card) at each node in the AltaLink core loop. Connections are made to the card for local radio site WAN access and in some instances, Ethernet connections are made to adjacent substations using Ethernet fiber-modems and multiplexers. The card performs some simple IP functionality such as MAC address filtering and VC-to-VC cell forwarding. Connections are made from each physical port using SPVCs to make Ethernet bridges and/or virtual connections to the ISC ATM router card. More on the ISC application is presented in the next section.

The ISC card (Internet Services Card) [B26] is only available for 7470 ATM shelves and is only installed in one location within the AltaLink network (Calgary). This card performs the virtual routing function of the WAN and can accept virtual connections via direct IP (AAL5) or using channelized frame relay links via AAL1. This card will act as a core-router within the AltaLink network and terminate point-to-point virtual links from all substations properly equipped. No physical connections are made to this card.

These paragraphs give a brief description of the planned ATM deployment within the AltaLink network. To better illustrate how each of these devices is connected logically within the radio site, the next page displays a block diagram of virtual connections. The center of the diagram is the ATM switch with all connections to external equipment shown. Network clouds show connections to the remainder of the ATM system, and where connections to T1 and Frame Relay Links are made.

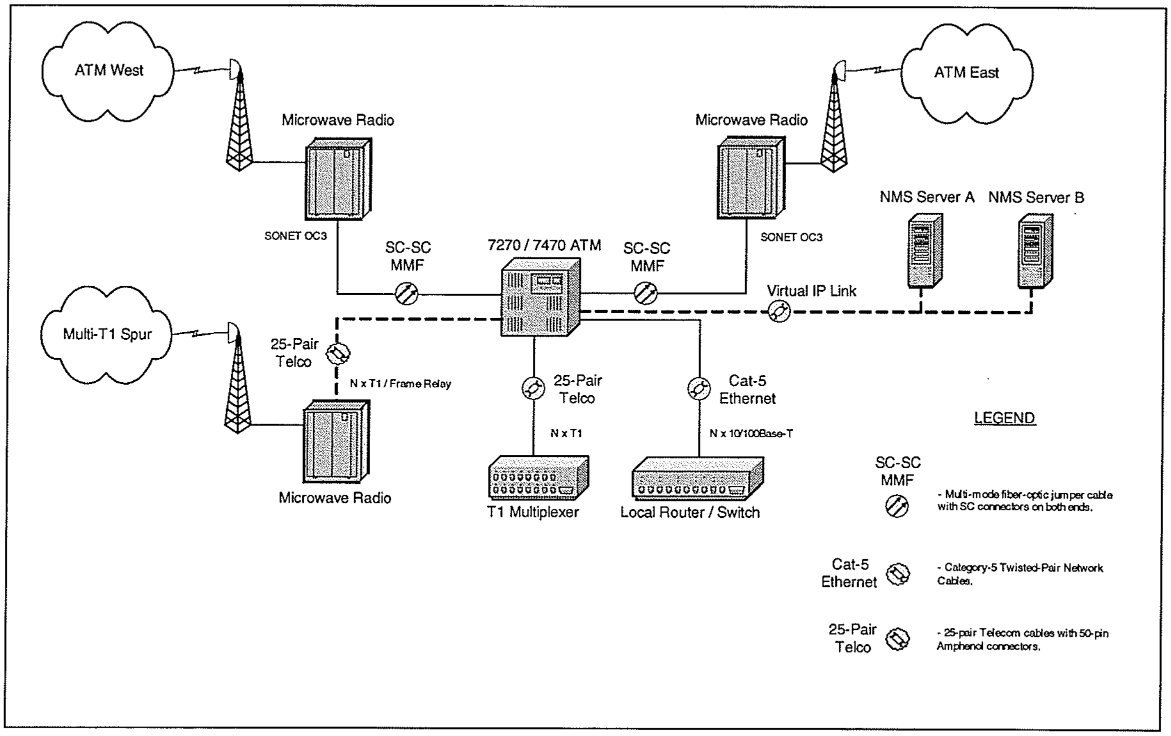


Figure 25-ATM Connection Block Diagram

7.3.3 ATM Network Management

Management of the ATM network consists of redundant servers running the Alcatel 5620 ATM network management system. This software package is installed on SUN™ servers running the X-Windows interface. It is used to control, configure, and monitor all aspects of the ATM network. The 5620 is also used to monitor the Alcatel 3600 T1 multiplexer. This permits configuration of both devices through one common interface.

This management system, when configured for access to a network ATM or T1 multiplexer node, permits direct access to all configuration parameters. This allows management changes to be conducted remotely instead of having to be on site physically. It also permits circuits to be provisioned much quicker than previously done. Through the coordinated use of PNNI protocols within the ATM switch and CPSS management circuits to the T1 multiplexers, only the circuit end points need to be known. The NMS locates the required bandwidth and provisions the circuit. Once circuit provisioning is completed successfully, the field technician needs only to connect to the multiplexer at both ends. Configuration of intermediate sites is no longer required.

The Network Management System also maintains the overall database of all provisioned circuits. This includes both TDM and ATM circuits. In the event of an ATM link failure, the PNNI-capable control cards within the ATM switch manage all possible rerouting within the ATM cloud. For link failures in the TDM network, the 5620 NMS performs this reroute function. Rerouting, where alternate routes exist, is slower than if done at the hardware level like ATM. Software rerouting completes in several seconds, which is still much faster than if requiring operator intervention.

The 5620 is an Alcatel –proprietary network management system communicating using the Alcatel CPSS protocols. The software package does have an SNMP (Simple Network Management Protocol) interface permitting SNMP traps (alarm or event messages) to be interpreted and stored within the 5620 software. This is particularly useful to AltaLink where non-Alcatel, but SNMP-compliant devices are used. In particular, the radio equipment and WAN devices are SNMP-capable. These devices will be configured to deliver traps to the 5620 such that their status can be continually monitored.

At AltaLink, the NMS servers are installed in the primary and secondary power-system control centers located in Calgary, AB. These units are considered critical to the network operation and treated the same as the servers running the energy management system (EMS). Redundant operation is required with failovers to the redundant server occurring monthly.

7.3.3 Alternate Routing

Presently the majority of the AltaLink network is self-contained. Meaning that nearly all circuits travel across dedicated links where the transport mechanism (fiber, radio) is owned and maintained by AltaLink.

This limits the redundant route options due to lack of route diversity at most sites. What is desired is to obtain bandwidth from alternate service providers such that backbone links may have alternate routes through other networks in the event of a major system outage. The use of ATM in conjunction with the 5620 NMS makes this a possibility.

In AltaLink's network, the desire is to obtain a minimum of 4-T1 circuits (96 channels) through the ATCO Electric network running in parallel with AltaLink's network between Calgary and Edmonton. These circuits would be dedicated to AltaLink, but would be used only in the event of emergency. ATM and TDM management circuits would be carried across these links, as would teleprotection for major high-voltage transmission lines. The additional bandwidth would offer a third level of redundancy to the already redundant core network loop.

Presently these additional links have not been obtained. Discussions are underway and the ATM network design has been completed assuming they are added.

7.4 ATM Conclusion

To conclude this section, the basic operation of ATM has been discussed. This includes both the quality-of-service levels available to the ATM designer, as well as the ATM Adaptation Layers used to convert different inputs to the ATM layer. The flexibility of ATM has been described including the potential benefits to using this design. The hardware components that comprise the ATM switch within the AltaLink network have been shown. The core components are presented and described, followed by their planned deployment. The section concludes with a brief discussion of Network Management and re-routing options.

8

8. Extending Ethernet to the Substation

Extending Ethernet to the remote substation and radio site is a relatively new concept for the utility communication planner. Those utilities such as AltaLink still using analog-based communications did not have the channel capacity or bandwidth available to offer such a service. With high capacity, digital radio deployment throughout the network, and fiber optics available within metro areas, the bandwidth requirement has become a reality.

Wide Area Ethernet Networks or *WANs*, offer flexibility in communication connection because they standardize on one common protocol. Interfaces are available in both twisted-pair copper and fiber optic ports. Port bandwidth ranges from standard 10Base-T to 100Base-T and even 100Base-FX and Gigabit Ethernet in some instances. Communication link bandwidth ranges from a single DS-0 circuit to full T1 bandwidth on TDM. Within the ATM network, bandwidth varies up to a full 100 MB/sec connection. Although not currently deployed, Dense Wavelength Division Multiplexing on fiber makes gigabit Ethernet possible.

Using a new utility ATM core network to deliver Ethernet services to the substation is also a new concept to the utility communication planner. Frame Relay links extend the Ethernet connection over TDM connections to arrive at the remote substation. There LAN (Local Area Network) gear provides the interfaces to substation equipment.

Substation network access has many benefits to the operations of a power utility. Communication staff can access equipment such as ATM multiplexer, T1 multiplexer, RTU (Remote Terminal Unit) at the remote facility without having to leave the central office, or possibly even home office. Protection engineers can interrogate relays to download recent incident reports and digital fault recordings. Even revenue metering can be polled using new substation meters built with Ethernet connectivity. The savings in time from reduced site visits and communication complexity are expected to be significant.

As a final note introducing the deployment of Ethernet to the utility substation environment, there are security concerns that need to be addressed when deploying a network like this. The utility must always be conscious of possible threats to cyber-security. Proper authentication and firewalls must be in place before an installation of a broad connectivity network takes place. Based on recent threats to national security and power system outages, security is no longer a simple matter, nor is it one to be taken lightly.

8.1 Province-wide Ethernet Network Planning

Planning to deploy a complete network across the utility service-area requires knowledge of the bandwidth available and in what form. In AltaLink's scenario, bandwidth is available as spare T1 circuits not currently allocated for use on the microwave radio system.

For spur connections using multiple-T1 radios, designation of one T1 circuit for each Ethernet network service area is for wide-area network traffic. This selection is beneficial because LAN gear can be readily purchased with T1 interfaces. What must also be determined is how routing of Ethernet data packets takes place throughout the network. Which device will perform the add-drop function for the Ethernet LAN? These questions are answered by using an Ethernet router with at least two T1 interface modules and one 10Base-T connection. The dual T1 interfaces permit upstream and downstream network connections. The 10Base-T connection is for local access to the operational network link. The term "operational" is used because it refers to the network as being an operational tool, differing from the networks deployed for corporate or energy management system *(EMS)* use.

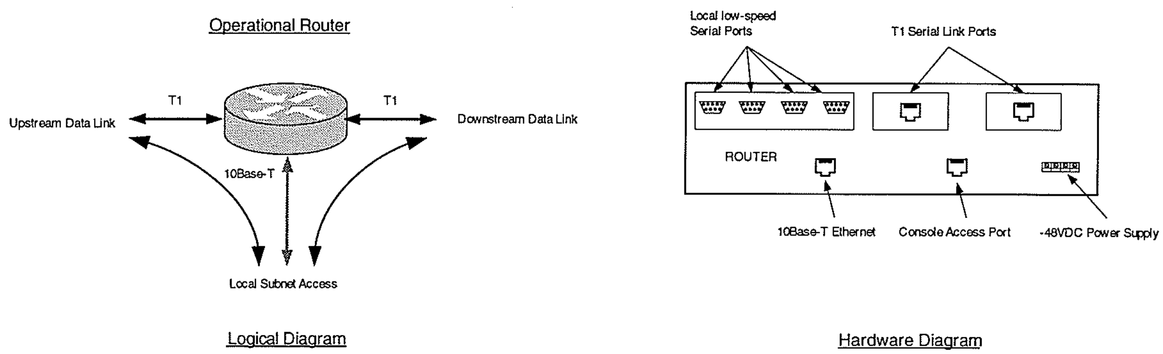
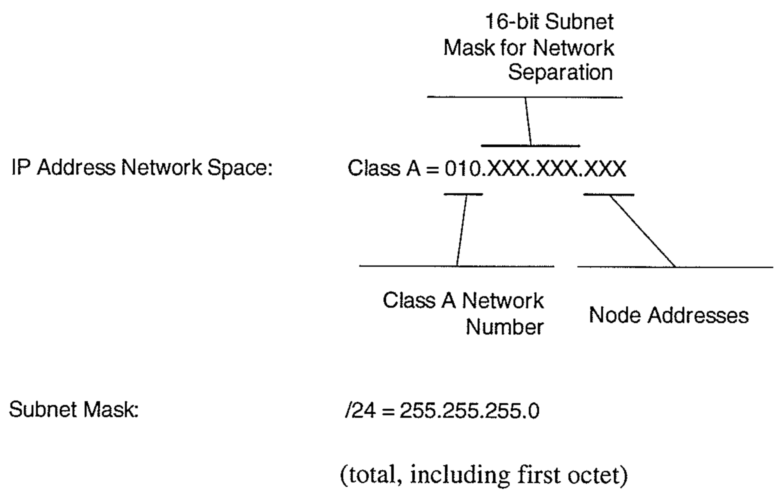


Figure 26-Operational Network Router

Allocation of network address space is the next design issue in planning a wide area network. A brief overview of the process is presented here, but it is assumed that the reader has a basic knowledge of IP network design and function. Ethernet networks are broken down into categories of networks and node addresses. The well known IP address and subnet mask indicate the number of separate networks within the total network address space as well as the number of node addresses within each network. Often the network designer is tempted to construct the address space with a larger number of networks and fewer nodes per network. Within the AltaLink network, this has posed problems when networks become congested due to too few node addresses available. To avoid the problem, the network address space is broken down as follows:

The existing network space within the AltaLink private address space starts with a Class-A network. This is already set due to prior network address selections, and unchangeable. Further to that, the Class-A space is subnetted to include subnets and node addresses. This design results in an individual Class-C subnet assigned to each site.

Explaining the address allocation looks like this:



Dividing the address space in this way with the associated subnet mask, gives a network address space of up to 2^{16}-2 = 65534 subnets with 2^{8}-2 = 254 addresses useable at each location. The choice of a full octet (8 bits) for addressing within each subnet is because it is presently unlikely that any AltaLink substation will exceed that number of unique node addresses. If such a scenario were to occur, the subnet mask could be reduced from 16 bits down to 15 bits giving a new address space of 2^{15}-2 = 32766 subnets with 2^{9}-2 = 510 addresses useable at each location. Changing of all device IP addresses would need to take place so that the different address space could be implemented. A simpler solution would be to assign a second subnet of 254 node addresses.

Network address allocation is per region within the AltaLink telecommunications network. Each spur and core loop is given a different network address. The benefit to doing this is that each network is then separated in its own broadcast domain. Broadcast network traffic is kept within its own network address space and not propagated throughout the entire network address space unnecessarily.

To summarize, allocation of the network address space is as follows. This is as described in [B16].

Valid Class-A Network Space: 1.0.0.0 to 126.0.0.0

Number of possible networks: 126

Number of possible nodes: (2^{24}) 16,777,216 – 2 = 16,777,214

Using a three-octet subnet mask divides the large number of nodes into a more useable form:

Total number of possible nodes: (2^{24}) 16,777,216 – 2 = 16,777,214

Three – octet subnet mask: 255.255.255.0 divides the total nodes into two octets of subnets and one octet of nodes (3x8 bits = 24, giving the /24 shorthand designation). This due to a Class A (10.x.x.x) network pre-selected.

Total subnets = 2^{16}-2 = 65534

Total nodes = 2^{8}-2 = 254

With network node addressing assigned, it is now possible to begin constructing the network. Routers connect each site via serial T1 links and provide routing intelligence to the network. Packets are either dropped locally at the site if addressed to a node existing within that subnet, or passed on to the next router in the chain.

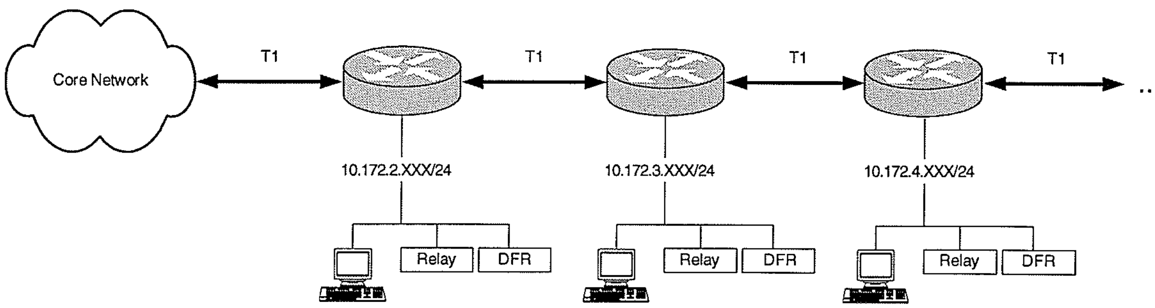


Figure 27-Router-Chain Block Diagram

This scenario applies where only T1 transport links exist and multiplexers have only limited cross-connect capability. The IP network deployment changes with the application of ATM and networking multiplexers.

Where ATM is deployed, within AltaLink's core network loop, routing is done within the ATM network. Virtual connections are made to an ISC card (*Internet Services Card*) that acts as a large router capable of up to 256 concurrent virtual connections. The ISC card is capable of terminating three types of virtual connections: IP over ATM, cell relay (ATM cells), and frame relay. Virtual connections are brought out through the ATM network cloud to frame relay interface cards located at the edge of the core ATM network.

