

CONNECTING LEARNERS: THE BASICS OF WIRELESS WIDE AREA NETWORKING



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EXECUTIVE SUMMARY

Albertans value the use of technology in education delivery. Alberta Learning is committed to supporting and enhancing the use of technology in learning and this is reflected in a variety of initiatives and collaborations with the learning community. Alberta Learning's participation in presenting *Connecting Learners: The Basics of Wireless Wide Area Networking* is another example of this commitment.

Responding to a recommendation by the School Technology Advisory Committee that a research study on wireless networks in the Kindergarten to Grade 12 environment should be conducted, Alberta Learning provided funding for the initiative. The funding assisted school jurisdiction technology staff in making decisions related to wireless networking.

Wireless networking is being used increasingly to provide improved communications and information access to Alberta students. Many schools already have wireless networks linking them to other schools or to the Internet. These existing networks and perhaps some new ones will be needed as interim solutions until SuperNet arrives over the next three years to replace or enhance them. Wireless wide area networks sometimes provide sufficient throughput (bandwidth) to rural areas, depending upon the nature of the service, and relatively inexpensive service in some urban areas.

To date, very little in-depth research has been available on the nature of installed wireless networks. This publication provides a base of knowledge regarding wireless networking solutions, and documents some of the insights that six Alberta school jurisdictions have acquired from their use of wireless data networks. The research includes information about throughput, packet loss, latency, streaming and videoconferencing.

This publication deals with three main wireless technologies: spread spectrum bridged Ethernet wireless solutions, a spread spectrum full duplex solution and a microwave radio solution. The performance of these options is compared with the performance of fibre optic cable.

Real throughput varies significantly across various vendor solutions. In the case of spread spectrum bridged Ethernet solutions there is also significant variance within vendor solutions. With these wireless systems, small frame sizes (i.e., 64 bytes) have much less throughput than large frame sizes (1518 bytes). This is significant because most educational network traffic is of the web variety, which has a predominance of small frame sizes. Similarly, significant numbers of packets can be lost, particularly with small frame sizes.

Overall, the spread spectrum full duplex solution is less variable than the half duplex bridged Ethernet solution. The microwave radio solution demonstrates almost no variance across frame sizes and is less likely to lose packets, even though real throughput is significantly higher when sending small frame sizes.

Regarding bandwidth requirements and packet size distributions for each of the wireless solutions, bridged Ethernet wireless solutions tend not to perform at expected throughput levels with smaller packet sizes. Some networked applications may not be appropriate in bridged Ethernet wireless environments.

A suggested general model for building wireless networks includes a fibre optic core at central locations. Each of these cores would feed a licensed microwave wireless backbone to sites that are more distant. This complimentary set of technologies provides a reliable, high-speed, scalable system with economic viability over the long term. To meet short-term needs, current spread spectrum bridged Ethernet solutions may serve more remote areas, if the network planner has accommodated some of the limitations of this technology. These limitations include the risks associated with unlicensed communications, the limitations on providing high-end applications and the need for a clear understanding of real performance by means of testing across frame sizes.

This publication provides background information about wireless networking for schools and recommends best practices on the basis of information received through formalized testing of six participating school jurisdiction networks.

CHAPTER ONE

INTRODUCTION TO WIRELESS

Context

Providing information and communications technology remains a challenge, particularly in rural areas. Traditional technologies, such as Switch 56 via telephone lines, fail to provide the levels of bandwidth that learners require. Newer technologies such as Internet services via cable modem or DSL (digital subscriber lines) technologies are typically not available in rural areas. Fibre optic cable, DSL and cable modems are serving regions with more concentrated populations, and other regions are falling increasingly behind.

Several Alberta school jurisdictions have installed wireless networks to help provide access at all of their educational sites. Other jurisdictions continue to explore options, but unfortunately little published information is at hand to guide them. Technical journals sometimes publish lab benchmark tests comparing specific products, but school jurisdictions need information about the benefits and shortcomings of various wireless solutions. Additionally, wireless brings a new set of vocabulary and skills that goes beyond traditional wireline networking environments.

This publication:

1. Provides a grounding in some of the foundational concepts of wireless networking.
2. Is based upon formalized research about the actual capabilities of a range of wireless wide area networks that are currently installed in six regions of the province.
3. Is designed to aid jurisdiction administrators, network designers and educational planners in decision making and planning, and in the implementation of wireless networks.

In this publication, wireless wide area networking options are compared to fibre optic cabling because of the positive characteristics of this medium. As Tanenbaum (1996) observes, “some people even believe that the future holds only two kinds of communication: fibre and wireless.” (p. 94).

Introduction to Wireless Networks

The wireless networks that have been created over the past few decades as a solution to a variety of communication needs include personal communications service (PCS), wireless local area networks, local multipoint communication systems (LMCS), cellular, mobile communications, satellite communications and cellular digital packet data (CDPD). The current document focuses on wireless wide area networks that operate over fixed links—that is, all components remain stationary.

Wireless Wide Area Networks Defined

Wireless wide area networks (wireless WANs) are a relatively new means of providing data networking services across a large geographic distance. In this document, wireless WANs refers to connecting traditional local area networks and their subsequent local computing work stations to a larger wide area network using wireless technologies. The intent of the WAN in this context is to provide connectivity between multiple local area networks, thus forming an organizational network. Wireless serves as the medium for this connectivity.

To effectively understand the role wireless plays in the networking domain, you must first understand a standard layered construct. The open systems interconnect (OSI) communications hierarchy, created by the International Standards Organization, serves as the underlying model (Figure 1–1). This layered construct enables the development of a series of building blocks, rather than requiring the creation of a proprietary system for each networked application. With given standards at each layer, developers are able to focus on development within the given layer. Thus, changes in a specific layer should not affect the nature of adjoining layers.

To effectively understand the role wireless plays in the networking domain, you must first understand a standard layered construct.

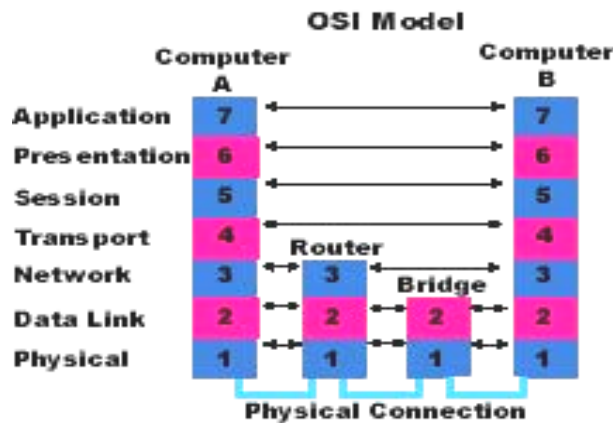


FIGURE 1–1: OSI MODEL

In this publication, we focus primarily on the lower three layers (physical layer, data link layer and the networking layer). Note that a given layer communicates only with another device at the same layer. Layer 1 devices communicate only with Layer 1 devices. Bridges, at Layer 2, communicate only with other Layer 2 devices. Routers, at Layer 3, communicate only with other Layer 3 devices.

Note as well that information travels down from the application level (Layer 7) to the physical layer (Layer 1), then across the network before travelling up from the physical layer (Layer 1) on the receiving device to the application level (Layer 7). Specific addressing or format information is included with the data created at each of these layers.

For example, in a wireless network an e-mail application may send information to another computer. The e-mail application (Layer 7) uses each of the lower levels, adding addressing information as it moves down, until it eventually reaches the physical layer. The physical layer carries the e-mail information across the network to the receiving computer. The receiving computer moves the information from Layer 1 up to Layer 7, progressively stripping off addressing information and processing pieces relevant to that layer until the e-mail itself is received by the e-mail application.

As an analogy, imagine that you are living inland in North America and are shipping a box of furniture overseas to Britain. First, you package the box of furniture (Layer 7) and address it to the receiver. Next this box is enclosed in a crate to be shipped to the coast. Think of this as Layer 3. A city address is included on the crate. When the crate arrives at the coast it is placed in a large boxcar container with many other crates (Layer 2). This boxcar container is addressed to a given shipyard. The boxcar container is then loaded onto a ship (Layer 1).

The ship then leaves port and physically transports the boxcar container and all its contents overseas to the British port (Layer 1). Upon arrival, the container is taken from the ship, the shipyard address is read, local customs processing occurs and the container is moved to the correct shipyard (Layer 2). The container is opened, the address on the crate is read and the crate is forwarded to the specific destination city (Layer 3). Upon receipt at the city, the crate is opened, the street address is read from the box and the box is finally delivered (Layer 7, again). The furniture arrives at the British destination, and the receiver can ignore the interim shipping details.

Layering enables each *department* to most effectively manage the transport of goods within its domain. The shipping company only covered activities on the water, whereas the local courier was most effective in city-to-city delivery. Layering also defines how the package must look as it is sent or received. Couriers do not want to receive boxcar containers, nor do ships want to receive small boxes. These same underlying rules apply to information as it is sent up and down the layers of the OSI model.

Within the domain of wireless networking, the actual wireless transmission and receiving of that wireless signal occurs at the physical layer (Layer 1). However, as the information is gathered by the receiving wireless radio, further decisions must be made to ensure efficient delivery of the information. These decisions must be made by devices at Layers 2 and 3—and eventually by devices operating at Layer 7. (For the purposes of this discussion, Layers 4 to 6 are not described.) Visit <http://www.lex-con.com/osimodel.htm> for further information on implementations of the other layers.

Wireless Communications Physical Properties—A Layer 1 Consideration

The building block for wireless communications is electromagnetic waves, which have two key characteristics: frequency and wavelength. Frequency, the number of oscillations of the wave per second, is measured in hertz (Hz); or in kilohertz (KHz) and megahertz (MHz) for high frequencies.

Wavelength is the distance between the tops (maxima) of two consecutive waves. All waves, independent of their frequency or wavelength, travel at the speed of light in a vacuum, approximately 30 centimetres per nanosecond. Waves are slowed somewhat by the type of media they travel in and can become slightly frequency dependent.

There are two key characteristics of electromagnetic waves: frequency and wavelength.

At low frequencies such as AM/FM radio, electromagnetic waves are dispersed broadly. The power level of such radios must be at a level to ensure that neighbouring radio stations do not interfere with each other. However, at these lower frequencies the waves travel through many objects. Thus, one can hear AM radio while travelling or inside a building. On the other hand, very little data can be carried on such a low frequency. The higher the frequency, the more data that may be carried.

Above 100 megahertz (100 million hertz), electromagnetic waves travel in straighter lines and can therefore be directed to specific locations. Some of the technical characteristics of this radio path must be managed. These considerations include:

- **Line of sight:** At higher frequencies, a radio signal is unable to travel through objects, so each radio path (antenna to antenna) must be in the *line of sight*. During the first draft and more granular levels of network design, general lines of sight may be ascertained. At the more refined levels, radio engineers explore a line of sight for each path.
- **Distance:** Higher frequencies enable increased data throughput. However, higher frequencies also cannot travel as great a distance without the signal being retransmitted using repeaters. Manufacturers often provide some sense of the distance capabilities and limitations of their equipment. Experienced radio engineers can provide additional detail beyond the manufacturer's guidelines.
- **Multi-path fading:** Although electromagnetic waves generally travel in a straight line, there is some dispersion. Some of the waves refract off atmospheric layers, causing the same signal to arrive at its destination at slightly different times and likely out of phase. Radio designers, radio engineers and network designers each can contribute to resolving some of the issues associated with multi-path fading.
- **Rain attenuation:** At frequencies above 8 gigahertz (GHz), electromagnetic waves have a wavelength sufficiently short that the wave may be absorbed by water droplets. Microwave radio engineers and network designers are able to accommodate some of the effects of rain attenuation through careful path design.

Wireless WANs may be licensed or unlicensed. Governments have recognized the need to regulate frequency ranges, given that frequencies are a finite resource. Nearly all of the frequency spectrum range is regulated, but three frequency ranges are made available in North America for broad public usage on unlicensed radios. In Canada, licensing of wireless WANs is obtained through Industry Canada.

Licensing can prove to be valuable insurance for a wireless WAN investment because it prevents another party from using the same frequencies as existing networks, which can slow or halt data transfer for either or both parties. Licensing provides a management structure and assurance that a given bandwidth is dedicated to the licensee within a specific geographic region.

All wireless WANs typically use frequencies above the 900-MHz range. One band has been allocated worldwide as an unlicensed range—2.400 to 2.484 GHz. In North America, federal governments have provided two additional unlicensed frequency ranges. Industry Canada and the FCC in the United States have each set aside the 902- to 908-MHz range and another range from 5.725 to 5.850 GHz to be used for wireless WANs, cordless telephones, garage door openers, wireless hi-fi speakers, security gates and other such uses. Of these unlicensed frequencies, the 900-MHz band tends to be the most congested; it has been available for some time, and vendors have made many products available within this frequency.

Unlicensed and licensed frequency ranges each offer some advantages. Unlicensed frequency ranges are free. Anyone, anytime, anywhere may choose to use the frequency. A breadth of consumer level equipment is available at these frequencies and many people are installing and using this equipment. An obvious disadvantage is the risk of having someone else opt to use the same frequency and interfere with the signal.

Licensing provides assurance that the given frequency range will be reserved across a specific geographic locale. An annual fee is required to maintain rights to the frequency.

CHAPTER TWO

INTRODUCTION TO UNLICENSED FREQUENCIES

Contemporary Use of Unlicensed Frequencies

Over the past five to 10 years there has been significant growth in the use of unlicensed radio technologies for everything from cordless telephones and garage door openers to private radio systems and radio network links. The technologies behind these devices also have grown. Just three or four years ago, a simple inexpensive cordless telephone had difficulties operating in the confines of the average home; today's newest cordless telephones work incredibly well, even in a neighbour's home down the block. Data communications also have become much more sophisticated. While radios of the mid-1990s purported to provide 1 to 2 megabits per second (Mbps) over a distance of 10 or 15 kilometres, newly released unlicensed radios suggest the ability to move up to 45 Mbps over even greater distances. As for the future, vendor claims of bandwidth over 100 Mbps are already being discussed.

Radio frequency (RF) has become a very active field in the past few years. One can scarcely guess at the limits of this emerging technology. As digital communications rely on microprocessors, every advance in the world of microprocessors means an advance in the speed and reliability of digital data communications. Advances in processor power, as opposed to boosting radio power, extend both the reach and services that radio frequency can provide.