Frame relay is another form of data encapsulation occurring at the data link layer of the OSI model (layer 2). The data link used by frame relay is via a channelized T1 circuit. Channelized meaning that the individual timeslots within the T1 circuit can be individually allocated. Fractions or entire T1 circuits may be designated to an individual frame relay link called a DLC (*Data Link Connection)* [B17]. These links provide transport across the TDM network ultimately ending at each substation serviced by a minimum of T1 bandwidth (1.544 Mb/sec). The frame relay link extends through the local multiplexer to the Ethernet router, also located on-site. The router is equipped with a T1 interface module capable of frame relay encapsulation. This makes it possible to have direct connection via point-to-point frame relay links to each router from the ATM network core. The following diagram illustrates the encapsulation process:

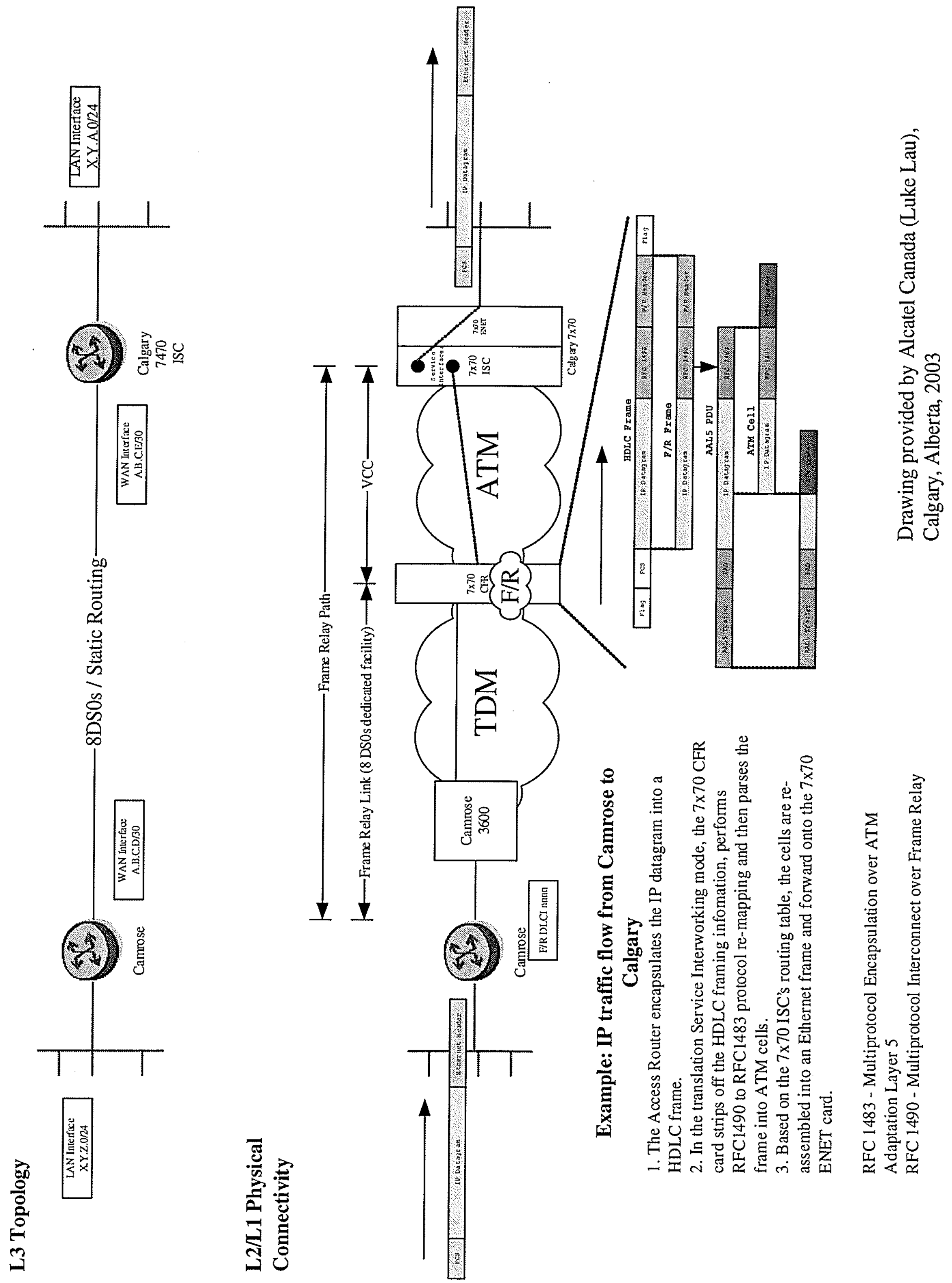


Figure 28-IP – ATM Adaptation Example

The benefit of designing a WAN this way is that it permits the IP network to be managed and controlled using the ATM/TDM network management system. The ATM/TDM management system is responsible for configuration of the frame relay links, and will alarm if any link fails. The IP network, using frame relay and ATM layer transport, appears logically as a hub-spoke design. The number of IP hops crossed to communicate between the remote facility and the substation is reduced from several down to one. This shortens latencies based on fewer examinations of the IP packet and fewer packet relays. All routing essentially takes place at the data link layer instead of the network layer (Frame Relay instead of IP routers).

To the core router, the network topology appears as a hub and spoke design, illustrated below.

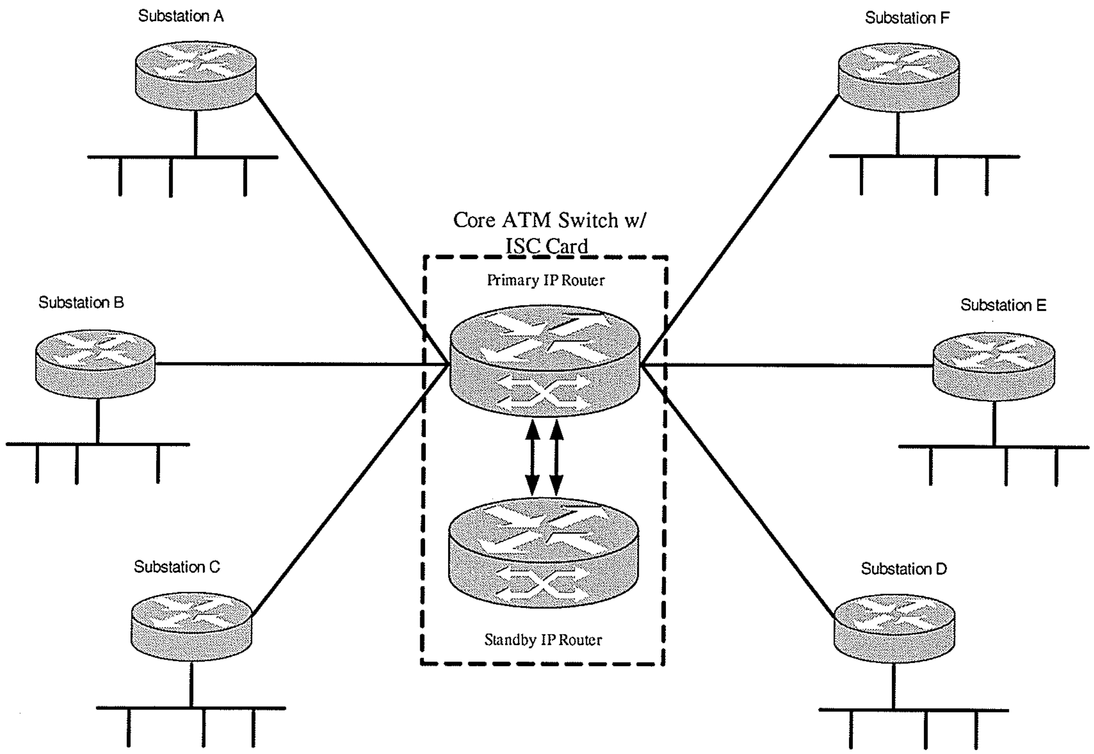


Figure 29-Core IP Network Topology

One argument faced when planning the IP network topology this way is that the design using frame relay is unnecessarily complex with a single-point-of-failure in the core router terminating all connections. This problem is addressed by adding a second ISC card as an emergency backup unit. This module acts as a monitored-hot-standby unit ready to take over the routing function of the network in the event that the primary unit fails. The backup unit may be located anywhere within the ATM core, permitting physical site diversity as another option.

This design is considered acceptable to AltaLink because a) expected repair times are short – at most, 30 days to obtain a replacement unit with advance replacement possible, b) Monitored Hot Standby configuration gives one immediate layer of redundancy, and c) Ethernet traffic is considered non-critical. Any forced outage of the WAN will not disrupt power system operations.

Looking at the actual design of the network, the ISC card is installed within a core node in the ATM system. In AltaLink's case, this is the ATM switch located in Calgary due to traffic flows primarily destined there.

Data links are configured to the ISC card from within the ATM management system. Once the ISC card is configured properly and active, SPVC connections may be terminated on the router.

Installation of frame relay cards occurs in the access nodes to the core ATM network. Switched permanent virtual circuits link the frame relay port to the ISC card. Where frame relay cards are not installed due to lack of frame relay circuits terminating at that node, the frame relay links in the form of channelized T1's are back-hauled using available T1 ports on the ATM T1 circuit-emulation cards. A block diagram illustrating this portion of the network is next:

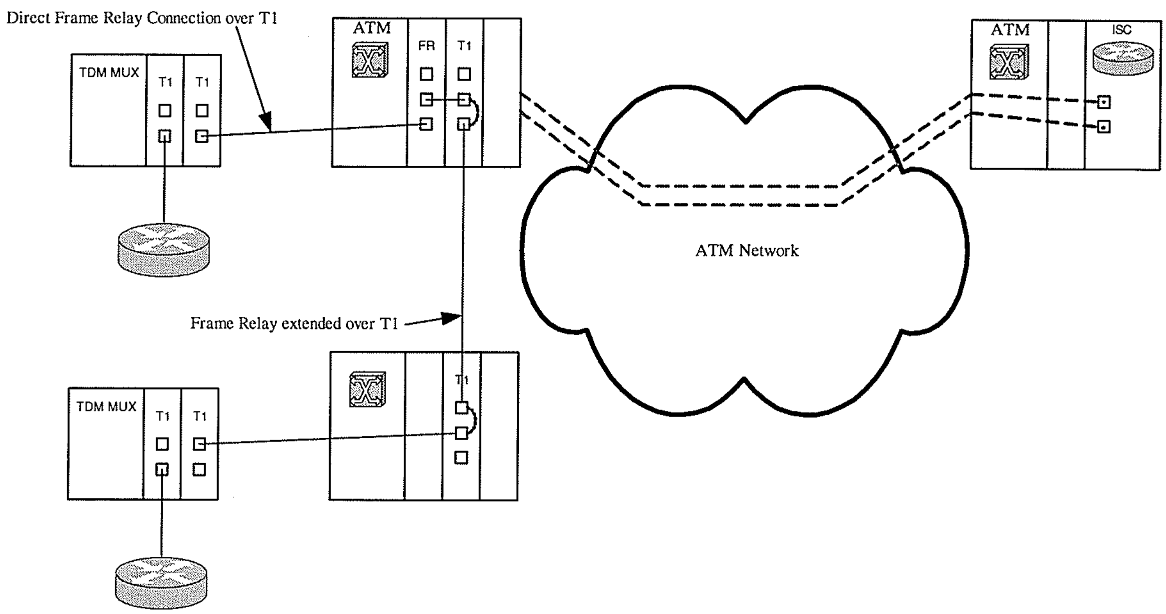


Figure 30-Frame Relay Transport Block Diagram

Where IP routers are installed within direct cable connection distance of a core ATM switch, an Ethernet card is installed. This card allows for direct IP connection and ATM AAL5-adaptation. The ATM encapsulation of the IP packets permits direct connection to the ISC without involving frame relay encapsulation.

8.2 Switching and Routing Terminal Equipment

At the substation-end of the Ethernet link, a local router provides network intelligence to monitor traffic flow, encapsulate IP packets either to T1 frames or via frame relay over T1, and route packets to remote data networks. Intelligence about the network is communicated between network routers using the OSPF (*Open Shortest Path First*) router information protocol. OSPF helps the network of routers determine the best possible path to relay IP packets between networks. OSPF is a common protocol and found on most networking equipment.

AltaLink has selected two vendors for their network routing equipment: Cisco Systems, Inc™ and Alcatel Canada™. These vendors offer products built for the telecom / networking environment. Selecting an industry-proven product line is beneficial because it allows for selection of products from known product lines. Existing staff are familiar with the equipment and assistance may be gained from corporate IT groups also using the same product line. Maintaining this vendor's product also allows for simplified training and design. The only drawback is that existing vendors may not be the most cost-effective option.

As an alternative, and specifically for those sites where the number of Ethernet devices are fewer than 10, the Alcatel OmniSwitch 512 product is the device of choice. It is inexpensive in comparison to Cisco and contains a 12-port network switch built into the router. This eliminates the need for installation of a separate switch at sites such as stand-alone radio repeaters.

Within substations, the selection of suitable networking equipment differs from that of a radio facility. Substations are harsh environments requiring different equipment built for that application. The use of substation-hardened equipment such as products from Rugged.Com[4] or Garrett[5] is required to ensure that local networking is as reliable as possible. Substation-specific networking products are constructed to meet substation-hardness standards. As a guideline, substation network equipment must comply with some or all of the following standards: [B19]

IEEE P1613 "Standard Environment and Testing Requirements for Communications Networking Devices in Electric Power Stations."

IEC 61850-3 "Communication Networks and Systems in Substations – Part 3: General Requirements." 2002-01

IEC TS 61000-6-5 "Electromagnetic Compatibility (EMC) – Part 6-5: Generic Standards – Immunity for Power Station and Substation Environments." 2001-07

IEC 61000-4-x - Series for Basic Immunity Standards.

IEC 870-2-2 "Telecontrol Equipment and Systems – Part 2: Operating Conditions – Section 2: Environmental Conditions (Climatic, Mechanical, and Other Non-Electrical Influences." 1996-08

ANSI/IEEE C37.90-1989 An American National Standard "IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus."

IEEE C37.90.1-1989 - revision of ANSI/IEEE C37.90.1.1974 "IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems."

IEEE Std C37.90.2-1995 - revision of Trial-Use IEEE Std C37.90.2-1987 "IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers."

IEEE Std C37.90.3-2001 "IEEE Standard Electrostatic Discharge Tests for Protective Relays 2001."

Substation-hardened devices offer several benefits over typical networking equipment. Firstly, shielding protects against the higher levels of noise and EMI commonly found in the substation environment. Because of this, the expected operational lifetime of the device and reliability of the device are improved over that of standard networking equipment. Second, substation units are available with DC power supplies

[4] Rugged Communications – website: http://www.ruggedcom.com/

[5] Garrett Communications – website: http://www.garrettcom.com/

capable of connecting to substation battery banks. Typical voltages range from 125VDC up to 250 and 300VDC. This makes deployment easier and more consistent with substation equipment. Third, some substation network units have modular interfaces capable of accepting either UTP (unshielded twisted-pair) or fiber-optic inputs (both single and multi-mode). Fiber is the communication medium of choice due to its non-conductive properties and resistance to EMI.

Within stand-alone radio facilities, standard networking equipment is sufficient due to the low risk of ground-potential rise resulting from a power system fault, the availability of typical telecommunications power-supply voltages of -48VDC, and smaller port count due to fewer Ethernet-capable devices installed on site.

Installing a standard network appliance within the substation environment is an issue considered during the planning stage of Ethernet network deployment. Is it okay to do this? The risk associated with doing this is difficult to assess. Within AltaLink's network, the scenario in question is the decision to deploy network routers within the substation without requiring that they meet the same substation-hardened standards that substation network switches meet. The reasoning for doing this is a lack of available equipment capable of routing Ethernet packets and complying with the required substation-hardened standards. Consideration of the risk found that it was acceptable for several reasons: a) lack of available equipment that complies with the substation-hardened standards meant that no suitable alternative could be found within the available price range, and b) the low-cost associated with replacement equipment. This implies that in the event of damage to a piece of network equipment due to GPR or EMI, replacing the equipment outright is an acceptable solution. It should be mentioned that the substation LAN carries only non-critical information. Loss of the network for a period, while inconvenient for users, would not detrimentally affect the local power system.

8.3 Access to Substation Equipment

The idea of a substation WAN is more broad reaching than just providing access from the substation to corporate network servers and email. The network provides access for a variety of users involving most disciplines of the power-system operating group.

To begin, new communication equipment in the form of radios and multiplexers, are commonly manageable via SNMP (*Simple Network Management Protocol*) or proprietary management software. Management of the network equipment itself is done using in-band SNMP and remote Telnet sessions via the Ethernet network. Radio site DC-power supplies can be monitored and remotely configured through terminal server RS-485 connections to battery chargers. As mentioned earlier, the network provides a common platform connecting all devices rather than separate management networks for each line of equipment.

Connecting a device to the local substation network is simple – another feature of Ethernet. Once physical connectivity is confirmed, all that is required is valid IP addressing information. For those devices not equipped with Ethernet access ports, terminal servers permit text-based terminal sessions to be opened via the operational Ethernet network. Connections are made using either RS-232 or RS-485 serial protocols.

Protection and control engineers can access IEDs remotely to examine and modify configurations due to system events, time of year (seasons), or power system changes. Fault information files may be downloaded from relays to assess performance and perform post-event analysis and simulation. Digital fault recorders (DFR) can be polled for their latest activity files.

Scada engineers can view/modify settings of RTUs and local HMI systems. New firmware files can be uploaded onto existing equipment, and in some instances, remote interface sessions from the local HMI can be viewed. One day polling of RTUs may be done using DNP-over-Ethernet. Current generations of RTU equipment are capable of providing information this way, but due to EMS system limitations it has not been implemented within the AltaLink network. The benefit of DNP-over-Ethernet is that is has the potential to eliminate hundreds of dedicated scada circuits.

Metering staff can use the Ethernet network to poll remote meters for load readings and remotely configure installed units.