Unlicensed radio technologies are being adapted for use in both local area network (LAN) and wide area network (WAN) environments, but this publication focuses on the use of unlicensed radios to create reliable and cost-effective WAN connections. Unlicensed radio products operate in what is termed the ISM (industry, science, medicine) radio bands. These radio frequencies have been set aside for public use and are used widely both in Canada and the United States. A perspective on the ISM band is provided in Table 2-1.

While restrictions on the use of these unlicensed frequencies have been somewhat relaxed in recent years, unlicensed does not necessarily mean unregistered. Industry Canada may require registration, depending on the design specifics and broadcast power of the radio system being used (see Appendix A). Registration provides the regulating agency with a means of monitoring, controlling and, if necessary, resolving conflicts created by two competing (interfering) radio systems.

RADIO FREQUENCY (RF) BASICS

Wave Type	Frequency Band	Abbreviation	Wavelength	Examples
Ground Waves	very low (3–30 KHz)	VLF	100+ km	submarine communication
Ground Waves	low (30–300 KHz)	LF	10–100 km	
Ground Waves	medium (300 KHz–3 MHz)	MF	1–10 km	AM radio
Sky Waves	high (3–30MHz)	HF	100 m–1 km	SW Radio/CB radio
Space Waves	very high (30–300 MHz)	VHF	10–100 m	FM Radio/Television
Space Waves	ultra high (300 MHz–3 GHz)	UHF	1–10 m	ISM/Cellular Telephone
Space Waves	super high (3–30 GHz)	SHF	10–100 cm	Microwave/RADAR
Space Waves	extremely high (30–300 GHz)	EHF	1–10 cm	

TABLE 2-1: THE ISM BAND IN PERSPECTIVE

Spread Spectrum Technologies

Wireless communications using unlicensed frequencies are typically implemented with spread spectrum technology. The history of spread spectrum technologies provides an interesting explanation of their workings and why they work so effectively. During World War II, the military had a need to develop communication technology that would allow for the transmission of radio signals that would be difficult to trace or intercept. The secret was to develop radio patterns and systems that looked like ambient radio frequency noise. This is essentially the main operating theory: encode the data with a random sequence, transmit the data across a wireless segment, and then decode with the same algorithm at the receiving end. Signals that look like noise are difficult to detect and, unless you know the exact algorithm used for the encryption, the signal cannot be decoded. As a side note, Hedy Lamar, a famous screen actress of the 1930s and 1940s, was one of the research scientists who contributed greatly to the development of this technology.

Regulatory Information

Industry Canada regulations for the ISM Bands are named *RSS-210*. Spread spectrum or other unlicensed radio products must meet Industry Canada <http://www.strategis.ic.gc.ca> specifications and must be certified before they can be marketed in Canada.

There are three basic rules for unlicensed radio products in Canada. First, radio transmission power is limited to a maximum of one watt. Second, the maximum antenna gain (EIRP) allowable is four watts. Effective isotropic radiated power (EIRP) refers to the total power of the radio system provided by the output of the radio transceiver plus the gain provided by the antenna. Third, the radio's antenna port must be fitted with a *non-standard* connector. This requirement is in place to help enforce the four-watt EIRP maximum limit through the use of special connectors.

The ISM range of allowable frequencies falls into three distinct ranges:

- 902–928 MHz
- 2.400–2.835 GHz
- 5.6–5.8 GHz

The 900-MHz range is commonly used for short distance communications and is very commonly used by cordless telephone systems. The 2.4-GHz range is the most widely used frequency for data communications. This frequency is used by many different manufacturers and almost has become the standard for unlicensed systems. The 5.8-GHz range is used primarily for data communications, but fewer manufacturers are developing products using this frequency range.

The rules for using the frequencies vary. The 900-MHz and 2.4-GHz frequency ranges can be used for both point-to-multipoint and point-to-point communications. This lends to greater flexibility; a single radio can be paired with multiple receivers to create a star configuration where one central node can feed multiple remote nodes. This can be cost effective and useful in some situations.

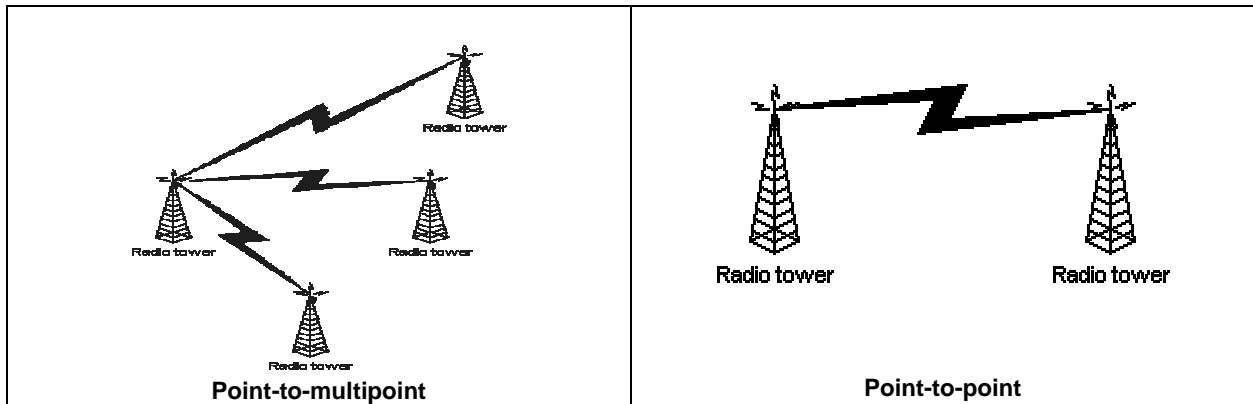


FIGURE 2-1: POINT-TO-MULTIPOINT AND POINT-TO-POINT COMMUNICATIONS

At the same time, this flexibility can reduce reliability. Point-to-multipoint communications require the use of antennas that transmit over a wide angle (25 to 360 degrees). Since these radio systems are not regulated, a nearby system using similar technology can render both systems useless. It is not uncommon for a 2.4-GHz or 900-MHz point-to-multipoint radio system to be installed, work well for a period of time and then be rendered inoperable when someone decides to deploy a similar system. In some cases, changes to the setup will resolve the problem, but the system may again be rendered inoperable by yet another conflicting deployment.

When 2.4-GHz and 900-MHz radio systems are used in point-to-point applications, reliability is generally better, but once again there is no guarantee that a competing system may not create problems. How much risk is there in using 2.4-GHz and 900-MHz radios? Unfortunately, in urban centres these frequencies are quite crowded. With careful planning and wise deployment, they can be used quite successfully over short distances with clear transmission paths (the shorter the distance, the less chance of interference). Also, with short distances if there is interference, the radio systems will still probably work. Unfortunately, the data throughput likely will be decreased.

When 2.4-GHz and 900-MHz radio systems are used in point-to-point applications, reliability is generally better.

The 900-MHz frequency has one unique ability that is not pronounced in 2.4- and 5.8-GHz systems. It is low enough not to be affected by line-of-sight constraints. In simple terms, the signal can bounce around obstacles such as walls, trees or buildings. While 900-MHz systems generally do not offer extremely high speeds or throughput, they may prove useful in providing communication within buildings or in short paths where line of sight cannot be achieved.

900-MHz and 2.4-GHz radio systems are being used successfully in rural areas to create point-to-point and point-to-multipoint systems that cover distances up to 40 kilometres. At this time, there are few competing systems in these areas, so these radio networks often work quite reliably. If others put up similar systems, the risk of having two conflicting systems increases.

900-MHz and 2.4-GHz radio systems are being used successfully in rural areas to create point-to-point and point-to-multipoint systems.

The 5.8-GHz frequency range is implemented somewhat differently. Like traditional microwave systems, 5.8-GHz products can be used only in point-to-point applications. This narrowing of the transmission direction somewhat reduces the risk of interference from other systems. While 5.8-GHz systems are generally more expensive, they are also often engineered to a higher level of reliability than 2.4-GHz systems.

Given the different costs and characteristics of each radio system, it often makes sense to use different products to meet different needs, thus achieving maximum reliability while optimizing costs.

Types of Spread Spectrum Technologies

Spread spectrum radios have become the standard for unlicensed radio communications because spread spectrum technology can increase reliability. In simple terms, spread spectrum is an encoding technique for digital communication. A spread spectrum system uses this digital coding to minimize signal interference and to avoid signal interception by spreading the signal over a range of frequencies in the spectrum. The coding transforms the signal to look more like noise. This approach makes the signal less likely to cause interference in other systems and less susceptible to interference from other systems.

The conventional radio signal is referred to as *narrow-band*, which means that it contains all of its power in a very narrow portion of the radio frequency spectrum. Unlike the spread spectrum radio, it does not spread the signal across adjacent frequencies. The conventional radio does not have the advantage of using a breadth of frequencies and hence can more quickly be rendered inoperable if interference occurs at the specific frequency being used.

Spread spectrum systems are typified by these properties:

- The signal contains unpredictable or pseudo-random components. Normally, the frequency or the amplitude is the random component.
- The amount of data actually transmitted is significantly higher than what the native RF frequency could transmit if no encoding method were used.
- A receiver must extract the useful signal from the spread signal by matched filtering or correlation with a locally generated copy of the pseudo-random component.

DSSS and Frequency Hoppers

There are two basic types of spread spectrum systems: frequency hopping (hoppers) and direct sequence spread spectrum (DSSS). While both are available across the unlicensed frequency ranges, the technologies are quite different.

There are two basic types of spread spectrum systems: frequency hopping (hoppers) and direct sequence spread spectrum (DSSS).

DSSS radios spread the signal from the original narrow-band signal to a wide-band spread spectrum signal using a code known as pseudo-random noise (PN). The advantage of DSSS is that it provides excellent data throughput while still providing some level of tolerance from outside interference. The disadvantage is that when outside interference or signal noise increases beyond acceptable limits, data throughput drops to near zero levels. DSSS systems spread their power (payload) over a wide frequency spectrum.

The frequency hopping spread spectrum (hopper) radios work by sending small amounts of data via random frequencies. This makes hoppers more robust in terms of resisting outside interference that actually curtails the signal. However, data throughput decreases with increased external interference. The performance of the radio is directly affected by the amount of outside noise or interference; as the amount of interference increases, throughput decreases.

Hoppers spread their payload over multiple neighbouring frequencies. This is why hoppers are more resistant to interference; if one frequency fails to deliver its payload, the other frequencies may not be affected and at least a portion of the payload is delivered. Assuming the missed portion of payload is relatively small, this data will be identified by other layers in the OSI model and retransmitted. This reduces throughput but increases reliability. The spreading of data or payload over neighbouring frequencies requires more processor power than for DSSS systems. While traditionally hopper systems have been limited in the throughput they can deliver, increases in processor power translates to direct increases in throughput and reliability.

A look at different vendor web sites (Appendix B) reveals strong competition between DSSS and hopper technologies, with each side claiming a superior technology. However, both technologies offer advantages and disadvantages, and the more successful spread spectrum technology certainly has not been identified to date.

General Properties of Spread Spectrum

Both DSSS and hopper technologies share several general properties, and each offers strengths in different areas.

1. Neither DSSS nor hopper technologies generally require licensing.
2. Hoppers tend to provide better resistance to interference or signal noise than DSSS, but DSSS is rated as providing satisfactory resistance levels.
3. Both forms offer high levels of data security because of the random nature of the signal. The original design by the military during World War II accommodated security considerations.
4. Both forms offer a low probability of detection due to the one-watt maximum power and four-watt maximum EIRP restrictions.
5. DSSS radios tend to offer stronger ability to transmit large amounts of data in *no interference* conditions. Hoppers are more reliable in interference conditions, but such conditions result in a drop in overall throughput.

The U.S. government declassified spread spectrum technology for commercial purposes mainly because of the heavy use of licensed radio bands. This release put robust communications technologies into unlicensed radio frequencies. These new unlicensed frequencies were released with the understanding that they would be available to industry, science and medicine.

As mentioned previously, one of the properties of radio products is that the higher the frequency, the more directional the signal becomes. In simple terms, as the frequency becomes higher the signal behaves more like light. While an AM radio can transmit over trees and bounce over obstacles like hills and valleys, the ISM band spread spectrum radios are generally influenced by physical geography and topology.

As a low frequency technology, 900-MHz spread spectrum radios are the least affected by physical geography. They are effective for use in sites where no clear line of sight exists between the two radio endpoints. (Remember, though, these radios carry less data than 2.4-GHz and 5.8-GHz radios.) In technical terms, *line of sight* is defined as the direct free-space

path between two points. Using binoculars on a clear day, you can determine relatively easily if visual line of sight exists between two points that are miles apart. Unfortunately, this definition of line of sight is not good enough for radio communications. Radio signals do not travel in a perfectly straight line. The signal pattern is actually shaped like a football. This football-shaped pattern is referred to as the signal's Fresnel zone. Not only must the visual line of sight be clear of obstacles such as trees, buildings and hills, but the Fresnel zone also must have certain clearance levels (Figure 2–2).

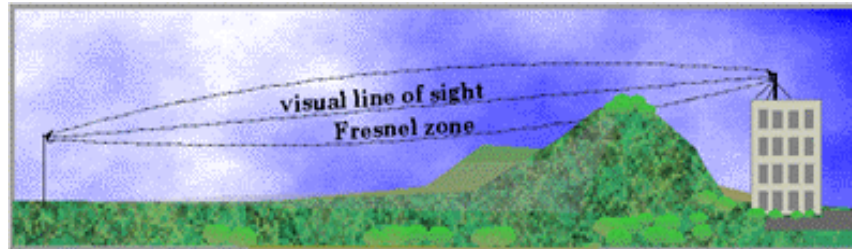


FIGURE 2–2: FRESNEL ZONES

Given these characteristics, a loosely engineered 900-MHz system will likely function in spite of the engineer's failure to effectively capture line of sight. At the other extreme, a high frequency system (e.g., 38 GHz) is more likely to encounter problems if line of sight has not been achieved through careful engineering.

Summary of DSSS and Hopper Technologies

There are no hard rules guiding when to use DSSS or hopper technology, nor are there any defining rules regarding when to use 900-MHz, 2.4-GHz or 5.8-GHz radios. However, these general guidelines apply to the design of spread spectrum radio network segments.

1. 900-MHz radios work well for non-line-of-sight applications.
2. 2.4-GHz radios, which can be used with omni-directional antennas, offer possible solutions for point-to-multipoint radio links.
3. 5.8-GHz radio solutions, which have a smaller Fresnel zone, make an excellent choice for long distance paths or other paths that may have unacceptable fade margins. The smaller Fresnel zone can be used to create more focused signals that offer a greater resistance to interference and as such can be engineered to a greater level of reliability.
4. Hopper technologies are a better choice in areas that are at risk from interference from other radio systems or other ambient radio frequency noise.
5. DSSS technologies offer better data transmission rates for point-to-point communication where there is little interference from other radio systems or ambient RF noise.

Industry Standards

While each radio system manufacturer has its own specifications and technologies, there has been movement towards some level of standardization. In 1997, the Institute of Electrical and Electronic Engineers (IEEE) <http://www.ieee.org> put forth a standard for wireless Ethernet technologies. This emerging standard is known as 802.11. While both vendors and consumers have viewed this as a positive step, there also are concerns about the standard.

While the standard has been accepted, it addresses only LAN environments. The standard was written to address wireless local area networks (LANs) as opposed to a technology for connecting LANs together to form wide area networks (WANs).

The other issue raised by the standard is that of inter-operability. The complicating factor is that 802.11 addresses the Ethernet aspect of communication as opposed to wireless aspects. The standard allows for the use of both hopper and DSSS technologies in the 2.4-GHz frequency range. Because the standard deals with the Ethernet level only, there is no provision to ensure that radio Brand X will inter-operate with radio Brand Y. The standard addresses the levels and type of service the system must provide, not how those levels are provided.

As vendor web sites are reviewed and vendor products are compared, it becomes evident that the 802.11 standard is accepted by some vendors but rejected by others. In many ways it comes down to the market the vendor is targeting. If the radio product is developed for a LAN environment, the 802.11 standard will most certainly be followed. If the vendor is aiming the product at a WAN environment, compliance with 802.11 is less likely and not necessary.

Radio Types

While the largest market share of unlicensed radio network products operate as Ethernet bridges, there also are unlicensed radio systems that work essentially as data modems.

While the largest market share of unlicensed radio network products operate as Ethernet bridges, there also are unlicensed radio systems that work essentially as data modems.

There are some inherent advantages to operating as data modems—the biggest one being nearly guaranteed throughput. A T1 radio system (a North American and Japanese standard of joining 24 voice channels) provides a full 1.544 Mbps of full duplex data transmission. Full duplex transmission means that information is being transferred between sender and receiver in both directions simultaneously—in simple terms, both systems are *talking* and *listening* at the same time.

By comparison, many of the wireless Ethernet bridges are half duplex solutions that offer less throughput than their theoretical maximum. One system talks while the other listens; the two systems cannot talk simultaneously. This has implications for maximum theoretical throughput.

Conventional wireless radio systems that operate as data modems (such as Harris radios) are generally available as T1 (1.544 Mbps), multiple T1, DS-3 (45 Mbps) or three DS-3 solutions. These are point-to-point solutions only requiring connection to a router or switch that includes a T1 or DS-3 port. The addition of either a router or switch is required to form the network layer. Alternatively, such radios may be connected to the router or switch using either a digital signalling unit (DSU—a modem-like device used between the radio and the router) or multiplexer (MUX—a device used to combine multiple signals into one large signal). A well-designed system of this type can provide telecommunications company reliability, and a very structured and elegant means of managing both network data and native voice traffic.

There are no hard rules describing when to use data modem-type solutions and when to use an Ethernet bridge data solution, but once again there are some general guidelines.

1. Structured DS-3/T1 solutions must utilize point-to-point links.
2. DS-3/T1 solutions offer channelization as a means of managing and prioritizing both voice and network data traffic.

3. DS-3/T1 solutions require additional hardware in the form of DSUs, MUXs, routers or switches systems.
4. Ethernet bridge solutions offer a simple means of linking Ethernet LANs. Although they cost less, there are also some trade-offs, as described later in this document.
5. Ethernet solutions can integrate voice traffic using *Voice over IP* or IP telephony solutions instead of approaching voice using the traditional approach.

Future of Spread Spectrum

The future of spread spectrum technology is interesting to say the least (see Appendix C). All spread spectrum technologies rely on high-speed data processors to provide the random nature of the signal. As data processing power increases, this power can be used to build better encryption algorithms to provide faster and more reliable data transmission.

DSSS radios have produced products that approach theoretical wireline Ethernet speeds of 10 Mbps. Hopper technologies, while being more resistant to interference, have lagged behind their DSSS counterparts in terms of bandwidth. However, this will soon change. Both Cisco and Wi-LAN have recently started shipping W-OFDM (wide-band orthogonal frequency division multiplexing) systems. W-OFDM is essentially hopper technology multiplexed over narrow frequencies. This allows for the robust aspects of frequency hoppers to be enhanced while greatly increasing the available bandwidth. Given increasing processor speeds, W-OFDM may allow for bandwidth exceeding 100 Mbps.

Perhaps the greatest promise of W-OFDM technology is its resistance to multi-path interference and its ability to work around line-of-sight limitations. The simplest way to understand W-OFDM is to think of multiple hopper-type radios being condensed into a single system. The processor power is used to coordinate (multiplex) the frequencies so that they overlap in power and time. Imagine eight, 10 or even 100 hopper-type radio systems co-existing within a single frequency range and a single radio box. Because there are multiple frequencies and many timeslots, the systems become highly resistant to interference. Line of sight becomes less of an issue as signals can, in essence, bounce around objects. Faster processors in this case mean more throughput and greater resistance to interference.

DSSS radio systems cannot be discounted yet. The same increases in processor speed will ultimately translate to enhancements in DSSS technologies as well.

CHAPTER THREE

HIGH FREQUENCY LICENSED MICROWAVE AND FIBRE OPTIC CABLE

Microwave Technologies

Microwave radio technology is not new. It is a proven technology that has been used in the field for approximately 30 years. Although many of the electronics in newer microwave radios are now digitally based rather than analogue, the underlying technology is largely the same. Digital information is now carried over analogue carrier waves, and during the past half decade this technology has significantly increased throughput capabilities.

Large corporate and government agencies have found microwave communications to be an effective means of sending and receiving information. Organizations such as Ontario Hydro, Motorola, the U.S. Navy, Bell Atlantic, TransAlta Utilities and TELUS Communications have deployed microwave technologies. Before fibre optics, microwave systems formed the heart of long-distance telephone transmission systems. In fact, the U.S. long-distance carrier MCI (Microwave Communications Inc.) built its entire system originally on microwave technologies (Tanenbaum, 1996).

Introduction to Microwave

There is common agreement on the approximate frequencies of the microwave range, but also some degree of variance. For example, Doble (1996), a university lecturer teaching line of sight propagation, defines microwave frequencies as covering “a 900-MHz to 60-GHz range.”

“The lower limit,” Doble adds, “is usually 1 GHz, but with cellular radio systems straddling this frequency, it is best to use 900 MHz as a starting point. Similarly, the boundary between microwaves and millimetrics is normally set around 30 GHz; however the nature of transmission around 60 GHz makes it of great interest to the mobile community, so we have also extended the upper limit.” (p. xvii).

On the other hand, Laverghetta (1998), a Purdue University professor of electronic communications, defines a microwave as “a radiowave operating in the frequency range of 500-MHz to 20-GHz that requires printed circuit components be used instead of conventional lumped components.” (p. 2). He further defines *lumped components* as those found in AM-FM radios and televisions, including such components as carbon resistors, mica capacitors and small inductors.

In the common vernacular within the field, the term *microwave* is often used to refer to upper level frequencies. For the purposes of our discussions, the terms *high frequency licensed microwave* and the abbreviated term *microwave* will refer to radio frequencies between 6 GHz and 38 GHz. These are frequencies for which one may apply for a licence to create a wireless microwave WAN.

The terms *high frequency licensed microwave* and the abbreviated term *microwave* refer to radio frequencies between 6 GHz and 38 GHz.

This definition helps differentiate the term *microwave* from the lower frequency *spread spectrum*, although, strictly speaking, the technical definition of microwave also includes spread spectrum frequencies.

General Properties of Microwave Frequencies

Licensed microwave holds some similarities to unlicensed spread spectrum: it is a radio frequency (albeit a higher-level frequency), it requires line of sight and it utilizes many of the same components (radio, antenna, coaxial cable). Yet, at the technical level, some characteristics of microwave frequencies are quite different from those of spread spectrum frequencies. Microwave does not *hop* or rotate across adjacent frequency levels as spread spectrum does. Instead, it operates consistently within a given frequency band, using all the available bandwidth to transmit data. It also uses a narrower range of frequencies than spread spectrum.

By its very nature, high frequency microwave has higher theoretical maximum bandwidth (data capacity) potential than lower frequencies. Higher frequencies are able to provide more bandwidth. For example, consider the following two frequency sine waves (Figure 3–1).

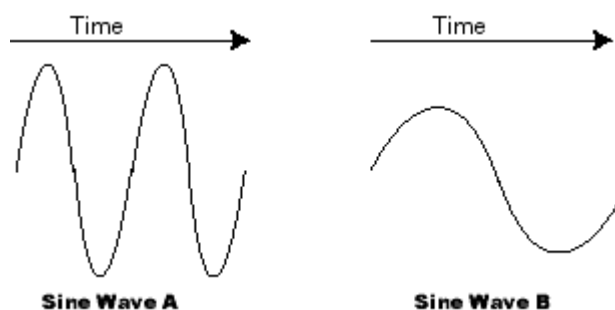


FIGURE 3–1: TWO SINE WAVES

Both waves travel at the same speed, namely at the speed of light within a vacuum (Tanenbaum, 1996). Both waves may also transmit the same amount of information within a single wave, for example, one bit of information. However, within a given time frame, the first sine wave is able to provide more information than the second. The waves in the second sine wave have a higher frequency—they are packed more tightly together. This enables the transmitting of more information, and the result is equivalent to increased bandwidth. To attain any similar levels of throughput at lower frequencies (for example, unlicensed frequencies), the broadcaster needs to introduce processing overhead.

By its very nature, high frequency microwave has higher theoretical maximum bandwidth (data capacity) potential.

Microwave radios operate like a conventional radio, or as described earlier, similar to a data modem. The fact that information is travelling by a wireless medium is not apparent to the user. The properties of this type of radio minimize latency and enable a level of throughput such that the end user will not know whether the information is transmitted by copper cable or by wireless.

Regulatory Information

Not surprisingly, high frequency licensed microwave requires a licence from Industry Canada, which is responsible for the management or allocation of frequencies across the spectrum.

Industry Canada authorizes the use of given bandwidth frequencies, with the exception of the unlicensed frequencies described earlier. Licensing provides the right to use a given frequency range within a specific geographic region. A detailed map and table of frequency allocations is available from Industry Canada <<http://strategis.ic.gc.ca/SSG/sf01608e.html>>. Licensing allocations are described from 3 KHz to 300 GHz. This covers all purposes, from aeronautical mobile to space research.

The basis of licensing is the assurance that, once a frequency range is licensed, no other agency or corporation within the allocated locale may use this frequency. You will recall a risk inherent in unlicensed frequency ranges, such as those used by spread spectrum. After investing significant funds in the development of a network built around an unlicensed range, others within the same geographic locale may opt to use the same frequency, and this can seriously affect communications. Bandwidth, latency and overall reliability may be lost as two or more organizations compete for the same frequencies.

Identifying the cause of network degradation can be a challenge in and of itself. Others may be installing an unlicensed system, or factors inherent to the network itself may be the source of the problem. Testing and identifying the specific cause can be demanding—especially if other parties are involved. Finally, unlicensed frequencies provide no formal mechanism for ascertaining rights. No governing body provides direction, nor are there specific rules for the parties to follow.

Licensing provides protection and assurance that, following substantial investment in building a wireless network, rights to the licensed frequency range are maintained. Controls are in place through Industry Canada to manage the assignment of frequencies and processes are in place to resolve potential frequency overlaps.

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Radio Types

The components that must be specified for a licensed microwave network include the microwave radio, a tower and an antenna. Microwave radios are addressed below, while towers and antennas are discussed in Chapter 4, along with the components common to both licensed and unlicensed radio networks.

Microwave radios are commonly designed around such frequencies as 10 GHz, 15 GHz, 18 GHz, 23 GHz and 38 GHz. Radios typically consist of an indoor mounted baseband unit; an outdoor, or possibly indoor, radio frequency (RF) transceiver; and an antenna mounted on a tower. The baseband and RF unit need to be within 300 metres of each other and may be connected using coaxial cable or wave guide. Wave guide is an older technology that essentially consists of pipes that carry RF signals from one point to another. Minimizing or avoiding the use of wave guide is recommended, as it is expensive, challenging to install and can be equally difficult to maintain. Some contemporary radios build the antenna into the outdoor transceiver to accommodate moderate path lengths, thus saving the extra cost of a larger antenna.

The bandwidth offered by microwave networks ranges from 1.5 Mbps to N times 155 Mbps where N is the number of radios installed on the same radio path. To keep communications interesting, the telecommunications industry tends to overlay additional vocabulary for different bandwidth levels. Generally one of three interfaces is included with radio equipment, which in turn determines the bandwidth level provided: a T1 interface (1.5 Mbps), a DS-3 interface (45

Mbps) or an OC-3 interface (155 Mbps). Microwave radios with T1 interfaces are typically offered with multiple T1s. For example, such radios offer single, four or eight T1 interfaces. Multiple DS-3 or OC-3s are typically provided by installing an additional radio, rather than additional interfaces. When purchasing a multiple T1 radio, be aware that inverse-multiplexing these multiple T1s into a single channel is relatively expensive. For example, it was found that it is actually cheaper to purchase a DS-3 radio (45 Mbps) than an eight T1 radio, given the additional cost of inverse-multiplexing to form a single channel (12 Mbps).

Bandwidth offered by microwave networks ranges from 1.5 Mbps to N times 155 Mbps.

Microwave radios are purchased as either *protected* or *unprotected*. These terms define the redundancy built into the radio. In essence, a protected radio is two radios built into one; it is one radio with duplicate electronics. In the event the first radio fails, the radio automatically switches over to the second radio, which continues communications without interruption. Sometimes such protected systems are also referred to as *hot stand-by* or *monitored hot stand-by*. Unprotected radios lack the redundant circuitry. Therefore if the radio fails, communications also fail.

The distances that microwave radio signals can travel are affected by both specifics within the radio and external factors. As described earlier, major determinants of the distance a signal may travel are the frequency chosen and the associated engineering of the implementation. Depending on the frequency range, the level of engineering, environmental factors (especially frequency and intensity of rain) and the type of terrain, microwave signals may be transmitted across distances as great as 60 to 80 kilometres (Dynes, 1995).

While licensed microwave systems have been relatively common among larger corporations, the public sector, and in particular education, has only recently recognized the role that such systems may serve in building network backbones.

Planning a Microwave Network

Installing a wireless microwave network requires considerable planning. Much of the reliability of the wireless microwave network will depend on careful planning and effective engineering. The following section, an extension of work by Little (1996), provides an overview of key steps in planning a licensed microwave network.