All of the benefits listed here save time and labor from reduced on-site visits by field staff. Coupled with an increase in information available from IEDs, they makes the network construction cost justified.

8.4 Network Security

Designing a network to connect substation equipment poses a security risk due to the possibility of unauthorized access to the network and devices connected to it. The remoteness of substations, the large number of sites involved, and lack of on-site staff all contribute to the overall risk. Security precautions must be included in the design phase of network planning.

Fortunately, there are guidelines to follow to ensure the network is secure. Guidelines published by NERC (*North American Electric Reliability Council*) [B18] give requirements for cyber-security. I have incorporated many of these guidelines into the AltaLink network design. A brief overview of network security policies is presented.

8.4.1 IP Security

Keeping IP and subnet addressing secure is the most difficult part of securing any Ethernet-based WAN. Products available today can 'sniff' a network and determine which devices are communicating. For this reason, all addressing information should be centralized and managed by approved individuals. Addressing lists must be maintained in a secure environment to prevent them from being compromised. The goal being that no outside individual can gain intelligence over the WAN and become able to pinpoint specific equipment within substations or control centers.

Simply having access to the network raises the possibility of port-scanning, denial-of-service attacks, unauthorized entry into other substations and facilities, and possibly access through to Corporate and EMS networks. Denial-of-Service attacks are possible, preventing authorized users from accessing the network. Denial attacks may also be caused by using improperly configured equipment. For this reason, all equipment must be monitored for a period after installation to ensure performance is as expected. Network equipment must be configured to isolate segments of the network in the event a portion is compromised.

Data connections must use authentication and secure data channels to prevent the possibility of protocol emulation and mistaken identity. The threat in this instance being that a malicious individual could emulate the scada master and instruct substation RTUs open or close devices. Communicating devices must have confidence with those that they are exchanging data. This confidence comes in authentication and encryption.

8.4.2 Physical Security

Implementation of tight security access policies are key to maintaining a secure environment. For safety reasons power utilities have been imposing these policies for years, but now there is an additional reason – prevention of unauthorized access to communication networks. This policy requires that all individuals entering a facility have proper security clearance before doing so.

Network management systems must alarm upon connection of new devices to WAN systems so that they can be verified against known configurations. Open ports on network switches must be disabled unless assigned for power system use and expansion. Substation buildings and Radio sites must have motion-sensors that alarm upon entry to the facility, and control centers must monitor these alarms 7 days a week, 24 hours per day.

In future network development, IP cameras should be installed to permit operators to view who is accessing a site. This possibility will improve security by shortening response times and notification of unauthorized entry.

8.4.3 Passwords

Passwords are the most difficult security policy to manage because they are selected by different users. This leaves a risk that a) passwords will not be set and enabled, and b) those that are enabled are left to the default password. Passwords must be set on all network elements that have the capability, with a list of passwords maintained by each discipline responsible for the equipment. Password rotation must also take place to ensure that compromised passwords are changed within a reasonable period.

Network equipment in particular must have secure passwords known only to network administrators to prevent access and revealing of network topology through routing tables and address lists.

All devices within the substation, such as relays and meters, must have passwords to protect against unauthorized access from both internal and external intrusions. Relays must be secure to prevent the possibility of unauthorized operation of a substation device. Meters must be protected to prevent corruption of revenue data.

8.4.4 Network Topology

Network topology is a significant risk to power utilities because of the connections possible between corporate, energy management, and operational networks. Control of interfaces between these networks is crucial to preventing unauthorized access from occurring even within the utility organization. The only way to ensure complete security is to isolate the networks from each other.

In AltaLink's network, the EMS or Energy Management System network is critical to the operation of the system control center. For this reason, its network is completely isolated from all connections to the outside world with the exception of one restrictive firewall port giving access to the corporate network. Rotating-key authentication is required to achieve access through the firewall, hence restricting all but authorized users. The Corporate network and Operational network are also connected to the firewall such that restricted access may be obtained through the corporate network to the operational LAN.

For corporate internet access, and access to servers as part of the EMS network, a DMZ (*Demilitarized zone)* is created. This zone contains servers that mirror the actual servers within the EMS network, and provide necessary information to the user without putting the actual servers at additional risk. Additional servers such as corporate email are also connected to the DMZ.

Internet access is firewalled before being connected to the demilitarized zone. Access through firewalls to the internet is controlled through authentication rules and rotating-key passwords. All ports must be closed down with the exception of those required by internal users. Stateful monitoring by the firewall is essential.

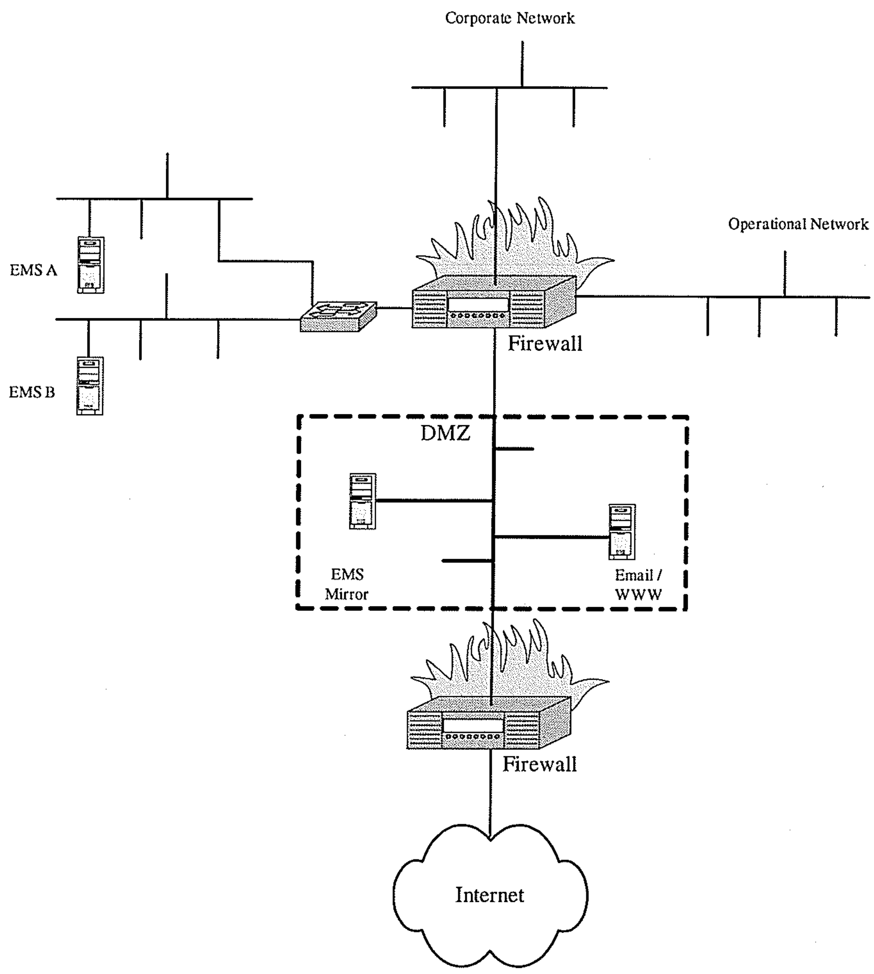


Figure 31-Overall Network Topology

8.5 Networking Conclusions

To conclude this section, it has been shown how the operational network has been planned for implementation within the new AltaLink digital communication network. Designs have been created for both scenarios depending on multiplexer design. Where only flexible multiplexers are used, T1 transport links interface directly to network routers. Where networking multiplexers are installed, cross-connected T1 circuits and Frame Relay links provide access to the ATM core network. Within the ATM network, adaptation of IP and Frame Relay circuits to the ATM layer has been explained.

IP address allocation has been described, permitting allocation of separate subnets for each substation.

AltaLink's choice of networking equipment ranges from devices designed specifically for the network/service provider environment, to those built specifically for substation environments. Access to the operational WAN has been described, briefly explaining how engineers from protection & control, scada, telecom, and metering will use the network to access their respective devices.

Network security and design is mentioned with reference to guidelines published by NERC. Issues around IP addressing, physical access, passwords, and network topology are described.

9

9. Radio Site Infrastructure

The engineering design that is required to construct a province-wide utility telecommunication network is immense. Not all substations are close enough to reach adjacent stations using microwave radio, and not many substations are located on land with the highest elevation. A clear line-of-sight is one of the key factors that make radio communication possible. This facilitates the requirement for a stand-alone microwave repeater station.

Whether constructing a new, stand-alone radio site or rebuilding an existing radio facility, the same reliability requirements must be kept in mind as when designing communications for a substation. This is imperative if radio sites are going to be transporting the critical teleprotection and scada circuits necessary to operate the power system.

Within the radio site, several sub-systems are present. Beginning with the building design, sufficient space must be made available to accommodate newly researched and designed AC and DC power supplies, standby generation, and HVAC (heating, ventilation and air conditioning). Equipment alarming and security must be installed using a dedicated remote terminal unit. External to the building, the layout of the building with respect to the communication tower, station security fencing, and grounding must also be considered.

The issues described here, and the solutions determined for the AltaLink network are the focus of this section of the report.

9.1 Building Design

No one building design can accommodate every possible scenario found within the utility network effectively. To solve this problem, three building designs are presented.

Beginning with building construction, previous experience has proven that telecom radio buildings must be designed for service life in excess of twenty years. This makes the external use of wood products a liability factor in building construction. The new AltaLink buildings are constructed using extruded aluminum panels with interior wood for rigidity. The panels are constructed so that they interlock together leaving a sealed exterior surface. Filling the interior of the panels is urethane insulation providing an insulation value of R14.

The bottom of the building is constructed using steel 'I' beams, 30 centimeters on-center. This creates a sturdy platform to withstand the significant weight of telecom battery banks. On the outside, bottom of the shelter a galvanized steel plate is welded in position to seal the surface and prevent rodent infestation. On the top of the platform, pressure-treated plywood covered with steel checker-plate makes for a slip-resistant surface allowing equipment racks to be securely mounted. For insulation, a minimum of 7.5cm of fiberglass insulation is installed between the upper checker-plate and the lower steel plate.

The roof is made from extruded aluminum and has a slight arch to precipitate water shedding. A rubber covering adds extra sealing against leaks.

Three sizes of building are selected for use in the AltaLink network. The smallest is for use at sites where less equipment space is required than typical sites, and no standby generation. This building has outer dimensions of L = 4.8m (16 feet), W = 3.6m (12 feet), H = 2.7m (9 feet). The middle size is the same as the small building with an additional generator room added. The dimensions for the medium building are L = 7.2m (24 feet), W = 3.6m (12 feet), H = 2.7m (9 feet). Medium-sized buildings are the most common units in the AltaLink network. The largest building is for use at densely populated sites and is an additional six feet longer than the medium building. Its dimensions are L = 9.0m (30 feet), W = 3.6m (12 feet), and H = 2.7m (9 feet). There is only one site in the AltaLink network using the large building, Stony Plain Radio.

To describe the layout of the new buildings, the medium building floor plan is shown. The small and large buildings are similarly equipped with shorter or longer equipment rooms.

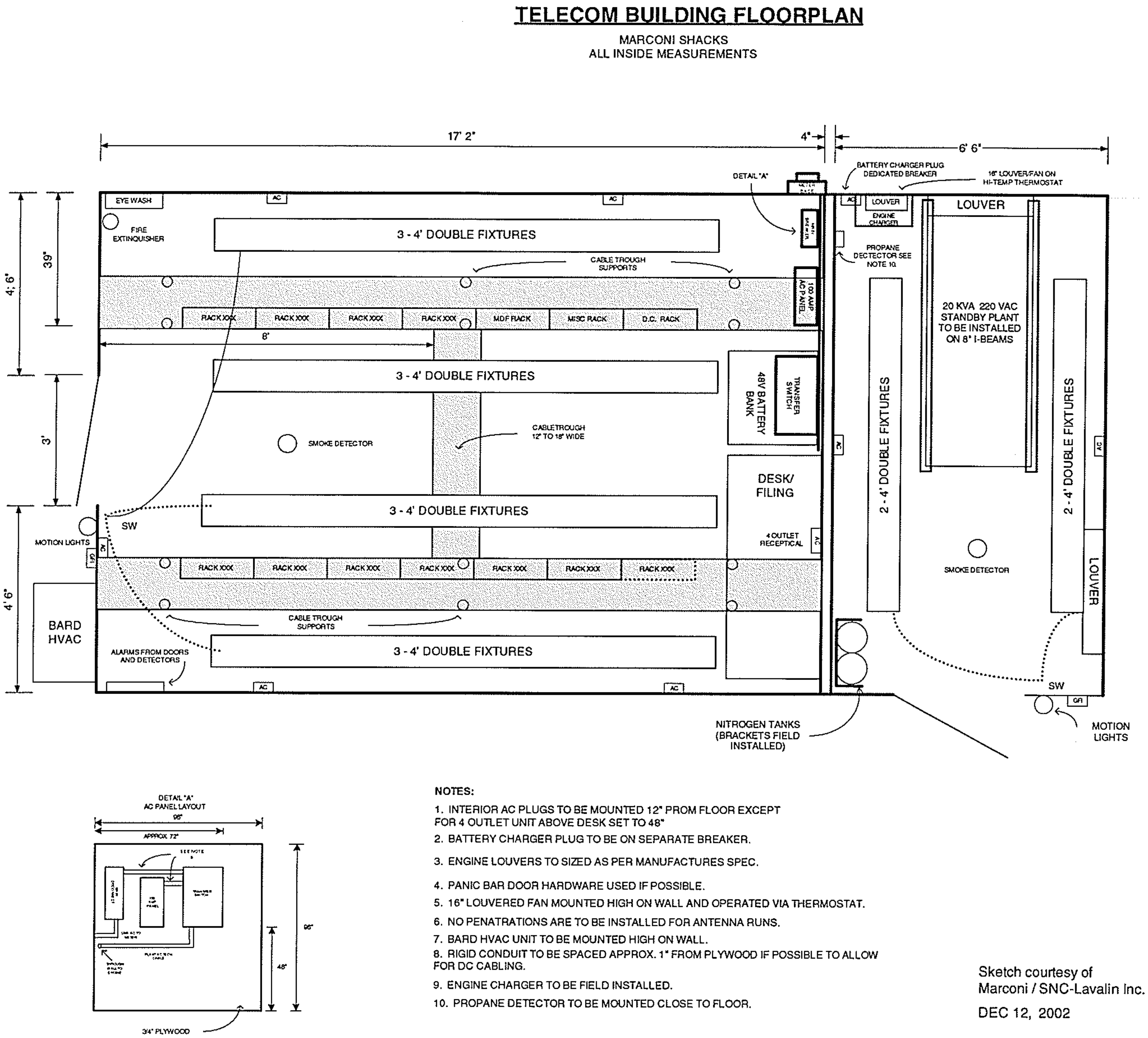


Figure 32-Telecom Building Sketch

The building sketch above also shows the location of overhead lighting, cable trays, and other supporting infrastructure such as desk, safety equipment, and proposed rack locations.

9.2 DC Power Supplies

The reliable supply of DC power is critical to maintaining operation of communication equipment. This supply of DC power is also a requirement in times of AC service disruption. For this reason, a standard backup operate time of 8 hours has been set for all radio communication facilities. The on-site battery banks must be able to supply DC power to all devices, within a specified voltage range, for a minimum of 8 hours. This time was selected because of an estimation of expected dispatch time, travel time, and on-site repair time for field technicians. The battery chargers must also be able to restore battery bank voltage to normal within 24 hours after an outage. These guidelines are as specified in [B27].

An industry standard of -48VDC has been selected for all new communication equipment. This aligns with current telecom standards and permits standardization on one type of power supply. For those legacy devices that require 24VDC and 12VDC, optional DC-DC converters may be used.

The DC power supply consists of two main components: the battery bank and the rectifier/charger unit. Sealed, gel-cell batteries have been selected for use in all radio sites. These batteries, also known as VRLA (valve-regulated lead-acid) cells are sealed units requiring no external maintenance to the electrolyte contained within the unit. The benefit is that a) no annual water addition is required b) potential contact with corrosive fluids is reduced, and c) the cells are constructed from steel making them resistant to damage. The units also emit lower amounts of hydrogen gas, permitting a safer operating environment.

Batteries in three capacities are selected. Just as in the radio shelter selection, no one battery meets all requirements at all facilities effectively. Absolyte IIP [B29] units of 350, 530, and 800 Amp-Hour capacities at -48VDC are used. Batteries are constructed of steel racks containing several cells. Shelves are stacked on top of each other to reduce the use of floor space.