Much of the reliability of the wireless microwave network will depend on careful planning and effective engineering.

1. Determine design objectives.
 - Assess bandwidth capacity requirements, both current need and future projections. Ensure that you have accommodated anticipated growth patterns due to the evolution of bandwidth-hungry applications.
 - Ascertain availability/reliability requirements (protected/non-protected).
2. Determine and produce a preliminary network design.
 - Identify all end nodes within the network.
 - Identify data bandwidth requirements to all end nodes.
3. Contract and work directly with a consulting microwave radio engineer (for all remaining steps).
 - Project approximate locations of repeated hop nodes.

4. Determine frequency availability and regulatory restrictions.
 - Work closely with Industry Canada to identify appropriate frequencies to reach the distances required.
 - Explore preliminary Ministry of Transport and local governance restrictions.
5. Conduct an engineered path study to identify topographical considerations and plot the signal across that topography. Path studies are vital in ascertaining the profile of the geography. Land that looks flat often has surprising rises or falls within a given path.
6. Establish the existence of a line of sight. Although a path study is an excellent tool for ascertaining paths in light of the geography, such studies fail to accommodate man-made and natural structures that may exist in the path; e.g., silos, trees.
 - Visually review at each of the paths.
7. Develop a detailed network design.
 - Identify the network topology, possibly a star design, a ring design or some hybrid of these.
 - Detail the bandwidth delivery to each site and the upstream requirements.
 - Identify preliminary network layer (Layer 2 and Layer 3) solutions.
8. Redraft the network design. The process is iterative. For example, the original network design may need to change when obstacles are identified within the line of sight. It may be necessary to identify a new path. Depending upon path length, it may be necessary to change frequency.

When planning a licensed microwave radio network, keep these general principles in mind:

- Higher frequencies are capable of travelling less distance. A 38-GHz microwave radio will not be able to travel as far as a 15-GHz microwave radio in a single hop.
- Higher frequencies are more susceptible to rain attenuation (rain will affect the signal) and hence require stricter adherence to engineering principles.
- Lower frequency systems, say in the 6- to 9-GHz range, tend to cost more to deploy.
- Ample lead-time may be required when ordering microwave radios. Ensure planning is completed well in advance.

Industry Canada, one of the key players in the development of a licensed wireless network in Canada, manages licensed radio frequencies. Therefore, to gain a further understanding of wireless networks and licensing considerations, the authors of this publication conducted an interview with Industry Canada staff (see Appendix A).

Industry Canada is one of the key players in the development of a licensed wireless network in Canada.

A number of companies that retail microwave radios also provide white papers and information on licensed microwave systems. These include Alcatel <<http://www.alcatel.com>>, Harris <<http://www.harris.com>>, Nortel Networks <<http://www.nortel.com>> and DMC Stratex <<http://www.stratexnetworks.com>>. Other companies are currently releasing microwave products as well. Given the demand for bandwidth, the desire to create protected networks and the need for reliability, it is anticipated that licensed microwave will continue to grow as a means of providing network backbones in designs where fibre optic cabling is not feasible.

CHAPTER FOUR

UNLICENSED AND LICENSED WIRELESS: COMMON CONSIDERATIONS AND COMPARATIVE MEDIA

Engineering Studies—Design Considerations

No radio technologies currently can be considered *plug 'n play*. The successful use of any radio system is tied to good engineering and design. Therefore, using the services of a professional microwave or RF engineer is highly recommended in the design of any network that is expected to operate at a high level of reliability.

What is reliable? For a telecommunications company or an RF engineer, reliability is generally defined as 99.999%, often referred to as *five nine's reliability*. This translates as 5.25 minutes of downtime per year. Although 99% might sound sufficient, it translates to 87.6 hours of outage per year, while 99.9% reliability means only 8.76 hours of downtime in a year.

For a telecommunications company or an RF engineer, reliability is generally defined as 99.999%.

Qualified microwave radio engineers must be involved in the design of a wireless licensed microwave radio system. It is possible to use *point-and-hope engineering* to implement spread spectrum radio systems, but the economics of such an approach are difficult to quantify, as is the overall reliability of such an installation. It simply is logical to define a sound engineering design and the reliability levels before implementing a system.

Antennas

Antennas, a critical part of any radio system, focus and absorb radio energy in specific directions depending on how they are designed. Considering that the maximum allowed transmission power of an unlicensed radio is one watt, proper antennas are required to ensure reliable data transmission. To understand the important role of an antenna, consider a typical flashlight. Without the focused reflector behind the flashlight bulb, the usefulness of the device is severely limited. The antenna in a typical radio system serves much the same function as the reflective shroud behind the flashlight bulb. It focuses the signal and extends its reach.

The ability of an antenna to focus a radio signal is referred to as *signal gain*. While an antenna cannot increase the power of a signal, it can focus that energy in a specific direction. The measure of this focus is usually compared to a theoretical antenna called an isotropic radiator. This theoretical antenna transmits the radio signal over a sphere-shaped area covering all three dimensions. In reality, however, we do not require radio signals to go directly into space or down into the ground. Hence, we use a focused antenna to direct the signal in a specific direction. Only by utilizing effective antenna design can low power spread spectrum radios be useful in providing long distance data communications.

Towers and Transport Canada

The towers used for microwave radio systems are generally constructed differently than towers used for spread spectrum radio networks. Given that the microwave signal is a narrow signal

(imagine projecting a relatively narrow doughnut) as compared to spread spectrum (imagine projecting a rather broad doughnut), a relatively stable mount is required to send and receive the microwave signal. Consequently, the tower specifications for microwave installations are more refined than for spread spectrum.

The fully installed cost for a 100-foot tower with Canadian Standards Association (CSA) approval may range from \$20,000 to \$25,000, depending on the inclusion of such features as lighting, anti-climb (to limit unauthorized climbing of the tower) and fall arrest (to reduce the risk of falling by authorized tower personnel). Towers that cost less would not be CSA approved, and it is suggested that towers be CSA approved—whether for microwave, spread spectrum or other frequencies—in order to ensure that the structure meets established safety guidelines, which is particularly important at school sites.

Large towers (30 metres or higher) are often used to achieve line of sight between antennas over long distances. While Industry Canada regulates radios, frequencies and tower locations, Transport Canada regulates other tower specifications.

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Transport Canada regulations are laid out in the *Standards Obstructions Markings Manual* <<http://www.tc.gc.ca/aviation/regserv/carac/cars/cars/62119e.htm>>, which states that, although compliance to the standards obstruction markings is voluntary, you are required to meet the aviation safety standards. It simply makes sense to register all towers to limit any future liability.

The forms to register towers or *other obstructions*, as they are described, can be downloaded from <<http://www.tc.gc.ca/aviation/regserv/carac/cars/cars/a62119ce.htm>>. While there may be costs associated in meeting the standards, there is no cost to register.

Wireless Security

The media have been paying close attention to networking and Internet security. Therefore, it is natural to ask, “Just how secure is wireless technology, especially since it operates across the open, public airwaves?” The short answer to this question is, “Very secure.”

Spread spectrum and microwave technologies are different with regard to security, yet both provide secure communication environments as compared to wireline media.

Spread spectrum and microwave technologies are different with regard to security, yet both provide secure communication environments as compared to wireline media. Spread spectrum technologies originated from military research and use, where security is very important. Spread spectrum technology is based on an encoding technique and the use of frequency hopping managed by a specific algorithm. Any breach of security would need to exactly match this algorithm and the associated timing. Most line-of-sight antennas are highly directional. In addition to this, the signals may be polarized (vertical or horizontal), so any potential eavesdropper receiver would have to be similarly configured.

Many wireless radios, such as Wi-LAN, allow multiple channels—each of which may have a different frequency. The 4.5-Mbps Wi-LAN radios have seven separate channels that assign a portion of the RF band between 2.4258 GHz to 2.4498 GHz. Any interceptor would have to be able to tune to the correct radio frequency to interpret transmissions. Further, most wireless transmitters have scrambling codes and other security features. Therefore, it is highly improbable that an unauthorized receiver who captured a wireless signal could decode any usable information.

Information on microwave transmitters generally is secure as well. A microwave radio engineer has these comments (May 16, 2000):

First, one must recognize that no transmission medium is totally secure if sufficient resources and technical knowledge are applied to the problem. Although it is theoretically possible to capture and decode microwave radio signals, it would be extremely difficult. Several factors contribute to this difficulty.

- 1. The microwave signal itself is a relatively small doughnut. Hence, capturing this signal would require placing a receiving radio directly into the radio path.*
- 2. The typical height of the signal off the ground would make it difficult to intercept.*
- 3. Fine tuning radio receiver signals requires a stable platform and very refined control of the horizontal and vertical directions of the dish (antenna).*
- 4. It would require a significantly large dish.*
- 5. The radio itself would need to match, and specific configurations within the radio would need to match. Even if the physical layer radio signal were captured, it would require even further decoding into the Layer 2 frames and Layer 3 packets. This would require very specific equipment with very specific configurations.*

None of the major carriers using microwave have identified security of the microwave signal as an issue across the many years of service that microwave has provided.

In summary, if we were the CIA, we would likely worry as much about fibre taps as we would about microwave interception. The overhead of even attempting such a security breach is daunting, much less the multi-level technical know-how.

Fibre Optic Cable

In the preparation of this manual, the authors compared various wireless data systems to fibre optic cable. Microwave radio presents an order of magnitude increase in throughput capacity over the capacity generally offered by half duplex bridged Ethernet spread spectrum radio. Similarly, fibre optic cable presents an order of magnitude increase in throughput capacity over the capacity of any form of wireless networking.

Fibre optic cable presents an order of magnitude increase in throughput capacity over the capacity of any form of wireless networking.

As a connectivity medium, fibre optic cable is as close to the ideal as one can currently find. The key to fibre optics is light. The speed of light defines the upper bounds at which one may transmit a signal. Fibre optic cable provides:

- An ability to control the light signal within a glass-clad cable.
- A reliable long-life characteristic.
- An ability to subdivide the signal into multiple frequencies (dense wave division multiplexing), thus providing tremendous bandwidth potential.

Fibre optic cable comes in two primary forms: multi-mode fibre and single mode fibre. Multi-mode fibre uses a light-emitting diode (LED) to transmit light. Single mode fibre, on the other hand, uses a laser beam and is capable of transmitting significantly greater distances than the multi-mode format. Therefore, the electronics that connect to single mode are more expensive than those used with multi-mode fibre.

The main limitation of fibre optic cable is cost. Although the cable itself is not very expensive, the associated capital cost of laying the cable across any significant distance is relatively high. Fibre may be laid underground using either standard trenching techniques or horizontal boring—a process of directional boring using specialized equipment. Alternatively, overhead fibre strung from telephone or power poles may be used. The associated costs of installing the fibre and conducting the necessary splices significantly increases the overall cost.

Additionally, right of way must be sought for installing cable. This may add significantly to the cost and can be a challenge in densely populated areas. The longevity of fibre life, however, does help rationalize the expense. Amortized over the life of the cable, the costs become affordable—especially given the open-ended bandwidth capability of the medium.

CHAPTER FIVE

TRAFFIC ON THE WIRELESS WAN

An Overview of Network Traffic

At its most granular level, one recognizes that wireless networks must carry traffic. Usually, Ethernet traffic is transmitted via Ethernet frames. Typically, within each Ethernet frame there is an IP packet. Some of this network traffic must be given high priority to be usable, while other traffic has delivery times that are less critical. Some of the traffic resides in small Ethernet frames, while other traffic resides in large Ethernet frames.

All of this network traffic will likely travel across the wireless WAN. The wireless WAN does not prioritize the traffic it carries and hence does not provide any assurance of delivering time-sensitive information traffic appropriately. Also, the specific nature of the WAN can affect the ability of a network to deliver packets in a timely manner. The type of wireless WAN can also define the profile of traffic that it is most suited to carrying. Some wireless WANs are capable of effectively carrying all forms of traffic; others are more limited.

There are many types of traffic on the Internet today. In addition to the common types (World Wide Web, electronic mail, file transfers), there are many emerging multimedia applications. People listen to music via RealPlayer and MP3; talk to friends through ICQ chat, Instant Messenger or NetMeeting; send e-mail; or watch news clips online with QuickTime and Media Player. When contemplating wireless networks, network planners need to consider the current and future bandwidth implications of these new applications.

To understand the implications of using a breadth of applications across a wireless WAN, people need to determine the profile, or footprint, of each type of application. This publication addresses network traffic, including the bandwidth required, the size of Ethernet frames on the WAN, and the type of application *conversations* occurring across the network.

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Networking Background

Ethernet is the collective name for a variety of closely related network standards. Each version of Ethernet includes specifications for the physical and data link layers. This defines how the signals will be sent and received. Protocols like IP define communications without reference to the physical medium. This chapter examines only the construction of Ethernet frames and IP packets.

Note: The term *frame* always refers to an Ethernet frame. However, the term *packet* may refer either to an IP packet or an Ethernet packet. An Ethernet packet is synonymous with an Ethernet frame.

Standards and Addressing

The standards described in this section are not unlike the earlier set of rules describing the shipment of furniture to Britain (Chapter 1). Certain attributes are defined and certain processes are followed to enable effective traffic movement.

Ethernet traffic is defined by the IEEE 802.3 standard. This standard determines the characteristics of an Ethernet network. This publication focuses on Ethernet because most school and jurisdiction networks utilize Ethernet, and many wireless radios connect directly to Ethernet.

The IEEE 802.3 standard defines *carrier sense multiple access with collision detection* (CSMA/CD) as a control mechanism for access to half duplex Ethernet networks. Data travels through an Ethernet network in frames that must be no smaller than 64 bytes and no larger than 1518 bytes. There is a gap between each frame that cannot be less than 9.6 microseconds (Figure 5–1) on a 10-Mbps Ethernet. There can be only one frame on a half duplex network segment at any one time. If a network interface card (NIC) is attempting to transmit a frame and a frame is already on the network cable, a collision will occur. Each of the sending NICs *backs off*, waits a random time period, then tries sending again.



FIGURE 5–1: ETHERNET FRAMES

Full duplex Ethernet <http://www.imcnetworks.com/fag/FDX-FO.HTM#removing> does not have collisions and hence does not require CSMA/CD to manage access to the network. Although simultaneous communication in both transmit and receive directions (without potential for collisions) certainly improves Ethernet standards, it does not actually double bandwidth. However, full duplex Ethernet is a significant stride forward for Ethernet standards as it avoids collisions, the greatest limitation of such networks.

Full duplex Ethernet is a significant stride forward for Ethernet standards as it avoids collisions, the greatest limitation of such networks.

As indicated earlier, data is transmitted through frames (see Figure 5–2) that vary between 64 and 1518 bytes in length. Any frame has two main components: a header and payload (the data that is in transport). The header information includes all of the information defining where the packet is coming from and where it is going. There are two addresses in this header—the Ethernet source address (which device is sending the frame) and the Ethernet destination address (which device will receive the frame). Ethernet addresses are part of any Ethernet adapter and are unique in the world. These addresses are always in hexadecimal with the first three hexadecimal numbers representing the manufacturer of the Ethernet connector and the last three representing a unique address within that manufacturer's set of products. A source address may be, for example, 00:E0:1E:60:8D:6D. The *organizationally unique identifier* (OUI) in this case, 00:E0:1E, belongs to Cisco (the address is a router). The *suffix*, 60:8D:6D, is unique among the Cisco product line. The Institute of Electrical and Electronic Engineers

(IEEE) manages such addressing standards
<<http://standards.ieee.org/regauth/oui/index.shtml>>.

The Ethernet frame's payload may hold an IP packet. The IP packet contains a header with an IP source address and IP destination address. These addresses, which are central to the operation of the Internet, consist of four numbers separated by periods (dotted quad notation). Each IP address is a 32-bit number divided into two fields—a network-identifier and a host-identifier. For example, rochester.real.com (Figure 5–2) has a destination address of 208.147.89.127. This IP address is unique in the world and is considered to be on network number 208.147.89 with a host number of 127.

Each computer that is attached to the Internet has an IP address. Detailed information on IP addressing is available from the American Registry for Internet Numbers <<http://www.arin.net>>.

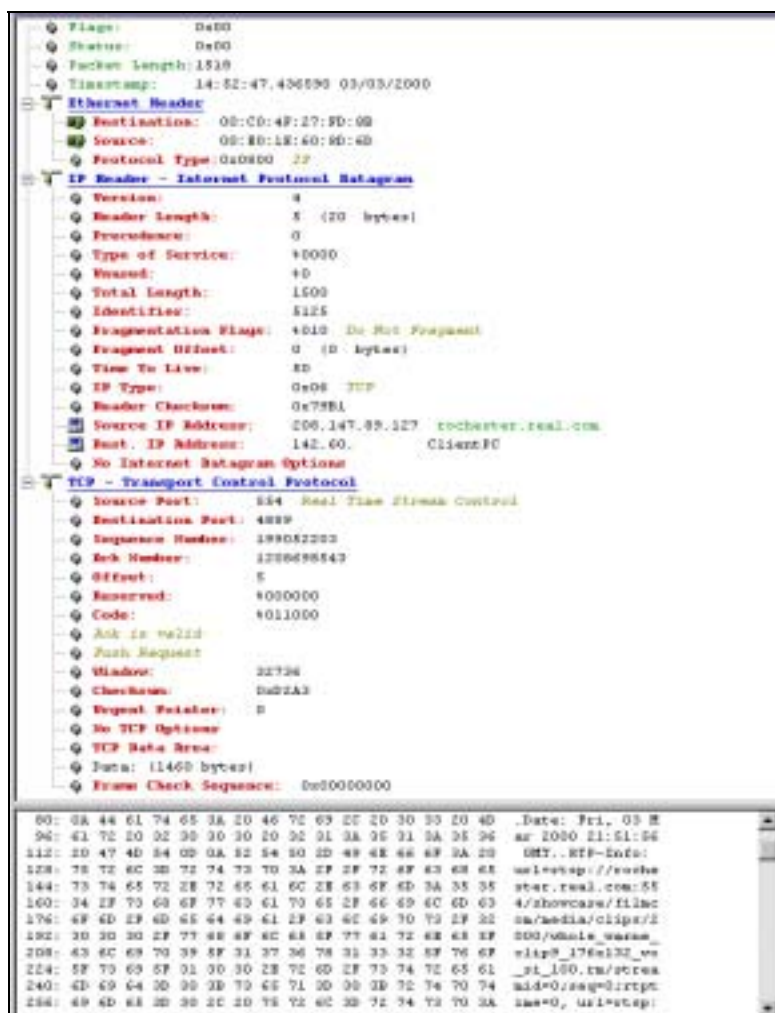


FIGURE 5–2: ETHERNET PACKET DETAIL

Protocols and Ports

A protocol is a set of rules governing communications. Networking protocols specify the types of data that can be sent, how each type of message is identified, what actions can or must be

taken by participants in the conversation, precisely where in the packet header or trailer each type of required information will be placed and more.

Transmission control protocol (TCP) and Internet protocol (IP) are two key examples of protocols in the suite of TCP/IP protocols. User datagram protocol (UDP) may be implemented instead of TCP and is quite common as a transport protocol. TCP and UDP each operate at Layer 4 of the open systems interconnect (OSI) model, as described earlier. Different protocols establish communications via port numbers. In the packet detail (Figure 5–2) one can see that the TCP connection is established by the source computer on port 554 and is connected to the local computer on port 4889.

Network devices need to be able to provide a variety of services to clients and peers on the network. To help manage these various functions, protocol designers created the idea of logical ports to which requests for particular services could be addressed. A source TCP-port conversation is held from the local computer to a host and a reverse TCP-port conversation back. Some common TCP port numbers used in these conversations are 21 (FTP), 23 (telnet), 25 (SMTP mail), 53 (name server) and 80 (HTTP). Typically, an acknowledgement (ACK) packet is returned during these conversations to indicate that a packet was correctly received.

Network Capacity

Wireless networks come in many forms, from 900-MHz bridged Ethernet to 38-GHz Microwave. Each of these systems typically interacts with an Ethernet connection (10/100 Mbps). The wireless connection will be either half duplex or full duplex. In a half duplex topology, a master/slave relation exists between the radios, with one of the two units controlling the transmission. The potential throughput between the radio links on the half duplex topology will be different than the potential throughput of directly connecting Ethernet devices via a switch or hub. A full duplex wireless connection tends to produce behaviour that is more closely aligned with local Ethernet connections. The *behaviour* of these wireless links can affect the performance of an Ethernet network, as the wireless link itself is not an Ethernet environment.

Application Bandwidth

The profile, or bandwidth implications of various multimedia, is important when estimating network capacity. To understand the bandwidth required by an application, it is necessary to understand the variables that impact that application. Since much of this is highly technical, only an overview is presented here.

To understand the bandwidth required by an application, it is necessary to understand the variables that impact that application.

As an example, assume that a student is studying an Internet video clip; i.e., playing a news video from BBC or CNN. Some of the technical variables in video are:

- *Packet overhead*—header information in the packets.
- *Video frame size*—number of pixels in each frame; e.g., 640 x 480 pixels/frame.
- *Video frame rate*—number of frames per second; e.g., 29.97 fps, 12 fps.
- *Video colour depth*—8 bit (256 colours) or 24 bit (16 million colours).

Each of these variables has a direct impact on the amount of bandwidth required for the video. For example, a video clip that plays in a format of 640 x 480 pixels will require a significantly larger file, and therefore more network capacity, than the identical clip in a smaller format. A clip that plays in 29.97 frames per second (normal video) will produce a significantly larger file than the identical file shown at 12 frames per second. By tuning these video variables, video distribution sites can tailor clips for the various Internet capacities of end users. A typical student in a school with 56-Kbps service cannot see a video clip that is 640 x 480 at 29.97 frames per second and 24-bit colour, whereas multiple students could watch several such video clips using a 45-Mbps wireless link.

On a network there are fundamental characteristics of service:

- Latency—measured by:
 - Simple round trip time (ping).
 - TCP probe.
 - Actual download.
- Jitter (inconsistency of delay).
- Reliability (uptime).
- Burst capacity (maximum required throughput levels).
- Traffic volume (average required throughput levels).

Transmission delay can be thought of in four categories—packet fragmentation, software delay, buffer hold times and queuing when higher priority traffic is being forwarded. For the purposes of this paper, it is sufficient to note that there are a variety of reasons why an end user's video plays *jerky*.

Much more important than the simple latency of both audio and video applications is the *variability* of latency. Multimedia applications are very time sensitive. Ethernet traffic is *bursty*—there are large variances in the percentage utilization of the network segment. If a video or audio clip is being received and there is a burst of traffic in one of the network segments, the user will quickly perceive the multimedia clip to be unsatisfactory. Multimedia is also prone to poor quality due to network congestion. When segments get very busy, queue depths increase and retransmissions occur. Such events have an immediate impact on the end user's perception of the multimedia stream. Because of the time sensitivity of audio and video applications, network architects are installing devices with *quality of service* (QoS) features that provide guaranteed bandwidth allocations to these specific types of applications.

Much more important than the simple latency of both audio and video applications is the *variability* of latency. Multimedia applications are very time sensitive.

All of the above behaviours occur, not at the physical (wireless) layer, but rather at layers above it. However, this has implications for the wireless wide area network connection. If retransmissions begin to occur, a burdened wireless link becomes even more congested. If a wireless link introduces extra latency, this may be compounded by latency introduced at the layers above.

Internet Traffic Profiles

Each conversation occurs between two applications sending and receiving packets that contain certain protocols and ports. Two examples of these conversations are presented in detail here: HTTP (web browsing) and a multimedia application, MediaPlayer. Remaining multimedia

profiles (RealAudio, RealPlayer-Video, QuickTime, FTP, file copying, etc.) are presented in summary table form (see details in Appendix D).

Web Browsing Profile

Most Internet traffic on an education network is of a *surfing* or HTTP nature (see Figure 5–3). When a user types in a URL address, the first process that takes place is a domain name lookup (DNS). The DNS returns an IP address to the user's browser, which in turn requests the web site from the IP address. Upon successful contact with the destination server at the IP address, multiple two-way conversations are established, using the TCP protocol with source port 80. A homepage usually consists of a composite of pictures, words and other objects. Each picture, frame or other object is downloaded in separate conversations, often concurrently, resulting in a composite of objects forming the homepage.

In the following Dilbert cartoon web site (see Figure 5–3), the cartoon characters have been removed because of copyright requirements. The *payload*, the cartoon that would appear in the gray box, comes from the Dilbert site and comprises part of the total number of bytes transferred. Many of the other pictures, advertisements and objects come from various other sites, notably sites dedicated to furnishing advertising.



FIGURE 5–3: HTTP HOMEPAGE FOR DILBERT CARTOON

Figure 5–4 demonstrates the overall distribution of packet sizes on the network resulting from browsing the Dilbert homepage. Packet sizes on an Ethernet may be between 64 bytes and 1518 bytes in length, but the majority of packets on the network are small (64- to 255-byte packets).

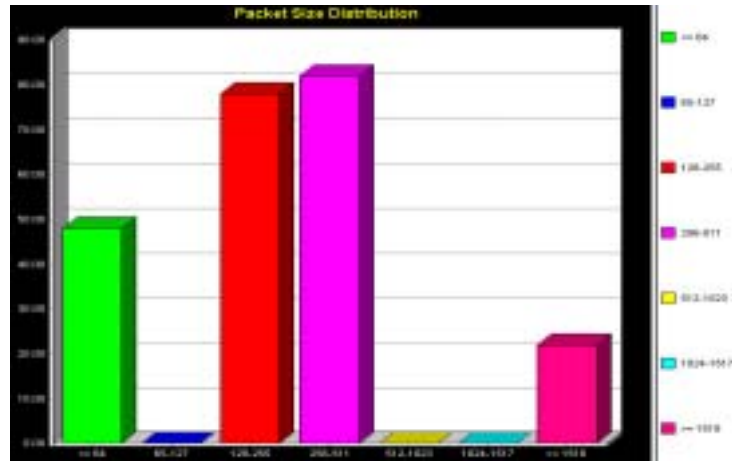


FIGURE 5–4: OVERALL HTTP PACKET SIZE DISTRIBUTION

A more refined analysis suggests that there is a difference in the packet size distribution, depending on whether one examines upstream or downstream traffic. This may seem irrelevant. However, findings suggest that half duplex wireless radios are asymmetric in performance—they demonstrate poorer performance when sending in one direction than in the other. For most half duplex radios, upstream packets (user to server) will demonstrate weaker throughput performance than downstream packets (target server to user). One may therefore anticipate different packet size distributions and different quantities of data for the downstream packets. The downstream HTTP traffic for the Dilbert homepage is illustrated below (Figure 5–5).

For most half duplex radios, upstream packets (user to server) will demonstrate weaker throughput performance than downstream packets.

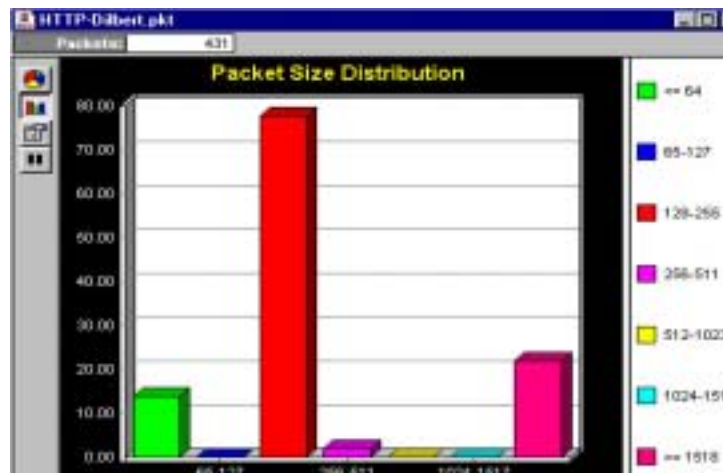


FIGURE 5–5: DOWNSTREAM HTTP PACKET SIZE DISTRIBUTION

- Downstream packet distribution:
 - 19% were 1518 bytes.
 - 2% were 256–511 bytes.
 - 67% were 128–255 bytes.
 - 12% were 64 bytes.
- Downstream capacity was 5343 bytes/sec (42.7 Kbps).
- Upstream packet distribution:
 - 70.2% were 256–511 bytes.
 - 29.8% were 64 bytes.
- Upstream capacity was 3518 Bps (8.8 Kbps).

The Dilbert site (209.67.27.69) was atypical in the downstream packet size distribution. Most downstream HTTP conversations have the highest packet percentage as 1518 bytes. As Figure 5–4 illustrates, the Dilbert web site had the highest category in the 128- to 511-byte range. Upstream packet sizes generally consist of smaller frame sizes.