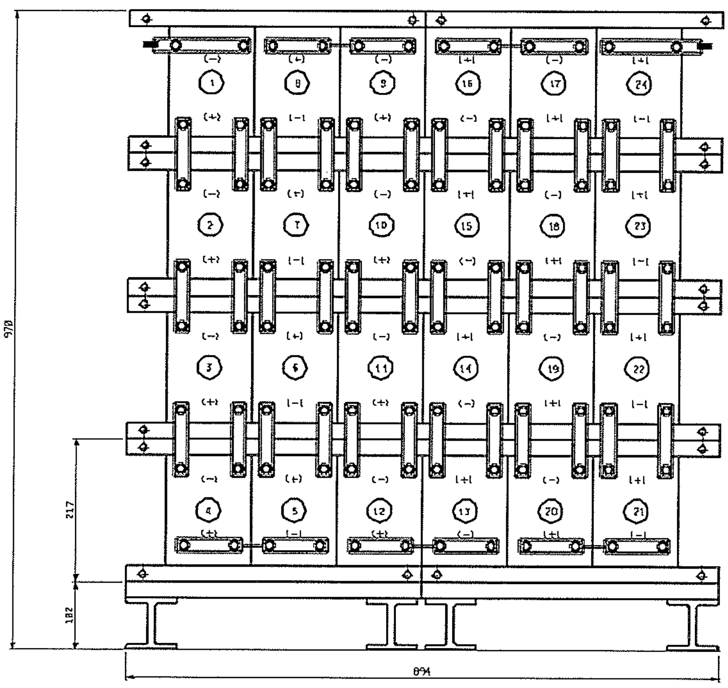


Figure 33-Example Telecom VRLA Battery Bank

Charging these units depends on the site loading. This is because the charger/rectifier units must maintain a float voltage across the battery while at the same time supplying a stable, clean source of DC current to all communication equipment. The charger/rectifier unit selected is the Argus Pathfinder 1.5kW/module charging system [B30]. This unit is a shelf and module design permitting up to three modules to be equipped per shelf. When combined in an N+1 protection configuration, loading is shared across two modules with the third acting as a backup. The maximum output per-shelf is 3000W, or approximately 60A at -48VDC. This configuration is sufficient to power all radio sites within the AltaLink network with the exception of one – Stony Plain. In that scenario, an identical second shelf is installed and connected across the battery bank.

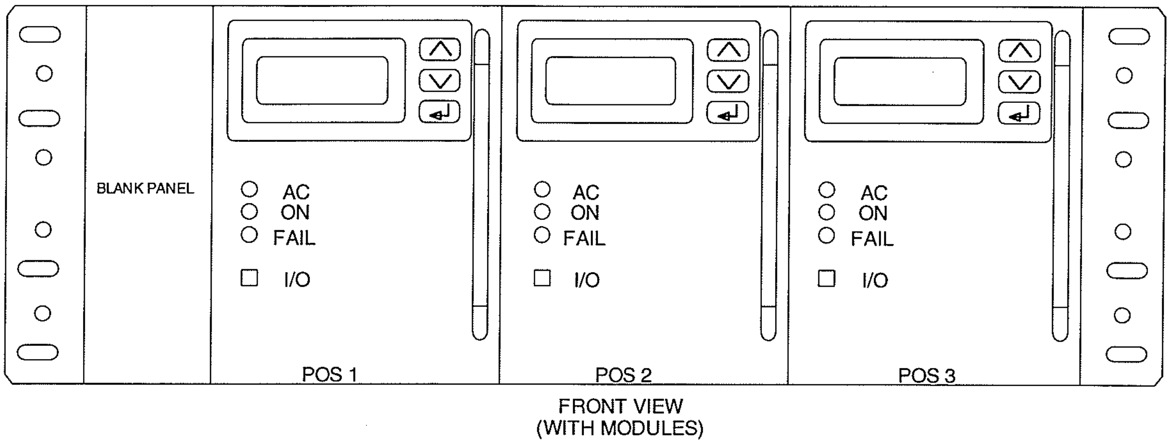


Figure 34-Example Telecom 3kW Redundant Charger Shelf

DC distribution takes the form of a central connection point creating a 400A DC copper bus. Batteries connect across this bus, as do the battery chargers. A 100A DC feed breaker protects the battery from short-circuit current. Chargers are cabled directly across the bus, energizing the circuit breaker panel and charging the batteries. Within the breaker panel, both 5A and 10A breakers are installed. These breakers are used to feed individual racks and devices, depending on their loading. Telecom equipment current draw ranges from 2A @ 48VDC for multiplexers to 9A @ 48VDC for microwave radios.

All breakers are alarmed to the local RTU for control center notification.

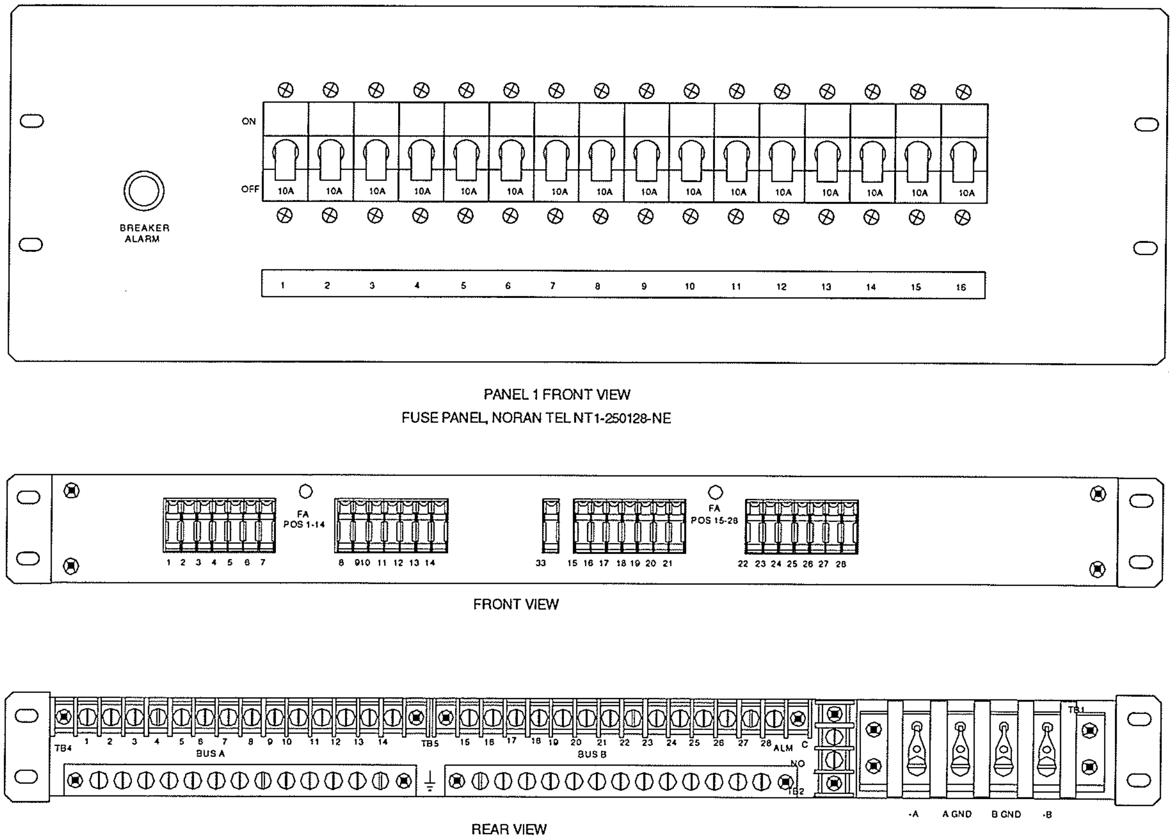


Figure 35-Example Telecom Breaker and Fuse Panel

The GMT-type fuse panels are installed in the racks where more than one device exists. These panels are capable of supplying power from both an A and B feed. This permits two separate breakers to be used, and adds redundant DC feeds to all capable devices.

9.2 AC Power Supplies

Normal power is brought into the radio site via typical overhead or underground conductors. The feed is 220VAC and connects to the exterior of the building at the meter base. The feed is supplied by the local electricity distribution company. The AC is metered before entering the building, and in some instances, a lightning surge protector is added across the main feed.

Once inside the building, AC is connected directly to a 100A transfer switch. The transfer switch transfers AC supply to the standby generator in the event of a distribution feeder fault. From the transfer switch, AC current is distributed via a 100A breaker panel capable of 24 separate breaker positions. This permits connection to building lighting, HVAC, wall-outlets and battery chargers. All distribution and switching are limited to 100A due to a) a 100A distribution feeder, and b) a generator capable of 125A, but equipped with a 100A circuit breaker. A fixed supply for all devices allows for standardization of equipment across various facilities.

The transfer switch is a break-before-make type, allowing time delays before switching over. Power quality units Line AC Voltage, Line AC Frequency, Generator Volts and Generator Frequency are monitored. The transfer switch will transfer to the alternate source, if any of these variables exceeds rated limits. This protects internal equipment from faulty AC feeds and prevents equipment damage. All status points from the transfer switch are connected to the RTU for monitoring purposes. Control center operators are alerted to any loss of line AC, and if the generator is operating. Standby generation control is provided by the transfer switch. A control relay contact is connected to the start relay of the generator.

9.3 Standby Generators

Standby generators are installed in two forms, and must be able to sustain all normal operations within the radio facility. This includes all heating, air-conditioning, lighting and equipment. Previous experience has shown that when Line and Generator AC systems are divided, internal wiring becomes more complex and the functionality of the facility is degraded. As a standard for all new AltaLink radio sites, standby generation must be capable of completely powering the entire site.

The first model is the most common and will potentially be installed at all but two of AltaLink's radio sites. This unit generates a maximum output of 20kW using LPG (Liquefied Propane Gas). While few radio sites require more than 10kW of AC feed, the excess output capacity of the generator engine is derated due to altitude. This is due to the increased expansion rate of liquefied propane at higher altitudes. The benefit of using LPG is that it is simpler to handle and store. AltaLink maintains a minimum of 1000L of LPG on site at all installations with new 20kW standby plants. The benefit of using LPG is that there is no chance of ground contamination. Any leaked LPG evaporates. Larger volumes of fuel located on-site permit the generator to operate several times per year, either for emergency generation or for plant maintenance purposes, without the need for refueling.

The 20kW generator is based on a domestic 4-cylinder engine and installed within the generator room of radio sites. A domestic engine manufacturer makes spare parts easier to locate in an emergency repair situation. Sufficient ventilation is provided to the engine using intake and exhaust hoods (to shield from rain and snow) and dampers. When the engine is started, the dampers open permitting cooling air to circulate throughout the generator room. After the generator is turned off, a time delay is permitted to allow for engine cooling and the dampers close.

The alternate unit deployed within the AltaLink network is a 30kW diesel unit designed for operation at higher altitudes – specifically mountaintop radio sites. The use of diesel allows for the larger generation loads required by the mountain sites. This is due to the larger amount of heating load required. A diesel engine must be used at these sites to the fact that it is equipped with a turbo-charger. The turbo-charger compresses intake air feeding to the engine and reduces the effect of higher altitude.

The diesel generator is coupled with a base 1000L diesel tank at the time of installation. The generator sits atop the tank and draws fuel upwards to the engine. This is more reliable because if a fuel feed-line were to rupture, the fuel would run back into the tank using gravity. The fuel tanks are double-walled for added security against leaks. It is understood that the mountainous regions where these units operate are very sensitive to pollution, and a fuel spill of any size would be detrimental to the local environment.

Air intake and exhaust is complex due to the high winds and snow accumulation experienced at mountaintop sites. For this reason, snorkel-type intakes and exhaust are installed on the radio building. This permits air to be taken in and exhausted via ports above the building roofline where wind keeps the snow clear. The engineering of these snorkel units required extensive design of both the building and the snorkel itself.

9.4 HVAC (Heating, Ventilation, Air-Conditioning)

Heating, Ventilation and Air Conditioning are three key elements to making a radio facility operate successfully. Radio equipment is very sensitive to overheating, causing the transmitters to overload and shutdown. This necessitates a trouble call to the site, and is expensive for the company operating the site. Multiplexing and network equipment also may fail at elevated temperatures. VRLA battery cells must be maintained within a strict temperature range or risk reduction of capacity. All of these described problems can be eliminated by using an HVAC unit. An HVAC unit is a self-contained device mounted on the external of the building. It contains heating elements, an air-conditioning system, and a forced-air blower to increase ventilation. Ventilation improves the cooling process by moving air around the building and preventing hot spots.

Previously, heating and air-conditioning within AltaLink radio buildings was accomplished using a separate air conditioning unit and electric baseboard heating. This design was flawed because the air conditioning units installed were residential models not built for the duty-cycles and continuous operation experienced at a telecommunications facility. Heaters and air-conditioners were often installed with separate thermostats making setting problems inevitable and the units working against each other. The reliability of the air-conditioners was in question, and a better solution had to be found.

The HVAC unit contains all three environmental functions – heating, air-conditioning, and forced air movement. Unit ratings are based on the heating and cooling capacity. Cooling is measured in Btu's and heating in kW. Previous air conditioning units operated with cooling capacities of 18000 Btu/h. This was increased to 24000 Btu/h with the HVAC unit due to the increased heat output of the new telecom equipment. Heating is matched to the existing baseboard heat requirements and a capacity of 5kW is installed. A continuous forced-air blower is also in operation, keeping air movement at approximately 800cfm.

Overall, it has been observed that the HVAC units are more reliable due to having only one thermostat for the entire facility. Environmental temperatures are now more consistent with reduced maintenance. AltaLink has standardized on this product.

9.5 Site Monitoring and RTU

Building security is of concern for all facilities required to operate the power system. With recent terrorist events, this has become of even greater concern. Security at the radio site begins with the perimeter fence. It is known that no fence will prevent entry by a determined individual, but everything that can be done, will be. The standard radio facility fence includes a 7' fence topped with barbed wire. All entrance gates are secured with hardened locks requiring specialized keys.

At the radio building, all entrance doors are alarmed with security contacts. These contacts are connected to the local radio site RTU and raise an alarm at the control center whenever the door is opened. All staff operating at the site must first call in to the control center to notify them of their presence. If notification is not received within fifteen minutes of a security alarm being raised, first operating staff in the area are contacted followed by the local authorities.

The radio supervisory RTU (Remote Terminal Unit) is a data concentrator device reporting digital and analog status points to a centralized control center using a dedicated digital communication circuit. Control functions may also be issued from the control center to the RTU using this channel. This is the same process used for substation command and control, also known as the SCADA network. The protocol used to communicate SCADA information is the DNP3 protocol. This protocol is a utility-standard SCADA protocol compatible with many different substation IEDs. All substation RTUs use this protocol, making it simpler to also interface radio site RTUs to the control center if the same protocol is used.

The RTU is an intelligent device capable of not only collecting status information, but also manipulating that data using simple logic functions. This permits time-delays to be added to status points to eliminate nuisance alarms, as well as create separate, virtual alarms from combinations of alarm inputs. This ability is useful for shaping the data reporting seen by control center operators.

The RTU selected for AltaLink's radio site supervisory is the GE D25 RTU. It is capable of 64 digital status inputs. These take the form of either a digital 1 or 0 and are generated using equipment status contacts. Points may take the form of either major or minor alarms. The RTU supplies a wetting-voltage to the status contact and monitors it on the RTU point input. When a status contact closes, the wetting voltage is seen on the input and the status changes from a digital low state to a digital high state.

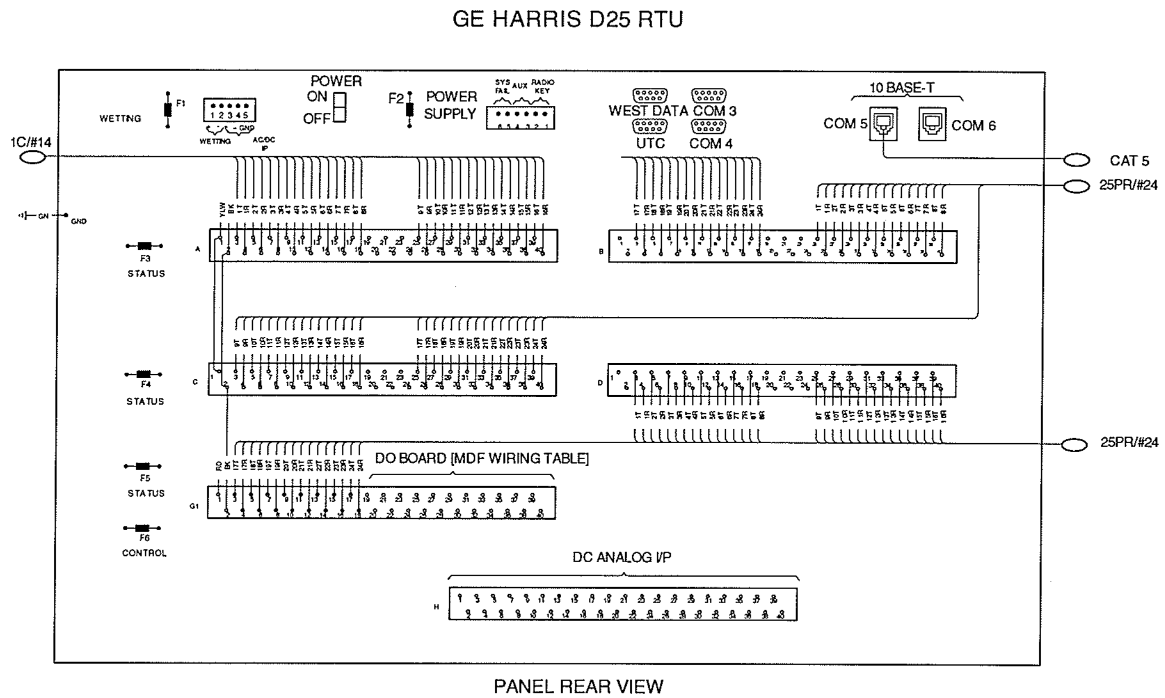


Figure 36-D25 RTU Connection Diagram

There are 16 analog inputs available on the D25 RTU. The analog inputs are used to monitor status of equipment room temperature, generator room temperature, fuel level, outside air temperature and wind speed.

Sixteen control point relays are available for control of radio station devices. The only controls used at AltaLink radio sites are for manual control of standby generators. Manual control allows control center operators to manually start and stop standby generators as part of a monthly maintenance program.

Because the D25 RTU installed at AltaLink radio stations communicates using the DNP3.0 protocol, radio station monitoring may be incorporated into the substation SCADA network. This offers a significant saving over having two separate control facilities. Telecom alarms are listed separately, but still monitored by the same operating staff as those monitoring substations.

The standard alarm point listing developed for AltaLink radio facility RTUs is included in the Appendix.

10

10. Conclusions

The development of communication network for a transmission utility requires examination of the many different uses of that network. The provincial power system in Alberta has generation in the form of coal, natural gas, hydro and wind. Power transmission and substations range in size and capacity from 69kV distribution lines to major 240kV and 500kV links. All of these are situated in different areas of the province and must be monitored and controlled via a control center located in Calgary. The safe, efficient operation of the overall power system is dependant upon having a reliable communication network infrastructure.

Simply having an operational network is not sufficient. The primary goal of this thesis is to examine the network from a high level and determine the purpose of the network. That is to provide reliable communication in sufficient capacity and functionality to facilitate the needs to the power system operator. Following that examination, a decision to migrate an aging, analog network and a description of the planning problems associated with that migration described. The primary focus in migrating an analog network is the lack of available capacity, and the inability to maintain the system due to lack of spare components.

Once the decision to migrate the network from analog to digital is made, the capacity after a migration is determined. The new network must provide sufficient capacity to meet the present needs of the network as well as provide room for future growth. A philosophy for building additional spare capacity is presented. Beginning to design the digital network requires classification of circuit types carried on the network. Teleprotection, Scada, Voice, Data, and Mobile Radio (voice) must all be planned for interfacing to the network. Transport microwave radio links are categorized based on capacity and network topology, giving rise to Backbone, Spur, and Last-mile classifications. The required reliability for each link is examined with Backbone links requiring the most stringent planning and design, followed by Spur and Last-mile links. The goal is to design radio links with near-100% reliability that can be constructed within the constraints of budget and timeline. Installed capacity allowing space for future growth is also a priority due to the increasing amount of data system operators require. Operational planning for the network including network security and reliability, network synchronization using GPS-based primary reference source clocks, and system event response plans are all presented.

Analyzing the core components of the digital network begins with detailed engineering of the microwave radio path. The core network will operate using a SONET OC3 capacity with 16 and 28-T1 spurs and single-channel UHF/VHF and 1-T1 spread-spectrum last-mile links. Each of these link classifications has different components, including radio, waveguide, and antenna. Reliability objectives are set for each type of link. Protection methods for radio equipment and their application are presented. Although now typically done using software the process for path engineering is discussed, specifically detailing the free space loss calculation and probability calculations for rain and multipath fading events. The outcome of the path analysis is an estimation of path reliability. Strict analysis and adherence to path availability objectives ensures that communication links will be available when needed.

The most critical use of the communication network is to carry teleprotection signals. These signals protect substation and line assets in the event of a line fault. For this reason, the latency involved with transporting these signals must be estimated as closely as possible for inclusion in protection and control design. The application of Asynchronous Transfer Mode multiplexers is shown. This includes detailed examination of the rerouting intelligence contained within the ATM fabric, and latency calculations for primary and secondary routes. ATM also provides intelligent circuit switching in the event of hardware failures, decreasing the outage time and increasing the reliability of the network when compared to older, analog frequency-division multiplexers.

The selection of a Time Division Multiplexer is made between flexible multiplexers and networking multiplexers. Each unit has a place in the network with specific functions utilized on each model. These include teleprotection, relay-to-relay communications, data, voice, Ethernet network extensions. The ability to cross-connect timeslots within T1 links is considered the most significant advantage of networking multiplexers, such as the Alcatel 3600 unit, over flexible multiplexers. Flexible multiplexers such as the Imux 2000 are applied where substation-hardened capability and direct relay-interfaces for transfer tripping are required.

Due to ATM's emerging use in the utility communication environment, an explanation of how ATM operates is required to assess how it will fit within the utility network space. Basic ATM theory is shown, including how the adaptation features found within the ATM layer are utilized to transport traffic of varying type and priority. Each type of interface card is described, including Sonet OC3, T1, Frame Relay, and Ethernet. An overview of circuit management and increased visibility provided by the ATM network management system is presented.

Ethernet networks are rapidly becoming the common link between remote facilities and utility control centers. The purpose of these networks is to permit direct communication between power system operators and engineers and the intelligent electronic devices deployed within the substation. To facilitate the creation of province-wide Ethernet networks, the ability to transport Ethernet across the ATM network is necessary. Creating a province-wide Ethernet network requires planning of IP address space and decisions on network topology design. For the utility environment, a hub-and-spoke design involving centralized routing and transport via Frame Relay is preferred due to its ease of management and point-to-point link monitoring. Selection of equipment for operation within the substation and radio site is presented including applicable industry standards for substation-hardened capabilities. OSI-model layer-3 switches are used to facilitate routing between networks and give flexibility to design. As Ethernet networks become integrated into substations and radio sites, cyber-security issues become a concern. Mitigating this risk through appropriate physical, password, and firewall security measures is a requirement and must be included in preliminary planning and design.

The final section of the thesis describes the required infrastructure used in a modern, utility radio site. Beginning with the communication shelter, the design of the building using durable building materials is the basis for a facility with an expected lifetime in excess of 25 years. Within the building, standardizing on a 48VDC power supply permits simplified design and consistency throughout the station. Battery banks using new gel-cell technology reduce required maintenance and provide for easier installation. Intelligent standby generators and transfer switches add increased reliability to remote sites where consistent utility AC power supply may be a problem. HVAC integrated air-conditioning and heating units provide more energy-efficient environmental controls while simplifying design and operational maintenance. Finally, remote terminal units capable of communicating using substation-standard protocols such as DNP3 make monitoring of remote radio sites similar to that of substations. RTU design is consistent with that of substation RTUs allowing for more standardized design and operation.

In summary, the topic of this thesis is to describe the problem associated with rebuilding a utility communication network. The basis for replacing the network is presented, followed by the constituent components. The advantages to deploying an ATM network switching layer are discussed, including the impact of circuit-switching to critical teleprotection circuits. Design and deployment of utility Ethernet networks is described, followed by new radio site infrastructure designed and installed as part of the complete upgrade project. The new network is superior to the old, analog network in both reliability and capacity, and it is expected that this network design will provide many years of reliable service.

Clinton Struth, P.Eng.

Telecommunications Engineer

AltaLink Management Ltd. 20/11/2003.

B

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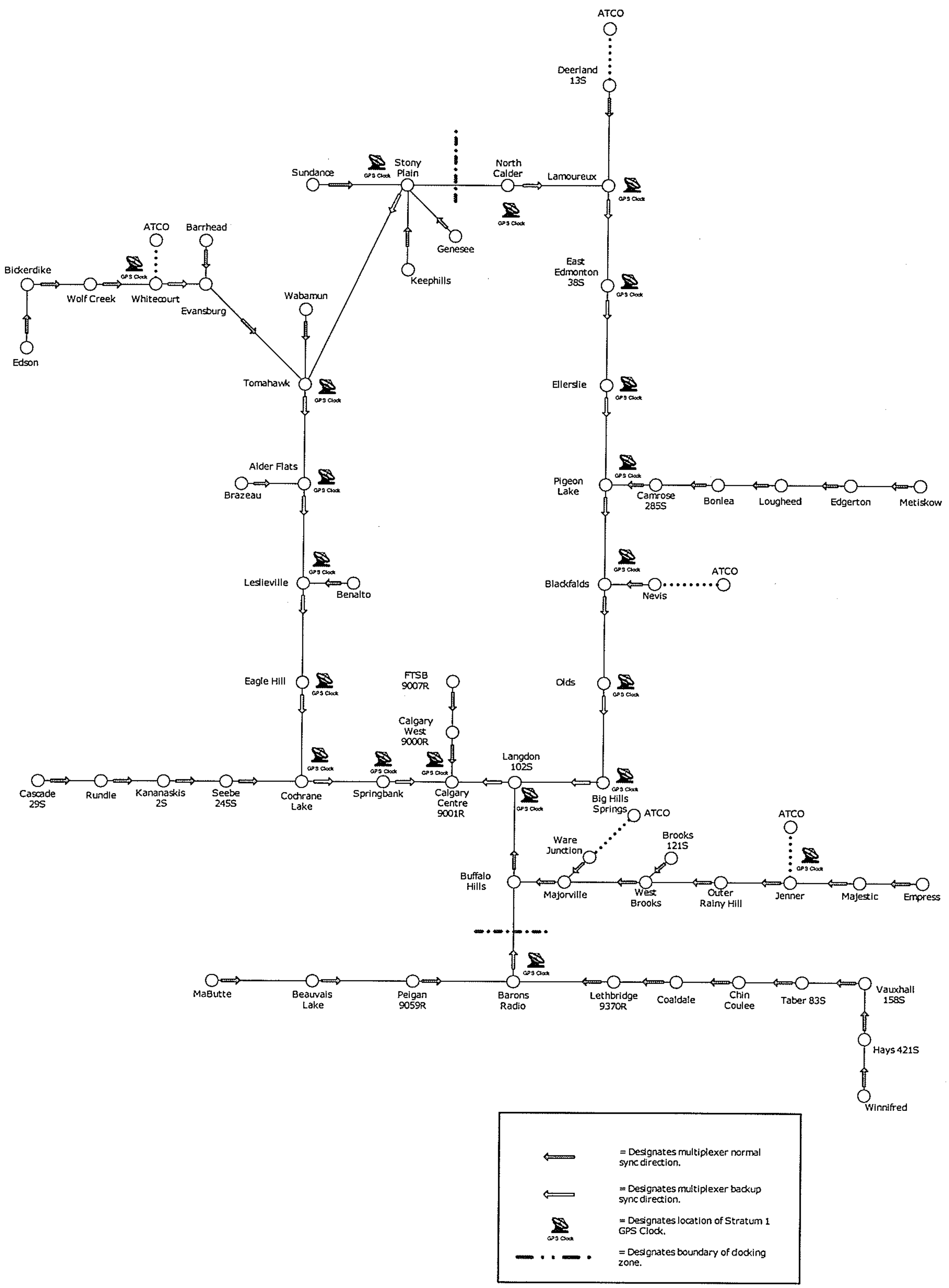
A

APPENDIX


ATCO
Deerland 13S
Sundance
Stony Plain
GPS Clock
North Calder
Lamoureux
Genesee
Keephills
ATCO
Barrhead
Bickerdike
Wolf Creek
Whitecourt
Evansburg
Edson
Wabamun
East Edmonton 38S
Tomahawk
Ellerslie
Alder Flats
Brazeau
Pigeon Lake
Camrose 285S
Bonlea
Lougheed
Edgerton
Metiskow
Leslieville
Benalto
Blackfalds
Nevis
ATCO
Eagle Hill
FTSB 9007R
Calgary West 9000R
Olds
Langdon 102S
Cascade 29S
Rundle
Kananaskis 2S
Seebe 245S
Cochrane Lake
Springbank
Calgary Centre 9001R
Big Hills Springs
ATCO
Ware Junction
Brooks 121S
ATCO
Buffalo Hills
Majorville
West Brooks
Outer Rainy Hill
Jenner
Majestic
Empress
MaButte
Beauvais Lake
Peigan 9059R
Barons Radio
Lethbridge 9370R
Coaldale
Chin Coulee
Taber 83S
Vauxhall 158S
Hays 421S
Winnifred
= Designates multiplexer normal sync direction.
= Designates multiplexer backup sync direction.
= Designates location of Stratum 1 GPS Clock.
= Designates boundary of docking zone.

COMMUNICATION AIDED LINE PROTECTION

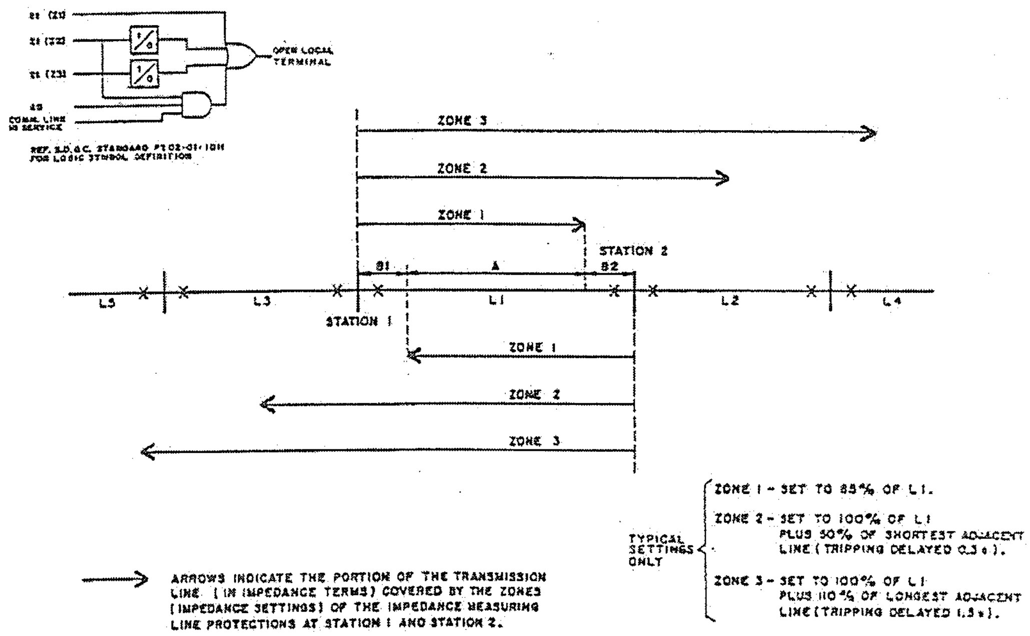


FIGURE 1
PERMISSIVE LINE PROTECTION

FORM NO. 305-9412 (82/02)

COMMUNICATION AIDED LINE PROTECTION

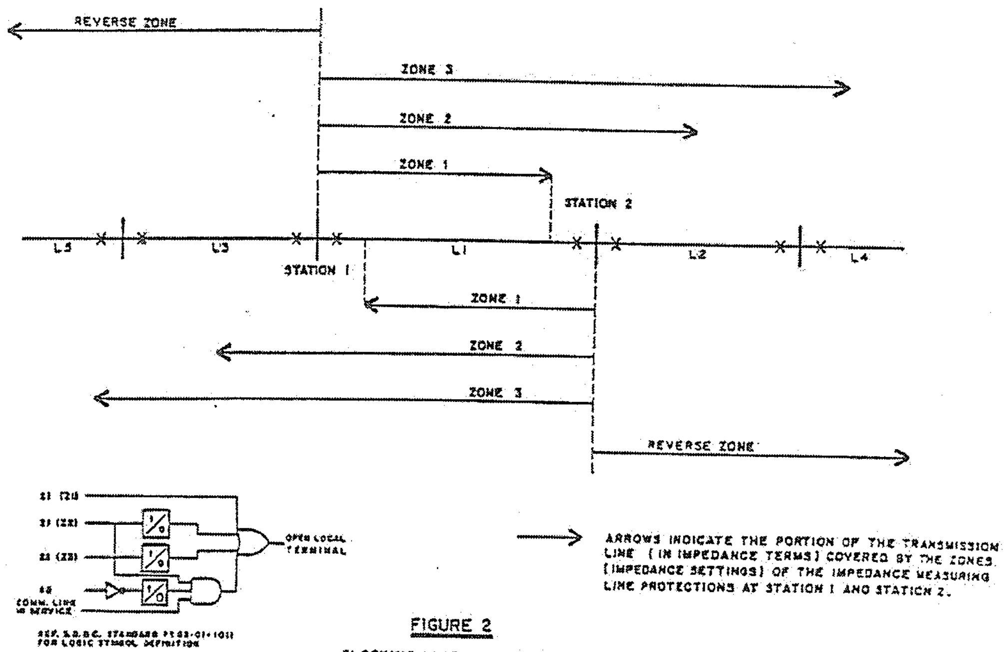
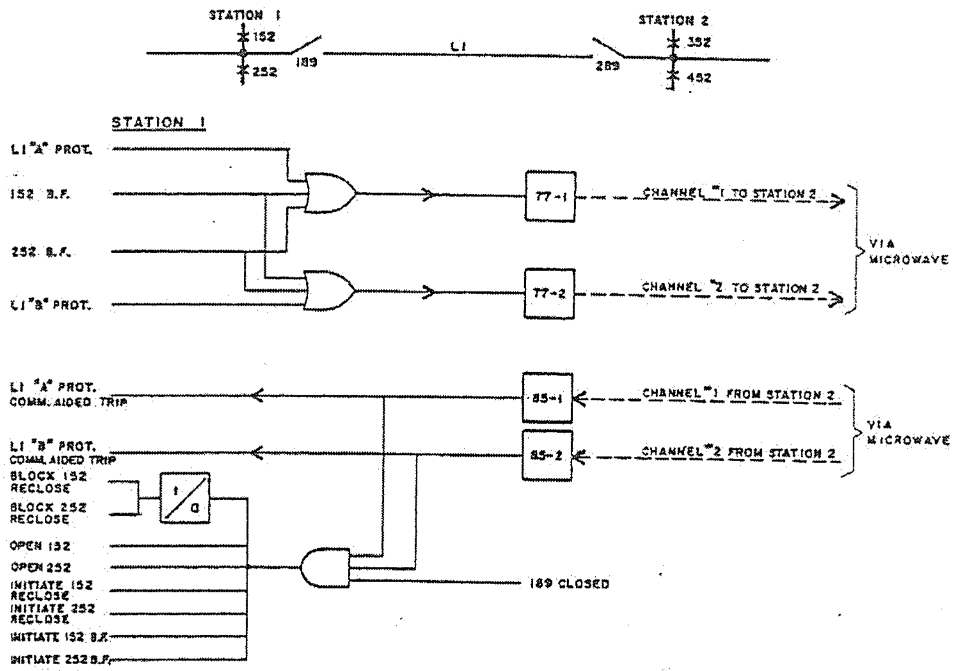


FIGURE 2

BLOCKING LINE PROTECTION

FORM NO. 308-9412 (82/02)

COMMUNICATION AIDED LINE PROTECTION



REF. S.D. & C. STANDARD PI 02-01-1011
FOR LOGIC SYMBOL DEFINITION.