Students in a school setting typically visit news sites such as CNN <http://www.cnn.com>. CNN is a very complex site that contains a great deal of breaking news, multimedia clips (both video and audio) and advertising. Tables 5–2 and 5–3 at the end of this chapter provide information on overall packet distribution and data transfers. A description of network activity when visiting the CNN site follows:

- Downstream packet distribution:
 - 38.6% were 1518-byte frames.
 - 2.5% were 1024- to 1517-byte frames.
 - 6.5% were 512- to 1023-byte frames.
 - 10% were 256- to 511-byte frames.
 - 4.5% were 128- to 255-byte frames.
 - 35.3% were 64-byte frames.
- Downstream capacity was 18,379 bytes/sec (2.25 Kbps).
- Upstream packet distribution:
 - 13.1% were 256- to 511-byte frames.
 - 13.1% were 128- to 255-byte frames.
 - 73.8% were 64 byte-frames.
- Upstream capacity was 2254 Bps (18 Kbps).

The Sydney Morning Herald <http://www.smh.com.au> was listed as a comparison. Tables 5–2 and 5–3 again provide an overview of packet distribution and data transfers. Following is a refinement of the analysis of network traffic when browsing the Sydney Morning Herald web site:

- Downstream packet distribution:
 - 40.3% were 1518-byte frames.
 - 2.5% were 1024- to 1517-byte frames.
 - 5.9% were 512- to 1023-byte frames.
 - 5.9% were 256- to 511-byte frames.

- 14.3% were 128- to 255-byte frames.
- 0.1% were 65- to 127-byte frames.
- 8.4% were 64-byte frames.
- Downstream capacity was 4253 bytes/sec (34 Kbps).
- Upstream packet distribution:
 - 21.4% were 256- to 511-byte frames.
 - 12.9% were 128- to 255-byte frames.
 - 65.7% were 64-byte frames.
- Upstream capacity was 793 Bps (12.8 Kbps).

In most HTTP download profiles, the packets are largely 1518 bytes and 64 bytes, and the upstream profile will be largely 64-byte packets. This profile can be utilized to model HTTP traffic patterns.

MediaPlayer Profile

Microsoft's MediaPlayer, a common multimedia PC application, may be used to play streaming radio. Thousands of radio stations broadcast on the Internet. For this example, an Australian station (4BH Brisbane) was selected. A name lookup was performed to determine its address; <http://www.4bh.com.au> has an IP address of 202.139.233.166.

This station broadcasts in TCP (not UDP) and controls the connection to the user via the use of a *cookie*. The music broadcast is 16 bit, signed and mono (Figure 5–6). A 30-second .wav clip is approximately 1.3 megabytes.

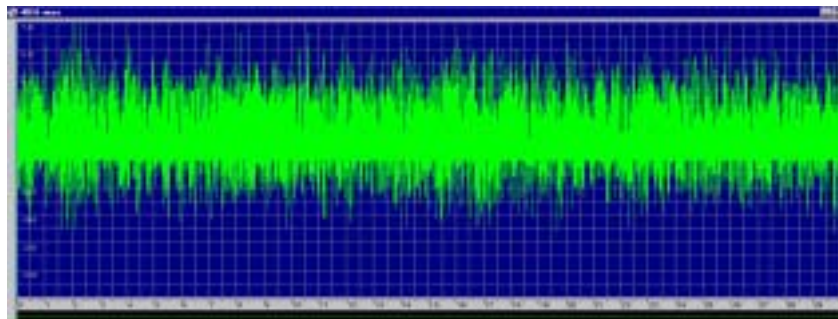


FIGURE 5–6: WAVE FORM ANALYSIS

Traffic on the Internet is dynamic—it varies over time. Examination of the total two-way traffic in the above music broadcast (Figure 5–7) illustrates a low of approximately 1500 bytes per second (Bps) and a maximum of approximately 8800 Bps. The average traffic flow for this sample was 3267 Bps.

Traffic on the Internet is dynamic—it varies over time.

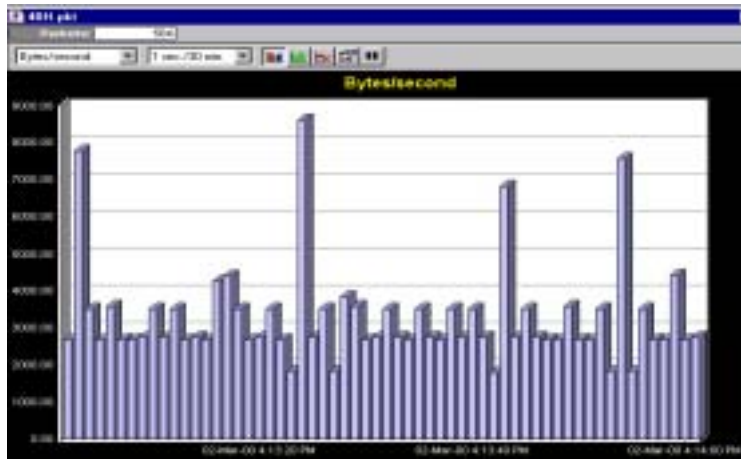


FIGURE 5-7: 4BH RADIO TRAFFIC (Bps)

An ACK packet acknowledges each TCP packet that is received by the user's browser. While the total number of packets in both directions is approximately the same in any given time sample, the total number of bytes in each direction is highly asymmetric, with the user receiving significantly more traffic (in bytes) than the server. This variable traffic pattern is illustrated in Figure 5-6. The entire sample averaged 3084 Bps downstream and 203 Bps upstream (Table 5-1 and Figure 5-8).

MediaPlayer (audio broadcast)	Bps Bytes/sec	pps Packets/sec
Downstream	3084	3563
Upstream	203	3488

TABLE 5-1: TRAFFIC PATTERN FOR MEDIAPLAYER

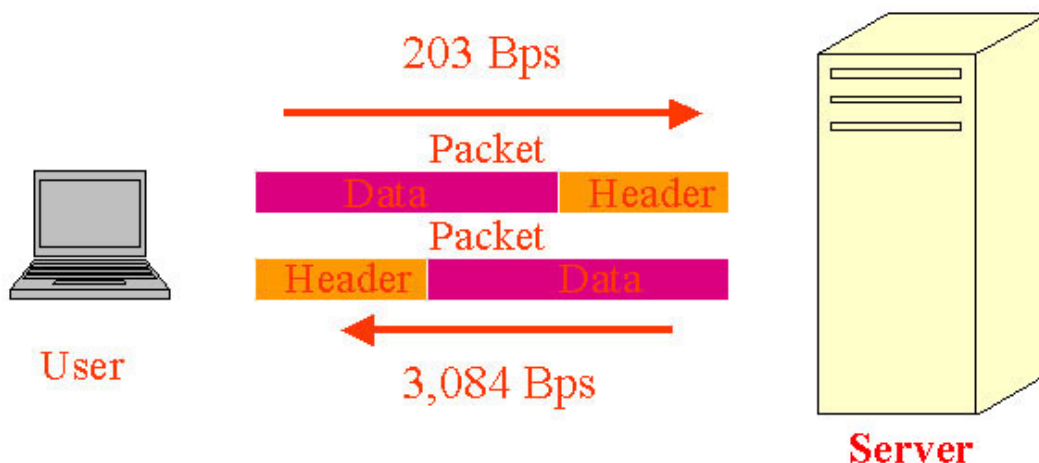


FIGURE 5-8: TWO-WAY MEDIAPLAYER AUDIO BROADCAST

There are also differences in packet sizes (see Figure 5–9). The majority of traffic sent from the user to the server was 58 bytes, which is then padded to the 64-byte minimum. The majority of packets travelling in the other direction, from server to user, were 839 bytes long.

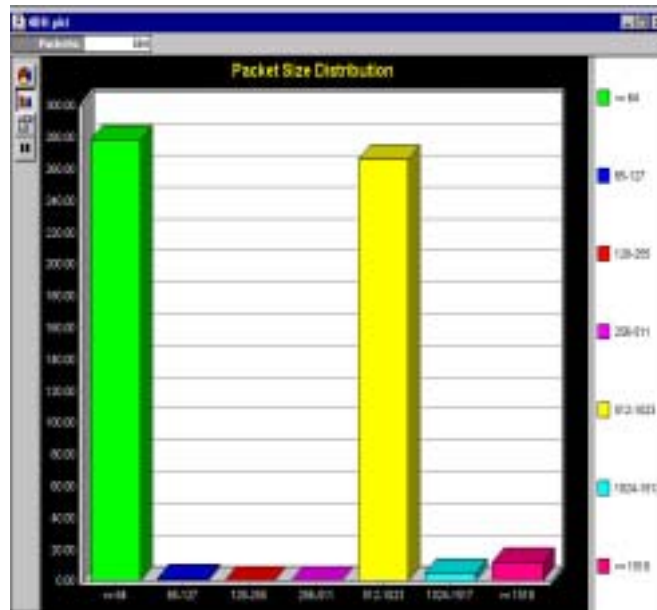


FIGURE 5–9: 4BH PACKET SIZE DISTRIBUTION

Overview of Traffic Profiles

In this chapter, Web HTTP traffic and MediaPlayer traffic were used to illustrate the ports and packet size distributions of two types of Internet traffic. In both cases, a significant percentage of the traffic is of a smaller packet size. The downstream (host to user) packet distribution is quite different than the upstream (user to host) portions of an Internet session. However, all of these packets must cross the same WAN link, independent of the direction travelled.

A significant percentage of HTTP and MediaPlayer traffic is of a smaller packet size.

The following two tables illustrate the packet size distributions (Table 5–2) and total bytes (Table 5–3) for many of the common multimedia and Internet sessions. These tables outline the network profile for various types of Internet activity. For more detailed information on Internet application profiles, see Appendix D.

	Packet Size Distribution							Total
	64	65	128	256	512	1024	1518	
MediaPlayer (audio Broadcast)	47.2%	0.4%		2.6%	24.5%	1.5%	23.8%	100.0%
RealPlayer (audio)	36.7%			0.5%	47.8%	6.6%	8.4%	100.0%
RealPlayer (video)								
FOX News	34.5%	0.2%	0.9%	0.7%	2.7%	3.9%	57.1%	100.0%
ABC	37.0%	0.5%	2.1%	3.9%	9.7%	10.8%	36.1%	100.1%
QuickTime (video)								
Disney 480x360	39.6%						60.2%	99.8%
Disney 240x180	40.1%		0.1%	0.1%		0.3%	59.3%	99.9%
BBC	33.7%	0.6%	4.4%	26.4%	34.0%	0.4%	0.4%	99.9%
CNN	35.2%	1.6%	0.9%	32.0%	13.9%	12.2%	4.1%	99.9%
ftp	38.5%	7.7%					53.8%	100.0%
ftp - web ftp server	32.8%	0.1%	4.8%	4.0%	32.9%	25.4%		100.0%
WinXX file copy	31.4%	2.9%	1.1%		0.7%	1.1%	62.9%	100.1%
WinXX page print (all protocols)	0.8%	0.016	5.0%	1.2%	0.2%	31.1%	60.1%	100.0%
HTTP - Surfing CNN	53.4%	12.5%	1.7%	12.8%	3.4%	1.1%	15.2%	100.1%
HTTP - Surfing zdnet.com (all protocols)	42.4%	8.7%	8.1%	17.3%	4.0%	3.2%	16.4%	100.1%
HTTP - Surfing smh.com (all protocols)	51.4%	10.2%	7.0%	11.3%	1.6%	1.4%	16.8%	99.7%
HTTP - Surfing Dilbert	43.1%	2.1%	19.0%	26.9%		0.2%	8.6%	99.9%
email - receiving large attachments	8.5%				15.2%		76.2%	99.9%
e-mail - receiving 37 small e-mails	71.9%		1.7%		3.5%		22.9%	100.0%

TABLE 5-2: PACKET SIZES OF VARIOUS TRAFFIC TYPES

	Down	Up	Total
	Bps	Bps	Bps
MediaPlayer (audio Broadcast)	24,672	1624	26,296
RealPlayer (audio)	116,824	4104	120,928
RealPlayer (video)	-	-	-
FOX News	173,272	3856	177,128
ABC	74,488	3472	77,960
QuickTime (video)	-	-	-
Disney 480x360	581,312	12,080	593,392
Disney 240x180	559,688	9344	569,032
BBC	89,360	5208	94,568
CNN	49,976	2304	52,280
FTP	362,392	9832	372,224
FTP—web FTP server	521,152	18,096	539,248
WinXX file copy	8,221,864	183,096	8,404,960
WinXX page print (all protocols)	-	-	472,288
HTTP—Surfing (Dilbert)	42,744	28,144	70,888
HTTP—Surfing CNN	147,032	18,032	165,064
HTTP—Surfing zdnet.com	94,728	7512	102,240
HTTP—Surfing smh.com	34,024	6344	40,368
E-mail—large attachment	202,920	9408	212,328
	-	-	-

TABLE 5-3: NETWORK APPLICATIONS TRAFFIC

Profiles can be determined for a number of common Internet applications. With information about the packet size distribution (both downstream and upstream) and the total bytes, it is possible to build a model to examine the impact of various types of application traffic on a WAN connection. For example, on a half duplex wireless link, the 480 x 360 QuickTime video with a downstream capacity requirement of 72,666 Bps (581,312 bps) would fully saturate a 1.5-Mbps connection with only 2.65 streams. The information provided in this chapter provides a basis for thinking about such a model.

CHAPTER SIX

STUDY FINDINGS

Participating school jurisdictions provided a test-bed yielding information about the performance of 20 different network links that represented a breadth of technologies, networking environments and geographic locations. Thus, information was obtained about throughput, packet loss, latency, streaming and videoconferencing.

Overall Network Design

Each network has specific requirements and a specific environment. It has particular types of traffic, areas of concentrated traffic, an anticipated network lifespan, specific geography, an environment over which the network must operate and, naturally, a given amount of available capital to implement and operate the network. Thus, a one-size-fits-all approach is not possible. However, a few suggestions and recommendations can be offered on network design, network planning and associated technologies.

Demand for network bandwidth has grown significantly over the past half-decade and it is expected that the demand for future network bandwidth will continue at a heightened pace. Bandwidth that satisfies information needs today likely will not be sufficient tomorrow. Wide area networks are frequently a bottleneck. Hence, scalability and reliability of any wide area networking solution are important considerations.

Bandwidth that satisfies information needs today likely will not be sufficient tomorrow.

Wireless Network Design

Figure 6–1 presents a general model for thinking about effective wide area network planning. At the core of the network sits centralized sites such as the jurisdiction central office and larger school sites. Ideally, these buildings are sufficiently close to each other to have fibre optic cable laid between them. In turn, these sites are connected via a microwave wireless backbone to sites further out from the core. Even further out, several remote, smaller sites may be connected via spread spectrum wireless under specific circumstances.