FIGURE 3

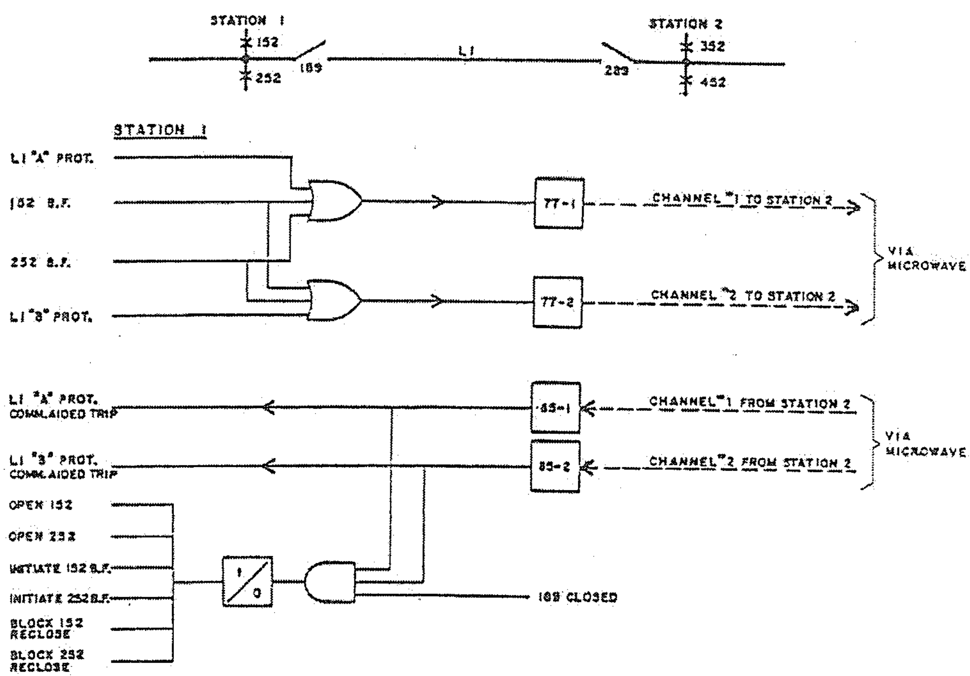
No. OF COMMUNICATION CHANNELS – 2

SYSTEM VOLTAGE – 240kV

TYPE OF LINE PROTECTION – PERMISSIVE UNDERREACH,
3 POLE TRIPPING

FORM NO. 308-9412 (82/02)

COMMUNICATION AIDED LINE PROTECTION



REF. S.D. & C. STANDARD PI 02-01-1011 FOR LOGIC SYMBOL DEFINITION.

FIGURE 4

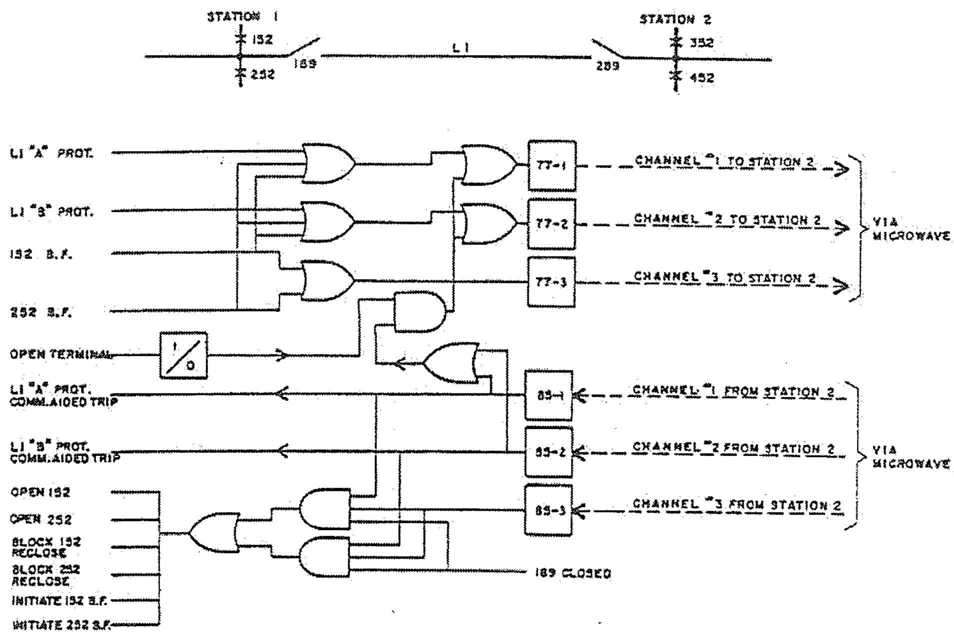
No. OF COMMUNICATION CHANNELS – 2

SYSTEM VOLTAGE – 240 kV

TYPE OF LINE PROTECTION – PERMISSIVE UNDERREACH, SINGLE POLE TRIPPING

FORM NO. 308-9412 (82/02)

COMMUNICATION AIDED LINE PROTECTION



REF. S.O. B.C. STANDARD PI 02-01-1011
FOR LOGIC SYMBOL DEFINITION.

FIGURE 5

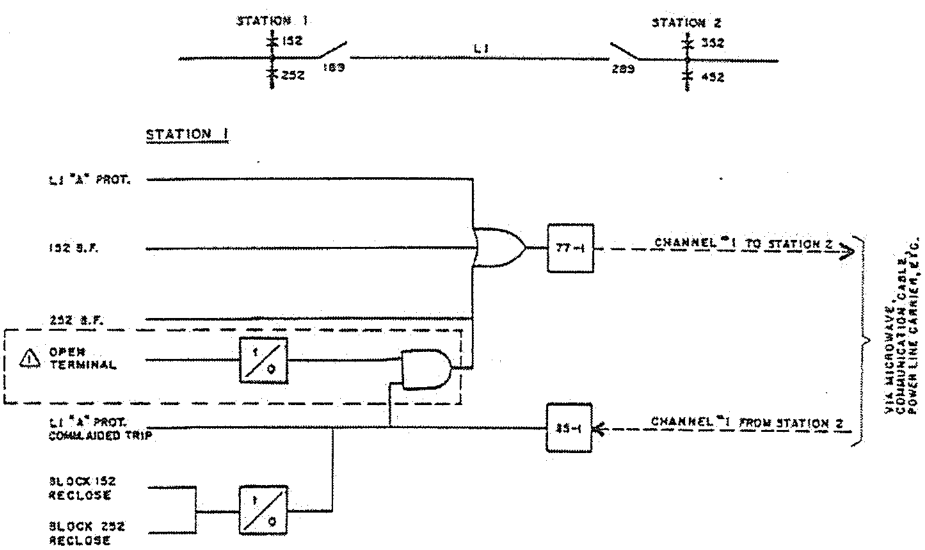
No. OF COMMUNICATION CHANNELS – 3

SYSTEM VOLTAGE – 240 kV

TYPE OF LINE PROTECTION – PERMISSIVE OVERREACH,
SINGLE POLE TRIPPING

FORM NO. 308-9412 (82/02)

COMMUNICATION AIDED LINE PROTECTION



NOTE :

1. THIS LOGIC IS REQUIRED ONLY FOR PERMISSIVE OVERREACHING SCHEMES.

REF. S.D. & C. STANDARD PI 02-01-1011 FOR LOGIC SYMBOL DEFINITION.

FIGURE 6

No. OF COMMUNICATION CHANNELS – 1

SYSTEM VOLTAGE – 138 kV

TYPE OF LINE PROTECTION – PERMISSIVE UNDERREACH OR OVERREACH, 3 POLE TRIPPING

FORM NO. 306-9412 (82/02)

COMMUNICATION AIDED LINE PROTECTION

FIG. 7 TELEPROTECTION RECEIVE MODULE PII 06.01.06

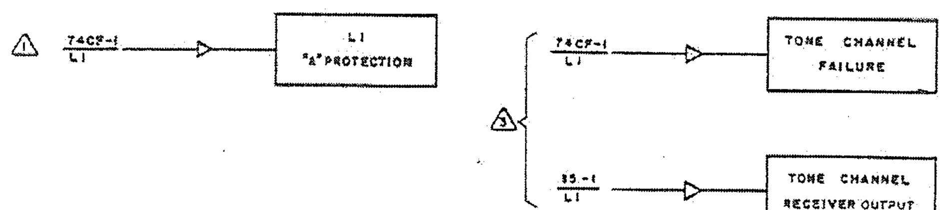
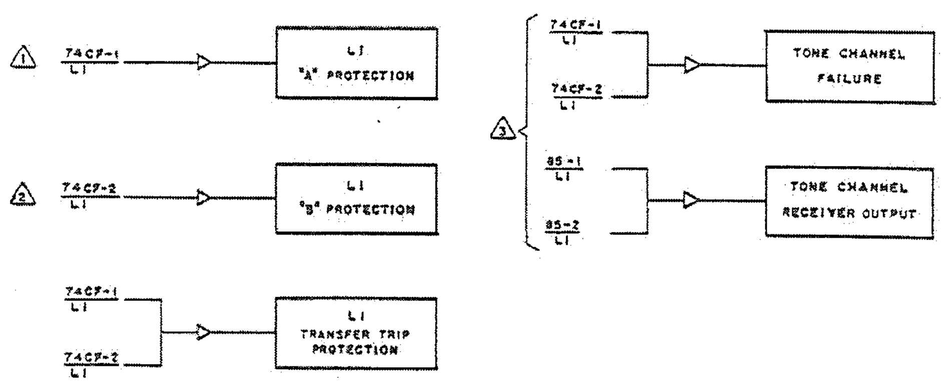


FIG 8 TELEPROTECTION RECEIVE MODULE PII 06.01.07



NOTES:

1. TO BE GROUPED WITH OTHER L1 "A" PROTECTION ALARM INITIATE CONTACTS.
2. TO BE GROUPED WITH OTHER L1 "B" PROTECTION ALARM INITIATE CONTACTS.
3. TO BE GROUPED WITH ALL OTHER TONE CHANNEL FAILURE AND RECEIVER OUTPUT ALARM INITIATE CONTACTS IN A STATION.

FORM NO. 308-S412 (82/02)

COMMUNICATION AIDED LINE PROTECTION

FIG 9 TELEPROTECTION RECEIVE MODULE PII 06.01.08

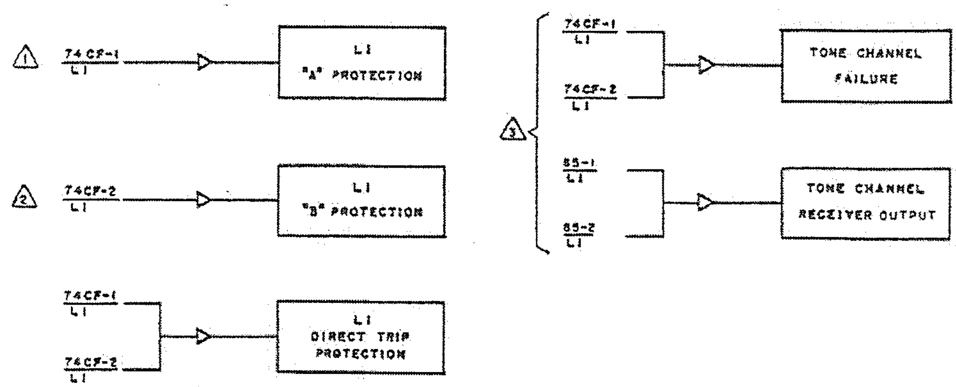
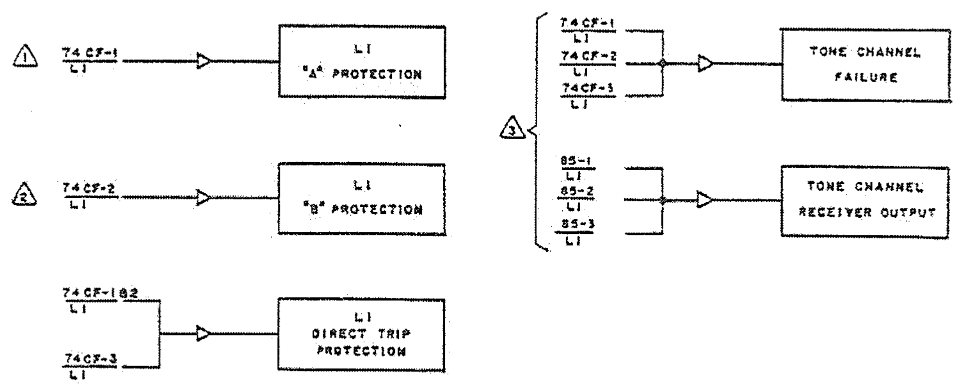


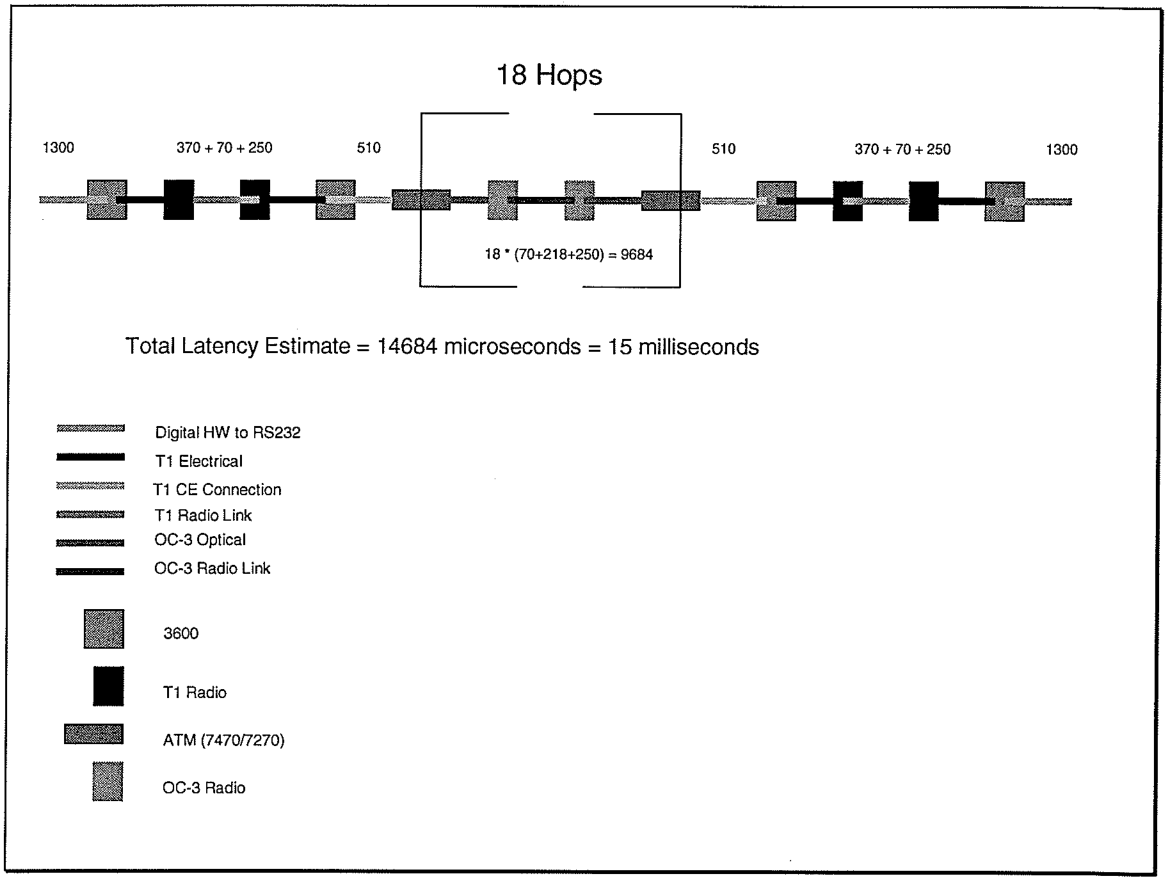
FIG 10 TELEPROTECTION RECEIVE MODULE PII 06.01.09

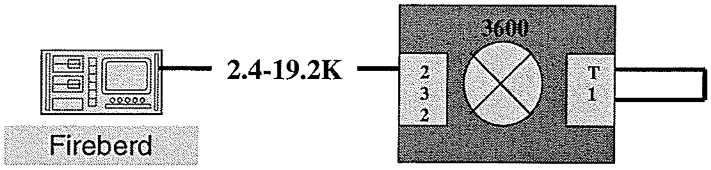


NOTES:

1. TO BE GROUPED WITH OTHER L1 "A" PROTECTION ALARM INITIATE CONTACTS.
2. TO BE GROUPED WITH OTHER L1 "B" PROTECTION ALARM INITIATE CONTACTS.
3. TO BE GROUPED WITH ALL OTHER TONE CHANNEL FAILURE AND RECEIVER OUTPUT ALARM INITIATE CONTACTS IN A STATION.

slr:D805/42/8

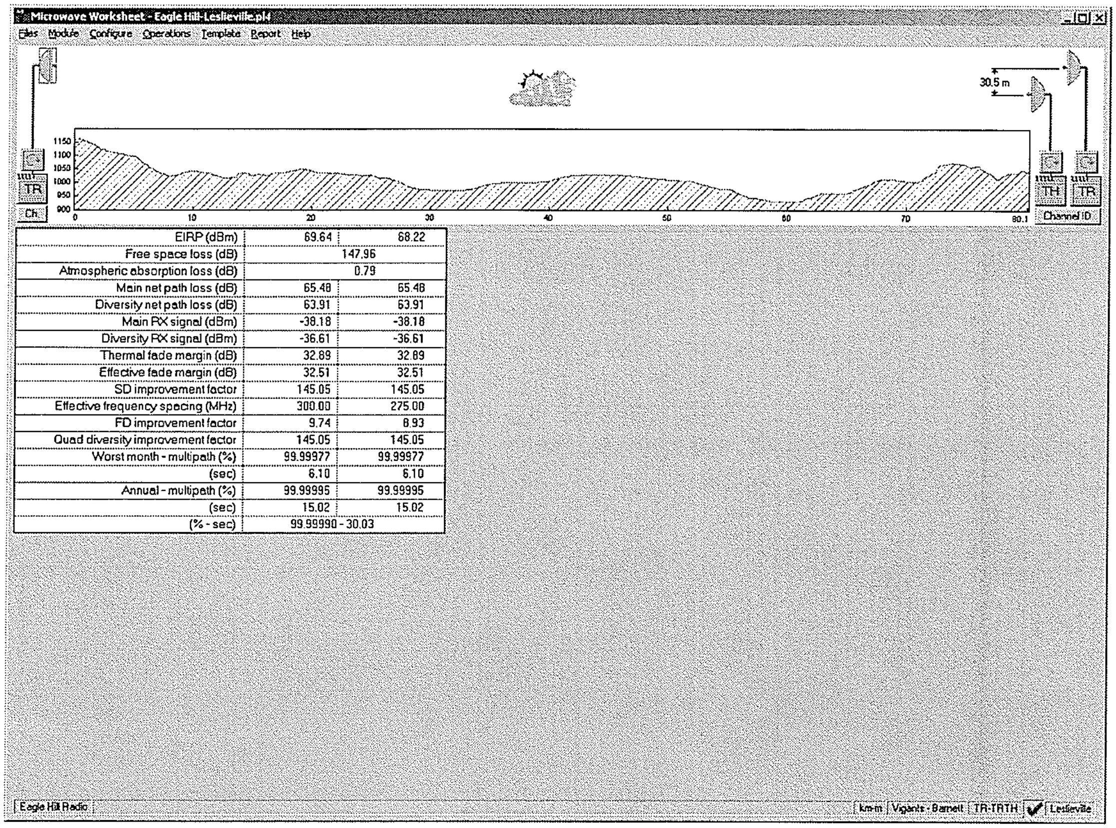

18 Hops
1300
370 + 70 + 250
510
510
370 + 70 + 250
1300
18 * (70+218+250) = 9684
Total Latency Estimate = 14684 microseconds = 15 milliseconds
Digital HW to RS232
T1 Electrical
T1 CE Connection
T1 Radio Link
OC-3 Optical
OC-3 Radio Link
3600
T1 Radio
ATM (7470/7270)
OC-3 Radio



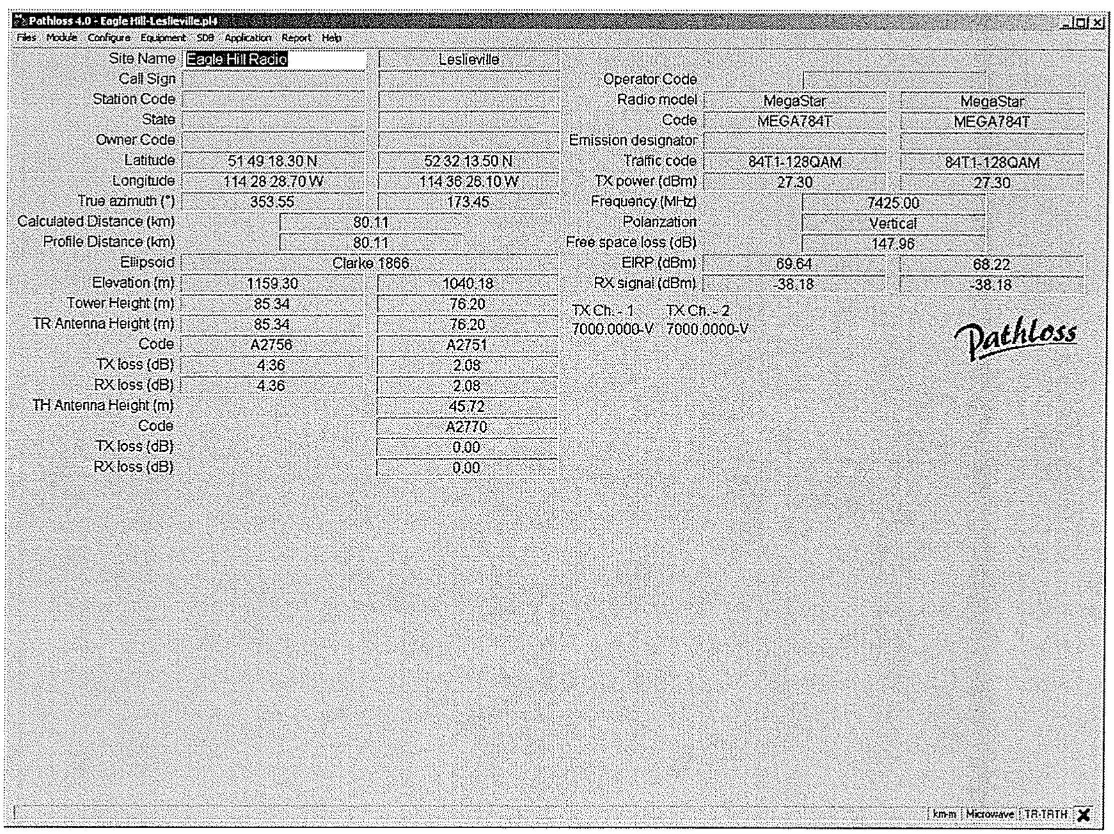
Pattern	Speed	Delay * One shelf	Delay * Two shelves
2 to 15	2.4K	8.1 msec	8.1 msec
2 to 15	4.8K	5.1 msec	5.1 msec
2 to 15	9.6K	5.9 msec	5.9 msec
2 to 15	19.2K	2.8 msec	2.8 msec
2 to 15	64K	1.2 msec	1.2 msec

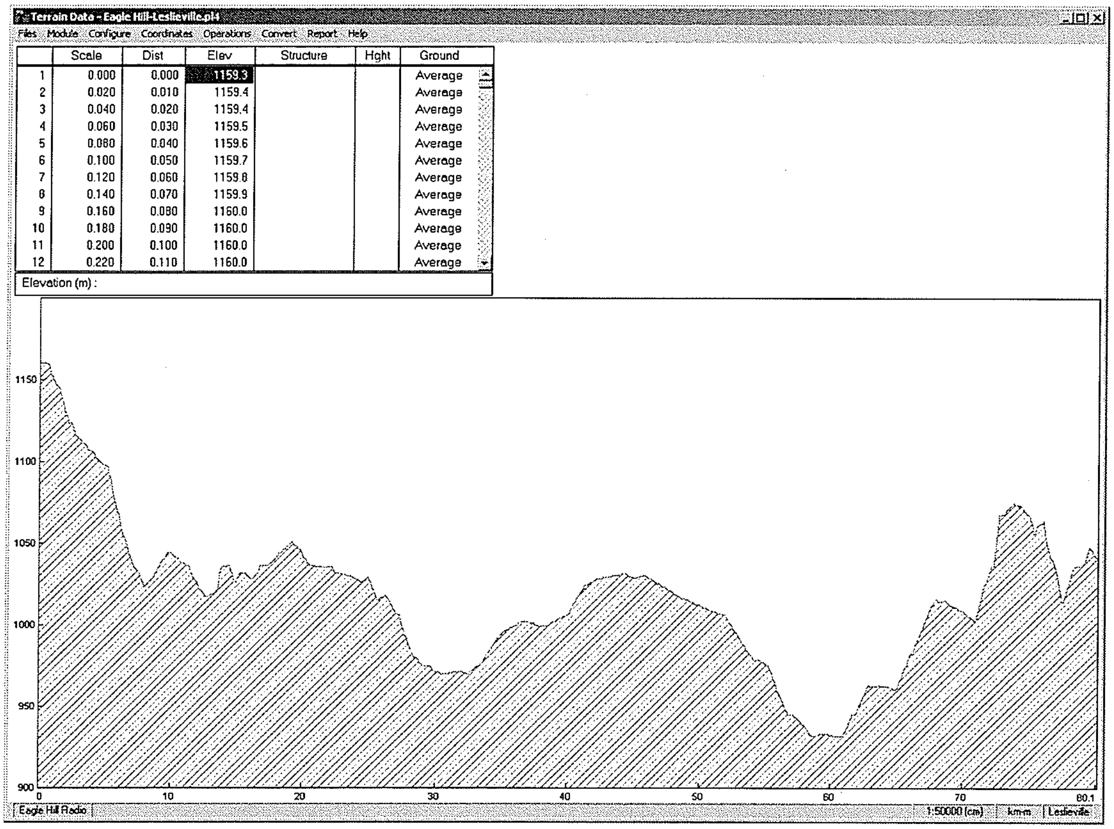
***Delay are round trip delays**
Two shelves refers to a dual shelf node

Delay Estimates Courtesy of Alcatel Canada

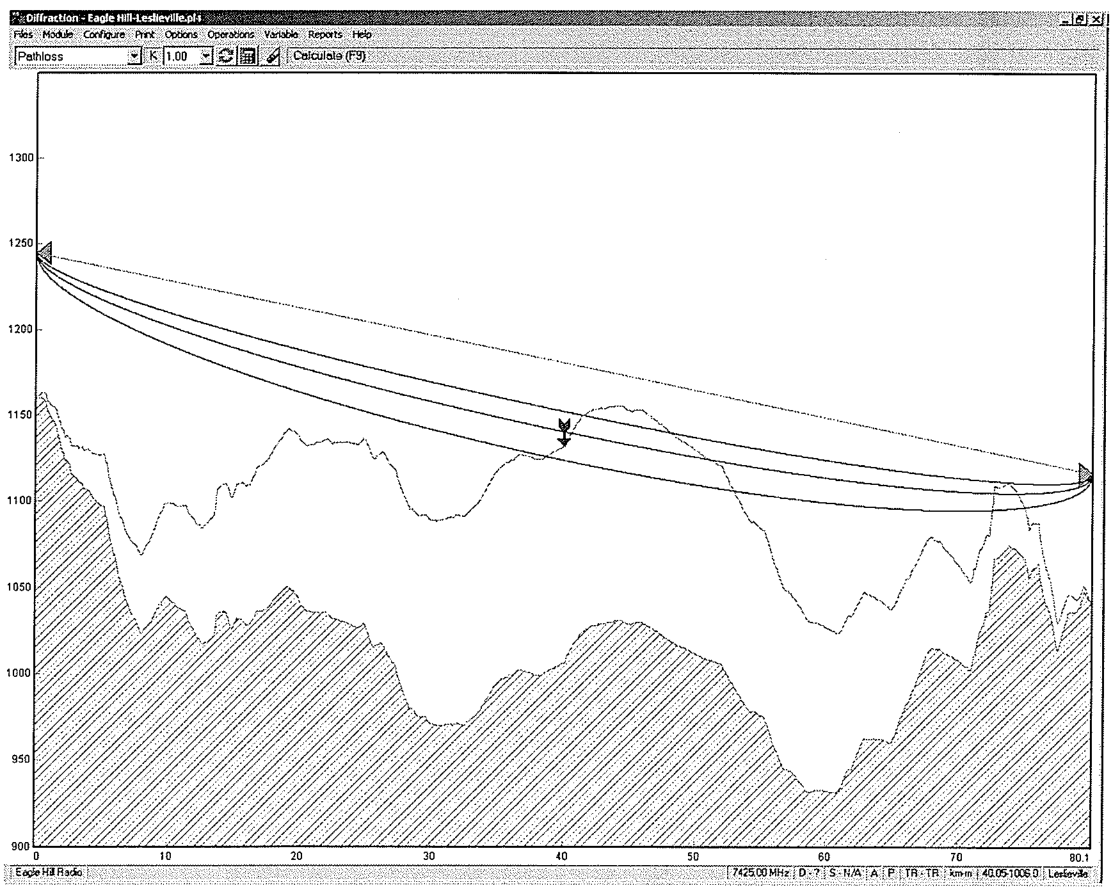


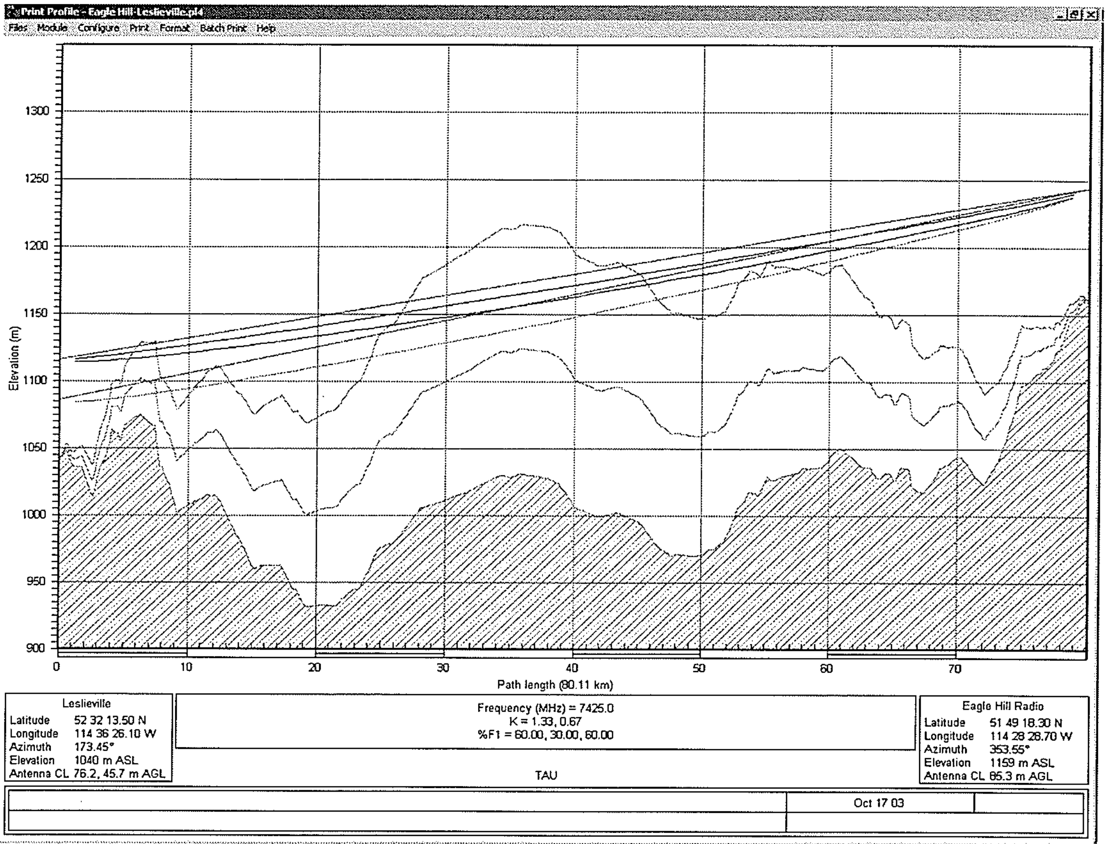
EIRP (dBm)	69.64	68.22
Free space loss (dB)	147.96	
Atmospheric absorption loss (dB)	0.79	
Main net path loss (dB)	65.48	65.48
Diversity net path loss (dB)	63.91	63.91
Main RX signal (dBm)	-38.18	-38.18
Diversity RX signal (dBm)	-36.61	-36.61
Thermal fade margin (dB)	32.89	32.89
Effective fade margin (dB)	32.51	32.51
SD improvement factor	145.05	145.05
Effective frequency spacing (MHz)	300.00	275.00
FD improvement factor	9.74	8.93
Quad diversity improvement factor	145.05	145.05
Worst month - multipath (%)	99.99977	99.99977
(sec)	6.10	6.10
Annual - multipath (%)	99.99995	99.99995
(sec)	15.02	15.02
(% - sec)	99.99990 - 30.03	