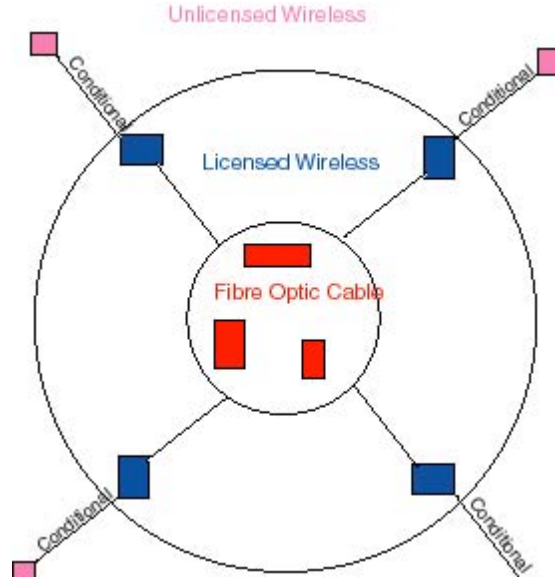


FIGURE 6-1: A GENERAL MODEL FOR PLANNING WIDE AREA NETWORKS

This model accommodates high traffic flows in the core area and provides maximum scalability. It assumes that each of the core sites will remain in place over an extended period of time, warranting an investment in fibre optic cable and thus justifying this expenditure to serve over a significant time frame. Fibre optics provides significant initial bandwidth, the capability of full duplex transmission, scalability over a very long time frame, reliability and economic viability across a significant time horizon.

One or more of these core areas is connected to the next layer via a microwave wireless layer. This serves as the backbone out from the core. While fibre optics provides the option of moving up to several gigabits of data per second, microwave will provide the option of up to several hundred megabits per second. Microwave wireless provides a longer term solution to bandwidth needs and remains less costly than laying fibre optic cable over extended distances. Microwave wireless provides significant initial bandwidth, the advantages of full duplex transmission, reliability, a long-term lifespan and scalability to ensure bandwidth for the future. This solution avoids the expensive ongoing upgrade cycles that can occur with low bandwidth solutions—especially solutions with variable performance metrics. Required licensing provides assurance that the investment will not deteriorate in value as others begin to use the same frequencies.

At the outer layer of this model are sites with lower bandwidth demands. These may be remote schools with small student populations in communities that are not expected to grow over the planning cycle and do not require advanced applications. Spread spectrum may serve as a meaningful solution in this *last mile* scenario, but with some conditional considerations. First, such a solution assumes that high-end applications (i.e., multimedia or real-time video) will not be required for these sites during the planned cycle. Given the rapid changes in demand for technologies, this may not be a safe assumption. Second, it assumes that such sites are sufficiently isolated that the use of an unlicensed frequency presents less risk of radio interference from others also using the same unlicensed band. Third, it assumes that, rather than relying solely on advertised throughput, the wireless devices are tested across a breadth of frame sizes to provide a full understanding of throughput capability. Although vendors may

advertise a given throughput level, such suggestions typically represent large frame size throughput rather than the predominant small frame sizes that make up the traffic on an educational network. Variance within and across bridged Ethernet spread spectrum solutions requires testing to enable effective decision making if such products are purchased.

In summary, use fibre optic cabling whenever it is affordable. Use microwave radio to reach all other sites, creating a backbone out to all core communities. Use spread spectrum bridged Ethernet where necessary to trim costs, recognizing the risks and the reduced level of service. Further decision points are discussed in Appendix E (Wireless and Fibre Options: Planning Questions). As well, a planning checklist is available in Appendix F to guide the reader through the major steps in planning a wireless network.

Use fibre optic cabling whenever it is affordable. Use microwave radio to create a backbone out to all core communities. Use bridged Ethernet where necessary, recognizing the risks and the reduced level of service.

Limit LAN Traffic from Reaching the WAN

As a general rule, it is fair to say, “If the traffic doesn’t need to be on the WAN, then try to avoid letting it on the WAN.” Wide area networks are typically the bottleneck in networked environments; to preserve bandwidth, permit traffic on the wide area network only if it truly needs to be there.

“If the traffic doesn’t need to be on the WAN, then try to avoid letting it on the WAN.”

One way to achieve this goal is through the use of Layer 3 routing protocols. The impact of local area network traffic on the WAN can be minimized by placing a router, a Layer 3 switch or an ATM switch capable of routing Layer 3 protocols at the exit point of the wide area network. Some of the newer wireless radios incorporate Layer 3 routing protocols.

Historically some large networks, both educational and non-educational, have been built using only bridges (Layer 2) to separate the smaller networks. Such a design can cause serious side-effects, ranging from slow-downs to having available bandwidth consumed in broadcast storms. A broadcast storm occurs when a broadcast packet is forwarded more times than it should be (see Appendix G for a full definition). Including Layer 3 routing at the exit point from each building to the WAN provides a mechanism for controlling traffic and keeping it local if it does not need access to the WAN. As an example of this, in one school jurisdiction site, the wireless connection was problematic. It was found that the wireless link likely was not the problem, but rather having specific protocols *leaking* into the WAN link.

To achieve the desired level of quality across a wireless link, particularly for time-sensitive real-time traffic (i.e., voice or video applications), some form of quality of service (QoS) management is required. QoS management may be attained through asynchronous transfer mode (ATM) or through a routed quality of service protocol such as DiffServ or MPLS (multiprotocol label switching). ATM focuses on providing quality of service features for voice, video and data on an end-to-end basis. Provisions can be made through ATM for specific paths to handle specific traffic with specific qualities of service, as shown in Figure 6–2.

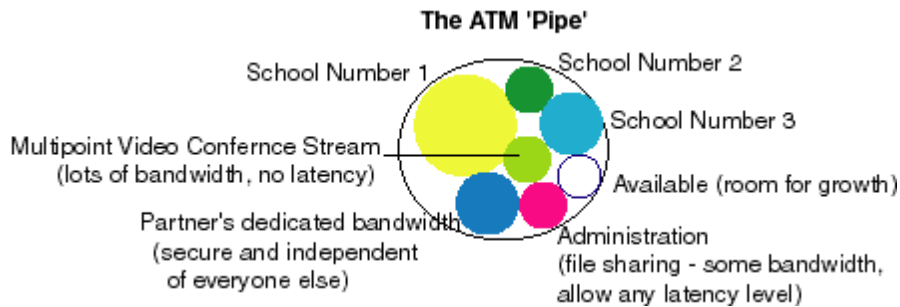


FIGURE 6-2: THE ATM PIPE

As an alternative to ATM, routed quality of service protocols can be used to meet QoS demands through decision making on a packet-by-packet basis. Different types of traffic are given different levels of priority, and decisions are made on the basis of the priority levels associated with the traffic. A full discussion of QoS is beyond the scope of this paper, but additional information is available at <http://www.atmforum.com> and <http://cne.gmu.edu/~sreddiva/Texttut.html>, or in the book *QOS in Wide Area Networks* by Uyles Black.

To achieve the desired level of quality across a wireless link, some form of quality of service (QoS) management is required.

Jurisdictions are encouraged to contract knowledgeable resource personnel who can help to guide the design of networks as required.

Towers

Towers may be installed in accordance with the needs and the location. School jurisdictions are advised to use Canadian Standards Association (CSA) approved towers when constructing large stand-alone or guyed towers. Meeting the CSA requirements provides some assurance that structures, particularly those placed in school yards, are safe.

The cost difference between CSA approved and non-CSA approved towers is fairly significant—but not relative to safety considerations and subsequent liability issues.

Sometimes, school authorities can take advantage of existing structures to extend the reach of the antenna. For example, an antenna may rest on a pipe mount on a high point of the school. Such construction should receive an engineer's seal, again as insurance that the structures are safe for school environments.

Additionally, anti-climb devices for towers should be considered—particularly for towers mounted at school sites. These devices, which prevent unauthorized scaling of the outside and inside of the tower, may need to be added above the roof line to prevent climbing the tower from the roof. The devices may be made of fine mesh or sheet metal, but wind loading on the tower needs to be considered.

Testing Wireless Radios and Links

It is often difficult to demonstrate the actual throughput of a given wireless link. Network managers typically conduct an FTP (file transfer protocol) session or simply copy across a large file from one system to another over the wireless link to gain a sense of its performance.

This approach may answer questions regarding throughput for large frame sizes, but fail to accommodate an understanding of the link's true performance ability across frame sizes and consequently its performance with other applications.

As new wireless radios are brought to market, independent testing needs to be conducted in the field to demonstrate actual throughput across frame sizes. This would serve both planners and those who are already using wireless solutions, but are looking at various upgrading alternatives.

As new wireless radios are brought to market, independent testing needs to be conducted in the field to demonstrate actual throughput across frame sizes.

Also, as jurisdictions install wireless networks, again, they should conduct tests across various frame sizes. This testing will provide:

- Assurance that the network is capable of producing expected performance levels.
- A baseline for future comparisons if a wireless link is not *behaving* as well as previously; i.e., "Is this a wireless issue or a Layer 2/Layer 3 issue?"
- A basis for determining whether further investment would be wise.

As jurisdictions install wireless networks, they should conduct tests across various frame sizes.

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APPENDIX A

AN INTERVIEW WITH INDUSTRY CANADA

Stephen Williams and David Smith of Spectrum Management and Telecommunications, Industry Canada, spoke with the researchers about wireless networks, licensing and the use of wireless in the education sector.

What are some of the most important things to consider when building a wireless network?

Involving consulting engineers early in the design process will ensure appropriate levels of reliability and performance. Most microwave systems in Canada are designed to have *five nine's* (99.999%) reliability. Each hop has a 10 to the minus 13th bit error rate (BER). When measured as a whole, the entire system from end-to-end has a 10 to the minus 6th bit error rate.

Also, building the backbone of the network with licensed frequencies will protect the investment. As the licensed user of the frequency, you have some assurances that your network will not face interference over time.

Are there advantages to using a licensed bandwidth, given that unlicensed frequencies are available?

If you choose to use licence-exempt equipment, you will be sharing frequencies with a number of other unlicensed users, and you will not be offered any protection from their systems. The situation for licensed microwave systems is much different. If there is a possibility of harmful interference between a proposed system and an existing system, Industry Canada asks the applicants to coordinate their proposal with those of existing users. The purpose is to resolve possible problems before they happen.

Some licensed frequency bands are no longer being used in congested areas of the province. The commercial providers have set aside this equipment, and there may be opportunities for educators to use this equipment in areas that are remote and less congested.

What is Industry Canada's involvement in the event that others are affecting a licensed frequency?

Users of licensed microwave systems are required to coordinate their systems with each other. If a licensee experiences harmful interference from an unknown source, Industry Canada will promptly investigate it.

What is Industry Canada's involvement in the event that others are affecting an unlicensed frequency?

Industry Canada does not typically investigate interference complaints by users of the licence-exempt frequency bands, as they are intended to be shared by a large number of users and products.

Are there any risks in using a licensed frequency?

Very occasionally, some bands are reallocated, but even in these circumstances ample time is given to make changes. Generally, however, the useful lifespan of the system is exceeded before such a change is required.

Can you provide some clarification on specifically which bands do not require licensing?

Three unlicensed frequencies are available: the 915-megahertz (MHz), 2.4-Gigahertz (GHz) and 5.8-GHz bands. Licensing requirements depend on specifics within that band. The 915-MHz band refers to 902 to 928 MHz. This band is always unlicensed and is currently very full. It operates at a maximum of one watt and a maximum of four ERP watts. Avoid using this band at radar sites, as it can have serious consequences on the radio transceivers.

The 2.4-GHz band is actually divided into three different bands, which in turn specifies the licensing requirements. In the 2.400 to 2.45 range, licensing is required, no matter what power level is supplied. In the 2.450 to 2.835 band, if one is using greater than four watts of transmitter power (to a maximum of 200 watts ERP), then it must be licensed with Industry Canada. If, however, one is using less than four watts of power within the same band (2.450 to 2.835), then no licences are required.

The 5.8-GHz band is relatively new. It operates in the 5.6- to 5.8-GHz range. To date, few vendors have been supplying equipment within this band, and it has been slow to grow. It can have a maximum of a one-watt transmitter, but there is no maximum on radiated power, so one is able to use an antenna of any size.

There seems to be some ambiguity about towers and requirements associated with towers. Does Industry Canada play a regulatory role with regard to towers?

Industry Canada is responsible for regulating all radio communications in Canada, and for authorizing the location of towers. We recognize that the local community should be given the opportunity to influence the final location of significant towers, so applicants who are proposing a new or modified tower are required to consult with the local land-use authority. More information about this is available on our web site at <http://strategis.ic.gc.ca/SSG/sf01702e.html>.

Industry Canada encourages all applicants to share towers whenever possible. We would encourage you to work with the commercial sector to seek out cooperative ventures. Constructing a new tower is very expensive, and the educational sector may be in a good position to obtain space on existing towers in exchange for the benefit of being able to advertise the donated assistance.

Nav Canada <http://www.navcanada.ca/> manages the specifications with regard to tower lighting and colouring. The regulations are for aeronautical safety, and are location-dependent rather than specific to given heights. For example, a tower of 25 feet may be of serious concern when located next to an airport, whereas a 90-foot tower in a remote part of the province may be of little concern.

As a summary question, I would like to learn of Industry Canada's perception of the education sector. Historically, Industry Canada's Spectrum Management has focused on working with commercial and industrial enterprises. Can you give me a sense of Industry Canada's interest in serving the public sector and more specifically the education sector?

Industry Canada is very supportive of the educational sector in applying for licensed bandwidth ranges. Our department also has a number of programs that benefit the education sector. For example, SchoolNet offers interactive computer-based learning and research collaboration. Information about this and other programs is available online at <http://www.connect.gc.ca/>.