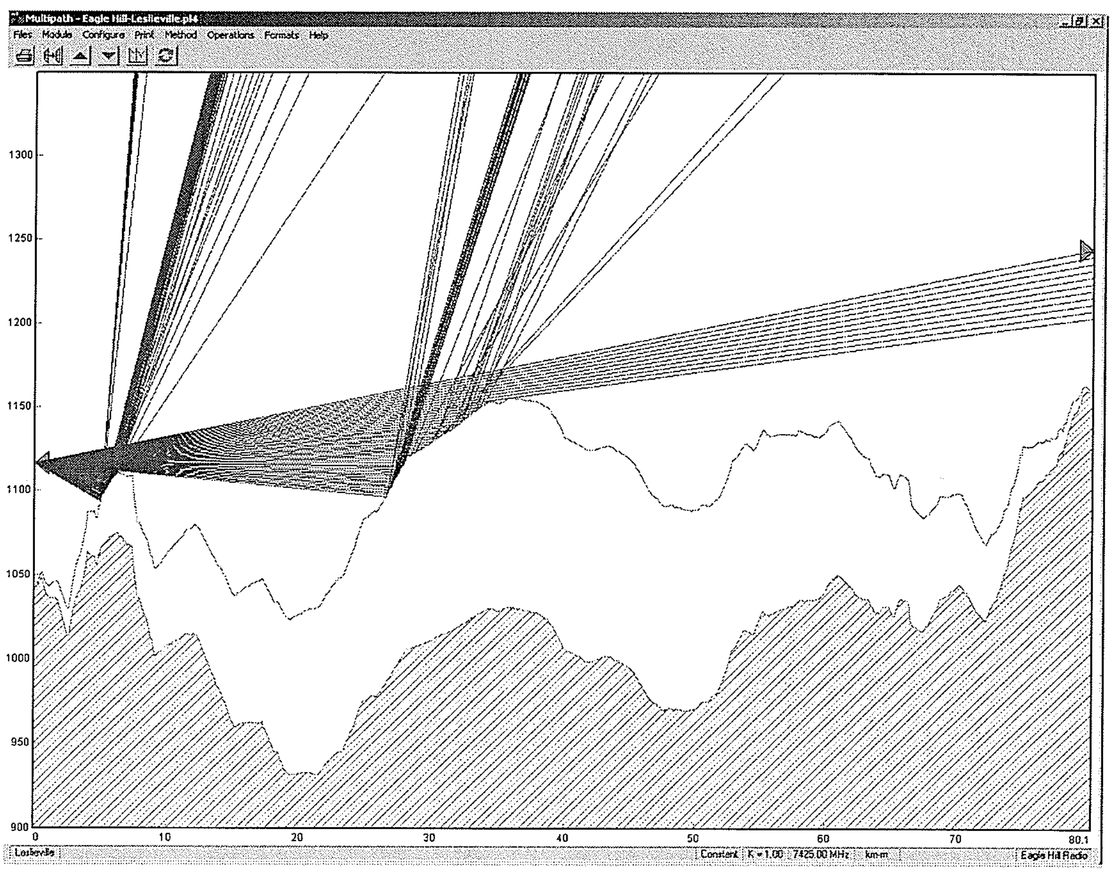


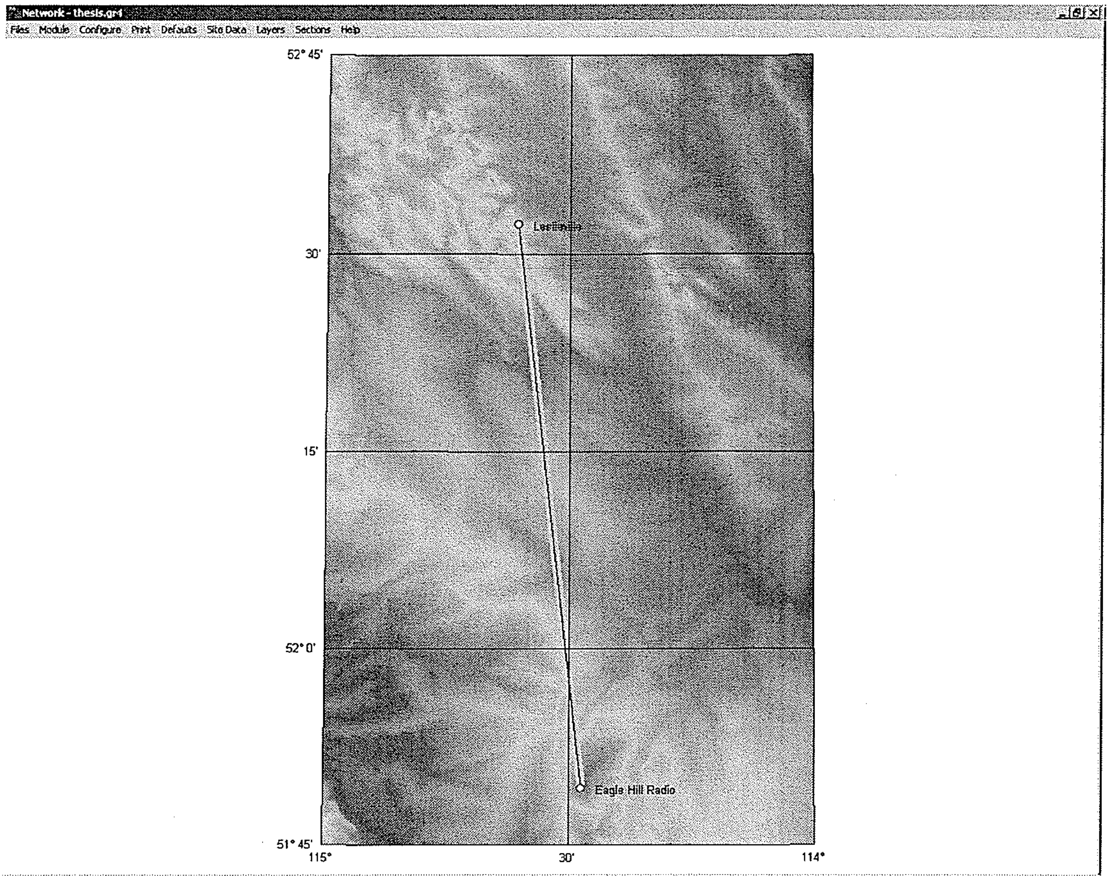


	Scale	Dist	Elev	Structure	Hght	Ground
1	0.000	0.000	1159.3			Average
2	0.020	0.010	1159.4			Average
3	0.040	0.020	1159.4			Average
4	0.060	0.030	1159.5			Average
5	0.080	0.040	1159.6			Average
6	0.100	0.050	1159.7			Average
7	0.120	0.060	1159.8			Average
8	0.140	0.070	1159.9			Average
9	0.160	0.080	1160.0			Average
10	0.180	0.090	1160.0			Average
11	0.200	0.100	1160.0			Average
12	0.220	0.110	1160.0			Average




Print Profile - Eagle Hill-Leslieville.pl4
Files Module Configure Print Format Batch Print Help
Elevation (m)
1300
1250
1200
1150
1100
1050
1000
950
900
0
10
20
30
40
50
60
70
Path length (80.11 km)
Leslieville
Latitude 52 32 13.50 N
Longitude 114 36 26.10 W
Azimuth 173.45°
Elevation 1040 m ASL
Antenna CL 76.2, 45.7 m AGL
Frequency (MHz) = 7425.0
K = 1.33, 0.67
%F1 = 60.00, 30.00, 60.00
TAU
Eagle Hill Radio
Latitude 51 49 18.30 N
Longitude 114 28 28.70 W
Azimuth 353.55°
Elevation 1159 m ASL
Antenna CL 65.3 m AGL
Oct 17 03


Multipath - Eagle Hill-Leslieville.pl4
Files Module Configure Print Method Operations Formats Help
1300
1250
1200
1150
1100
1050
1000
950
900
0
10
20
30
40
50
60
70
80.1
Leslieville
Constant K = 1.00 7425.00 MHz km-m
Eagle Hill Radio



Network - thesis.grd
Files Module Configure Print Defaults Site Data Layers Sections Help
52° 45'
30'
15'
52° 0'
51° 45'
115°
30'
114°
Eagle Hill Radio

HMI STATUS ID	TSCC Substation ID	TSCC Device Type	TSCC Device Name	TSCC Point ID	Source	Terminal if applicable	DWG	Dev #	Application	Local Point	System Point	DPA 1 Local HMI Point	DPA 1 Local HMI Class	DPA 2 SCC DNP Point	DPA 2 SCC DNP Class	SEVERITY	Comments	Rev
Supervisory Switch	9nnnR	ALRM	SUPV_SW	O/F						1	1	1	1	1	1	MAJ		
Building Temperature High	9nnnR	ALRM	BUILDING_TEMP_HI	N/A						2	2	2	2	2	1	MAJ		
Building Temperature Low	9nnnR	ALRM	BUILDING_TEMP_LO	N/A						3	3	3	3	3	2	MAJ		
Building Door Open	9nnnR	ALRM	INTRUSION	N/A						4	4	4	4	4	2	MAJ		
Tower Light Fail	9nnnR	ALRM	TOWER_LIGHT	N/A						5	5	5	5	5	2	MAJ		
Coax Pressure Low	9nnnR	ALRM	COAX_PRESSURE	N/A						6	6	6	6	6	2	MAJ		
Power Line Fail	9nnnR	ALRM	AC_FAIL	N/A						7	7	7	7	7	2	MAJ		
HVAC Fail Alarm	9nnnR	ALRM	HVAC_FAIL	N/A						8	8	8	8	8	2	MIN		
Spare			spare							9	9	9	9	9	2			
Main DC Breaker Fail	9nnnR	ALRM	XXXV_MAIN_DC_BKR	N/A						10	10	10	10	10	2	MAJ		
Fuse / Breaker Fail	9nnnR	ALRM	XXXV_FUSE/BKR_FAIL	N/A						11	11	11	11	11	2	MIN		
Battery Charger Major Alarm	9nnnR	ALRM	XXXV_BATTERY_MAJOR	N/A						12	12	12	12	12	2	MAJ		
Battery Charger Minor Alarm	9nnnR	ALRM	XXXV_BATTERY_MINOR	N/A						13	13	13	13	13	2	MIN		
Battery Charger AC Supply Fail			spare							14	14	14	14	14	2			
24 VDC DC-DC Converter Fail	9nnnR	ALRM	24V_DC_CONVERTER	N/A						15	15	15	15	15	2	MIN		
12 VDC DC-DC Converter Fail	9nnnR	ALRM	12V_DC_CONVERTER	N/A						16	16	16	16	16	2	MIN		
Spare			spare							17	17	17	17	17	2			
Spare			spare							18	18	18	18	18	2			
Standby Plant Engine Alarm	9nnnR	ALRM	ENGINE_TRBL	N/A						19	19	19	19	19	2	MAJ		
Standby Plant Engine Running	9nnnR	RAD	ENGINE	STSP						20	20	20	20	20	2	MIN		
Standby Plant Engine Lock-out	9nnnR	RAD	ENGINE_LOCKOUT	O/F						21	21	21	21	21	2	MIN		
spare			spare							22	22	22	22	22	2			
spare			spare							23	23	23	23	23	2			
spare			spare							24	24	24	24	24	2			
spare			spare							25	25	25	25	25	2			
Spare			spare							26	26	26	26	26	2			
Spare			spare							27	27	27	27	27	2			
Radio A Major Alarm	9nnnR	ALRM	9nn1R_RADIO_MAJOR	N/A						28	28	28	28	28	2	MAJ		
Radio A Minor Alarm	9nnnR	ALRM	9nn1R_RADIO_MINOR	N/A						29	29	29	29	29	2	MIN		
Radio A Path Alarm (misc.)	9nnnR	ALRM	9nn1R_RADIO_TRBL	N/A						30	30	30	30	30	2	MIN		
Radio A Transmitter Fail	9nnnR	ALRM	9nn1R_TX_FAIL	N/A						31	31	31	31	31	2	MIN		
Radio B Major Alarm	9nnnR	ALRM	9nn2R_RADIO_MAJOR	N/A						32	32	32	32	32	2	MAJ		
Radio B Minor Alarm	9nnnR	ALRM	9nn2R_RADIO_MINOR	N/A						33	33	33	33	33	2	MIN		
Radio B Transmitter Fail	9nnnR	ALRM	9nn2R_TX_FAIL	N/A						34	34	34	34	34	2	MIN		
Radio B Path Alarm (misc.)	9nnnR	ALRM	9nn2R_RADIO_TRBL	N/A						35	35	35	35	35	2	MIN		
Radio C Major Alarm	9nnnR	ALRM	9nn3R_RADIO_MAJOR	N/A						36	36	36	36	36	2	MAJ		
Radio C Minor Alarm	9nnnR	ALRM	9nn3R_RADIO_MINOR	N/A						37	37	37	37	37	2	MIN		
Radio C Transmitter Fail	9nnnR	ALRM	9nn3R_TX_FAIL	N/A						38	38	38	38	38	2	MIN		
Radio C Path Alarm (misc.)	9nnnR	ALRM	9nn3R_RADIO_TRBL	N/A						39	39	39	39	39	2	MIN		
Radio D Major Alarm	9nnnR	ALRM	9nn4R_RADIO_MAJOR	N/A						40	40	40	40	40	2	MAJ		
Radio D Minor Alarm	9nnnR	ALRM	9nn4R_RADIO_MINOR	N/A						41	41	41	41	41	2	MIN		
Radio D Transmitter Fail	9nnnR	ALRM	9nn4R_TX_FAIL	N/A						42	42	42	42	42	2	MIN		
Radio D Path Alarm (misc.)	9nnnR	ALRM	9nn4R_RADIO_TRBL	N/A						43	43	43	43	43	2	MIN		
Radio E Major Alarm	9nnnR	ALRM	9nn5R_RADIO_MAJOR	N/A						44	44	44	44	44	2	MAJ		
Radio E Minor Alarm	9nnnR	ALRM	9nn5R_RADIO_MINOR	N/A						45	45	45	45	45	2	MIN		
Radio E Transmitter Fail	9nnnR	ALRM	9nn5R_TX_FAIL	N/A						46	46	46	46	46	2	MIN		
Radio E Path Alarm (misc.)	9nnnR	ALRM	9nn5R_RADIO_TRBL	N/A						47	47	47	47	47	2	MIN		
Multiplexer Major Alarm	9nnnR	ALRM	MUX_EQUIPMENT_MAJOR	N/A						48	48	48	48	48	2	MAJ		
Multiplexer Minor Alarm	9nnnR	ALRM	MUX_EQUIPMENT_MINOR	N/A						49	49	49	49	49	2	MIN		
Miscellaneous Alarms			spare							50	50	50	50	50	2			
Miscellaneous Alarms			spare							51	51	51	51	51	2			
Miscellaneous Alarms			spare							52	52	52	52	52	2			
Miscellaneous Alarms			spare							53	53	53	53	53	2			
Miscellaneous Alarms			spare							54	54	54	54	54	2			
Miscellaneous Alarms			spare							55	55	55	55	55	2			
Miscellaneous Alarms			spare							56	56	56	56	56	2			
Miscellaneous Alarms			spare							57	57	57	57	57	2			
Miscellaneous Alarms			spare							58	58	58	58	58	2			
Miscellaneous Alarms			spare							59	59	59	59	59	2			
Miscellaneous Alarms			spare							60	60	60	60	60	2			
Miscellaneous Alarms			spare							61	61	61	61	61	2			
Miscellaneous Alarms			spare							62	62	62	62	62	2			
Miscellaneous Alarms			spare							63	63	63	63	63	2			
Miscellaneous Alarms			spare							64	64	64	64	64	2			

HMI Device name	TSCC Substation ID	TSCC Device Type	TSCC Device Name	TSCC Point Id	Function	Source	Trip Terminal (If applicable)	Close Terminal (If applicable)	Com. Terminal (If applicable)	DWG	Dev #	Application	Trip Terminal (If applicable)	Close Terminal (If applicable)	Com. Terminal (If applicable)	Local Point	System Point	DPA 1 Local HMI DPA Point	DPA 2 SCC DNP Point	Comments	Rev
Standby Plant Engine Stop/start	9nnnR	RAD	ENGINE	STSP	START/STOP											1	1	1	1		
Standby Plant Engine Reset	9nnnR	RAD	ENGINE_RESET	O/F	T/C											2	2	2	2		
Standby Plant Engine Lock-on	9nnnR	RAD	ENGINE_LOCKON	O/F	T/C											3	3	3	3		
Spare			SPARE													4	4	4	4		
Spare			SPARE													5	5	5	5		
Spare			SPARE													6	6	6	6		
Spare			SPARE													7	7	7	7		
Spare			SPARE													8	8	8	8		
Spare			SPARE													9	9	9	9		
Spare			SPARE													10	10	10	10		
Spare			SPARE													11	11	11	11		
Spare			SPARE													12	12	12	12		
Spare			SPARE													13	13	13	13		
Spare			SPARE													14	14	14	14		
Spare			SPARE													15	15	15	15		
Spare			SPARE													16	16	16	16		

HMI Analog Point ID	TSCC Sub ID	TSCC Device Type	TSCC Device Name	TSSC Analog ID	Source	+ Terminal (If applicable)	- Terminal (If applicable)	Drawing	- RAW Counts Full Scale	+ RAW Counts Full Scale	- ENG Counts Full Scale	+ ENG Counts Full Scale	Application	Local Point	System Point	DPA 1 Local HMI Point	DPA 1 Local HMI Class	DPA 1 Local HMI Deadband (Counts)	DPA 2 SCC DNP Point	DPA 2 SCC DNP Class	DPA 2 SCC Deadband (Counts)	Comments	Rev
	9nnnR				D25				-32767	32767	-32767	32767	D25	1	1								
	9nnnR				D25				-32767	32767	-32767	32767	D25	2	2								
	9nnnR				D25				-32767	32767	-32767	32767	D25	3	3								
	9nnnR				D25				-32767	32767	-32767	32767	D25	4	4								
	9nnnR				D25				-32767	32767	-32767	32767	D25	5	5								
	9nnnR				D25				-32767	32767	-32767	32767	D25	6	6								
	9nnnR				D25				-32767	32767	-32767	32767	D25	7	7								
	9nnnR				D25				-32767	32767	-32767	32767	D25	8	8								
	9nnnR				D25				-32767	32767	-32767	32767	D25	9	9								
	9nnnR				D25				-32767	32767	-32767	32767	D25	10	10								
	9nnnR				D25				-32767	32767	-32767	32767	D25	11	11								
	9nnnR				D25				-32767	32767	-32767	32767	D25	12	12								
	9nnnR				D25				-32767	32767	-32767	32767	D25	13	13								
	9nnnR				D25				-32767	32767	-32767	32767	D25	14	14								
	9nnnR				D25				-32767	32767	-32767	32767	D25	15	15								
	9nnnR				D25				-32767	32767	-32767	32767	D25	16	16								