APPENDIX B

VENDOR WEB SITES

Vendor Matrix

This list is by no means complete nor is it an endorsement or recommendation of any product. This list is presented as a starting point for additional research into wireless networking products.		
Vendor Name	Product Type	Web Site
Adtran	T1/E1 Modems	< http://www.adtran.com >
Aironet	Ethernet Bridge	< http://www.aironet.com >
Alcatel	T1/DS-3	< http://www.alcatel.com >
Breezecom	Ethernet Bridge—T1	< http://www.breezecom.com >
DMC Stratex Networks	T1/DS-3	< http://www.dmc.dmcstratexnetworks.com >
Harris	T1/DS-3	< http://www.harris.com >
Nortel	T1/DS-3	< http://www.nortel.com >
Proxim	Ethernet Bridge	< http://www.proxim.com >
Solctek	Ethernet Bridge	< http://www.solctek.com >
SpeedLan	Ethernet Bridge—T1/E1	< http://www.speedlan.com >
WaveLAN	Ethernet Bridge	< http://www.wavelan.com >
WaveRider	Ethernet Bridge	< http://www.waverider.com >
Western Multiplex	Ethernet Bridge—T1/E1	< http://www.wirelessinterconnect.com >
Wi-LAN	Ethernet Bridge	< http://www.wilan.com >

APPENDIX C

WEB RESOURCES

Colin Seymour's Spread Spectrum Page
<<http://www.users.dircon.co.uk/~netking/spread.htm>>

Spread Spectrum Scene Online
<<http://www.sss-mag.com>>

The Institute of Electrical and Electronics Engineers, Inc.
<<http://www.ieee.org>>

The Wireless LAN Alliance
<<http://www.wlana.com>>

Transport Canada
<<http://www.tc.gc.ca>>

Welcome to the Wireless Ethernet Compatibility Alliance
<<http://www.wirelessethernet.org>>

Microwaves—A Brief Introduction
<<http://www.wa1mba.org/MICROS.HTM>>

Wireless RF Systems
<<http://www.cs.berkeley.edu/~suchi/classes/mobile/NOTES/notes.html>>

APPENDIX D

INTERNET APPLICATION PROFILES

Streaming Video

Newscasters as well as other sites are making increasing use of streaming video. Major software for this application includes RealPlayer for video, Windows MediaPlayer and QuickTime. The larger the picture size, the higher the colour depth. The higher the frames per second, the greater the bandwidth required for viewing streaming video (Figure D–1).



FIGURE D–1: RELATIVE MOVIE SIZES

The area of multimedia is rapidly changing. Synchronized multimedia integrated language (SMIL) recently became available for both QuickTime and Real. This is an emerging standard for interactive media.

On June 12, 2000, Real and Apple announced that Real was building support for QuickTime streaming format into RealServer 8. Real further announced support in version 8 for MP3 and *animation overlaid on video*. The reader is therefore cautioned that the information provided in this publication will become less and less complete as these new applications emerge. Further investigation of the network profiles of these new technologies will be warranted.

RealPlayer—Video

The summary information for streaming video through RealPlayer is show in Table D–1. RealPlayer video is composed of an audio stream and a video stream. The sum of both the audio and video stream is the bandwidth required for this application.

RealPlayerG2 (video)	Bps Bytes/sec	bps Bits/sec	Ports PC	Ports Host
176x132 Down	9609	78,872	554	4889
178x132 Up	285	4889	4889	554
FOX News Down	21,659	173,272	554	1112
FOX News Up	482	3856	1112	554
ABC Down	9311	74,488	554	1317
ABC Up	434	3472	1317	554

TABLE D-1: REALPLAYER BANDWIDTH SUMMARY

- Sources:
 - Rochester.real.com for ABC.
 - Ticonderoga.real.com for FOX.
- Downstream packet sizes:
 - Test 1: 82% were 1518 bytes; 7% were 1024–1517 bytes.
 - Test 2: 58% were 1518 bytes; 17% were 1024–1517 bytes; 14% were 512–1023 bytes.
- Upstream packet sizes ~98% were 64 bytes.
- Like RealAudio, dynamic bandwidth is reset on regular basis.

QuickTime

QuickTime, first developed by Apple but put into the public domain, is a widely utilized application. QuickTime software is required to run the Macintosh file type *MooV* or Windows file extensions *.mov* or *.qt* (MIME type video/quicktime).

QuickTime (video)	Bps Bytes/sec	bps Bits/sec	Ports PC	Ports Host
ToyStory Disney				
480x360 Down	72,664	581,312	80	1266
480x360 Up	1510	12,080	1266	80
240x180 Down	69,961	559,688	80	1298
240x180 Up	1168	9344	1298	80
BBC Down	11,170	89,360	80	3610
BBC Up	651	5208	3610	80
CNN Down	6247	49,976	80	3652
CNN Up	288	2304	3652	80

TABLE D-2: REALPLAYER VIDEO STREAM



FIGURE D-2: QUICKTIME—BBC WORLD LIVE



FIGURE D-3: TOY STORY OUTTAKE IN QUICKTIME

This movie was 2.6 MB in two components—2.3-MB video stream operating at 122.2 Kbps and 201.8 KB of audio operating at a data stream rate of 15.5 Kbps. The total stream for this movie trailer was 137.8 Kbps. This is the rate at which the clip was encoded to play.

RealAudio

RealAudio (.ra) and RealVideo are played on a proprietary software package from Real.com <<http://www.real.com>>. The download page offers free public versions, as well as enhanced versions available for a fee.

A real audio hotlink, *Diva Duet* (Figure D-4) was selected for this example. The destination for this music clip was redirected to thomson-1.real.com (207.188.7.102).



FIGURE D-4: REALPLAYER FOR AUDIO

An analysis of the traffic received during this session (Figure D-5) clearly illustrates a gap (the space between the bars) due to other Internet activities, followed by a peak of approximately 53,000 Bps. The average of the downstream sample was 14,603 Bps (116,824 bps). The actual average approximates the metric from the RealPlayer bandwidth tab, indicating that it is a reasonable metric to use for bandwidth purposes.

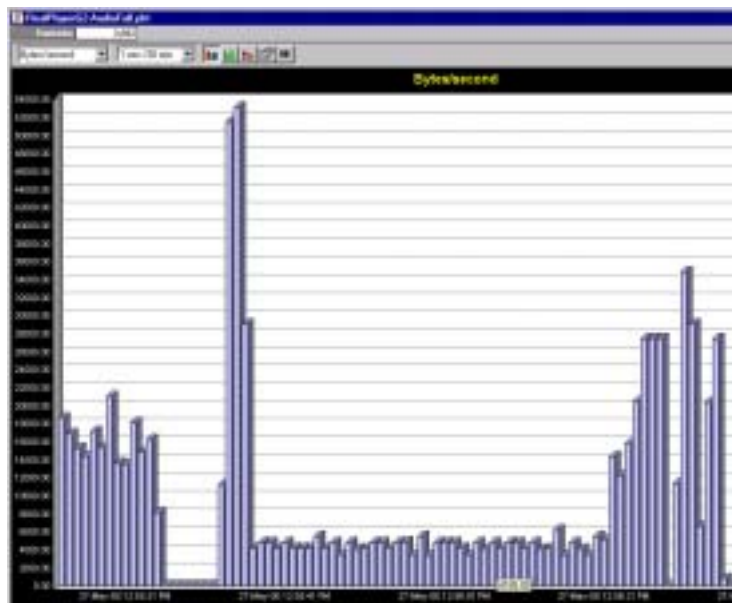


FIGURE D-5: REALPLAYER AUDIO CAPACITY SAMPLES

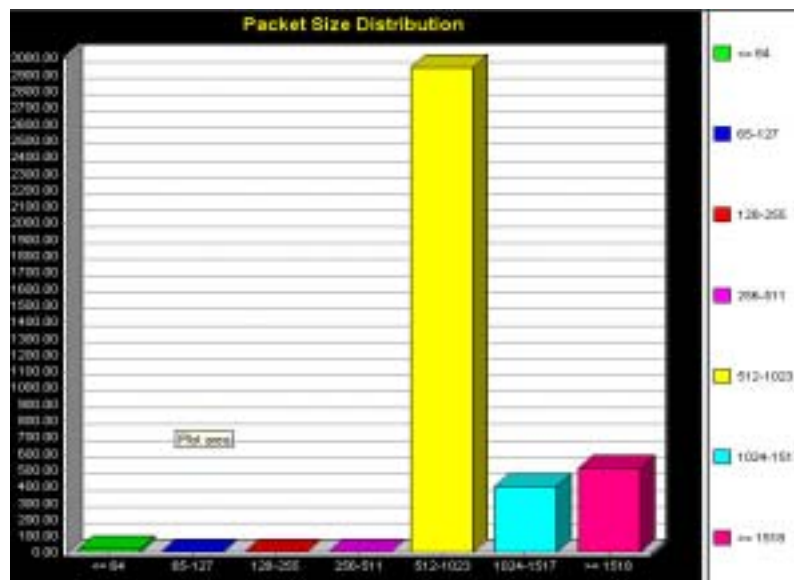


FIGURE D-6: REALPLAYER DOWNSTREAM PACKET SIZE DISTRIBUTION

Since the audio downstream (Figure D-6) contains much information the packets are relatively large. In this case 13% of the packets were 1518 bytes, 10% were between 1024 and 1518 bytes and 76% were between 512 and 1023 bytes. This distribution will vary widely during different times of the day as various parts of the network are congested.

- RealPlayer utilized ports 554 from the host and 1630 at the user PC.
- The traffic was highly asymmetric, with 96.6% of the total bytes downstream and 3.4% of the total bytes upstream.

An interesting observation was made while analyzing the detailed RealPlayer video packets. At regular intervals, approximately every 10 seconds, packets that were larger than the rest were sent upstream (Figure D-7).



FIGURE D-7: LARGE PACKET UPSTREAM

In the packet detail (Figure D-7), note the bottom frame of the figure. This is the hex data that actually comprises the packet. In this section there are hex characters on the left and the ASCII equivalent on the right. The notation *Bandwidth=122163* near the bottom represents a dynamic setting of the bandwidth from within the ACK packet. In other words, the application is regularly checking on the *end-to-end* bandwidth capacity and making dynamic adjustments to the speeds of the data stream.

RealPlayer (audio)	Bps Bytes/sec	pps Packets/sec	Ports PC	Ports Host
Downstream	14,603	14,362	554	1630
Upstream	513	8384	1630	554

TABLE D-3: REALPLAYER—AUDIO SUMMARY

File Transfers

A number of types of file transfers can take place over a network. These include:

- A *copy and paste* via the Windows GUI interface.
- A file download from a server on a network to a computer using the FTP protocol.
- A file transfer from a server over the Internet using FTP.
- A file transfer through HTTP.

File Transfer Protocol—FTP

To minimize network variables, a cable modem in a private home was used to transfer files to and from a school jurisdiction network. The maximum upstream bandwidth was 1 Mbps while there were very few hops in the connection. Most applications attempt to be as close to the maximum 1518-byte packet as possible with each packet being verified by an ACK packet.

- File transfers, and certainly FTP file transfers, attempt to use all the available bandwidth. In other words, if there is a T1, the transfer will attempt to use all of the T1. Limiting factors tend to be the server and client performance, and any network hops that are slower.

FTP	Bps Bytes/sec	bps Bits/sec	Ports PC	Ports Host
Host to PC	45,299	362,392	20	2859
PC to Host (ACK)	1229	9832	2859	20

TABLE D-4: FTP FILE TRANSFER

Note: Normal FTP occurs between ports 20 and 23. Higher port numbers are negotiated through the FTP process.

- Downstream packet sizes were almost all 1518 bytes.
- Upstream packet sizes were almost all 64 bytes.

The maximum upstream cable modem speed is 1 Mbps (125,000 Bps). The observed throughput (Table D-4) was much lower than this theoretic maximum. This was likely due to congestion on the network.

File Copy/Paste

To eliminate various segments of the network as variables, the researchers performed a Windows file copy/paste through a single Ethernet network segment. This was not an FTP session. It utilized the file transfer TCP NetBIOS (port 139). There is a measurable amount of extra protocol traffic when this type of file transfer occurs, as illustrated in Figure D-8.

Source Node	Destination Node	Protocol	Bytes	Packets
ServerIP	ClientPC	TCP NetBIOS	21,976,985	14,813
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP NetBIOS	21,976,985	14,813
ServerIP	ClientPC	TCP MB SessMsg	2,228,189	1,497
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB SessMsg	2,228,189	1,497
ServerIP	ClientPC	SMB Rdx	1,176,450	775
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	SMB Rdx	1,176,450	775
00:C0:4F:27:FD:8B	00:80:5F:31:B1:11	TCP MB SessMsg	498,510	8,595
ClientPC	ServerIP	TCP MB SessMsg	498,510	8,595
ServerIP	ClientPC	TCP MB DU Dgram	149,005	99
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB DU Dgram	149,005	99
ServerIP	ClientPC	TCP MB QryReq	144,251	97
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB QryReq	144,251	97
ServerIP	ClientPC	TCP MB PQRsp	130,348	87
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB PQRsp	130,348	87
ServerIP	ClientPC	TCP MB DG Dgram	129,820	87
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB DG Dgram	129,820	87
ServerIP	ClientPC	TCP MB BC Dgram	127,292	84
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB BC Dgram	127,292	84
ServerIP	ClientPC	TCP MB PResp	115,738	79
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB PResp	115,738	79
ServerIP	ClientPC	TCP MB Err	100,251	69
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB Err	100,251	69
ServerIP	ClientPC	TCP MB RpaIv	95,388	66
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB RpaIv	95,388	66
00:C0:4F:27:FD:8B	00:80:5F:31:B1:11	SMB Rdx	95,038	779
ClientPC	ServerIP	SMB Rdx	95,038	779
ServerIP	ClientPC	TCP MB SessReq	94,995	64
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB SessReq	94,995	64
ServerIP	ClientPC	TCP MB NResp	93,676	62
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB NResp	93,676	62
ServerIP	ClientPC	TCP MB MQRsp	79,177	53
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB MQRsp	79,177	53
ServerIP	ClientPC	TCP MB RResp	77,659	52
00:80:5F:31:B1:11	00:C0:4F:27:FD:8B	TCP MB RResp	77,659	52
ServerIP	ClientPC	SMB X2IO	1,290	6

FIGURE D-8: FILE COPY/PASTE PROTOCOLS

In this diagram, only the *ServerIP* and *ClientPC* lines are significant. The MAC traffic listed is a duplicate due to the capture software.

File Copy	Bps Bytes/sec	bps Bits/sec	Ports PC	Ports Host
Host to PC	1,027,733	8,221,784	2125	139
PC to Host (ACK)	22,887	183,096	139	2125

TABLE D-5: FILE COPY UTILIZING CUT AND PASTE TOTAL TWO-WAY TRAFFIC

- The average throughput of 8.221 Mbps (82.2%) is largely at the maximum capacity of a 10-Mbps link.

File Copy Through a Wireless WAN

A file copy (Table D-9) through a *standalone* Ethernet segment provided an average of 8.2 Mbps. The question arises, “What would the same process yield over a wireless WAN link?” This test involved a school server over a bridged Ethernet spread spectrum 2-Mbps wireless link that operated through a repeater. The topology was: server to wireless at school, wireless—wireless store and forward at a repeater tower, and wireless at jurisdiction office to a PC client. Figure D-9 shows bytes received at the destination PC.

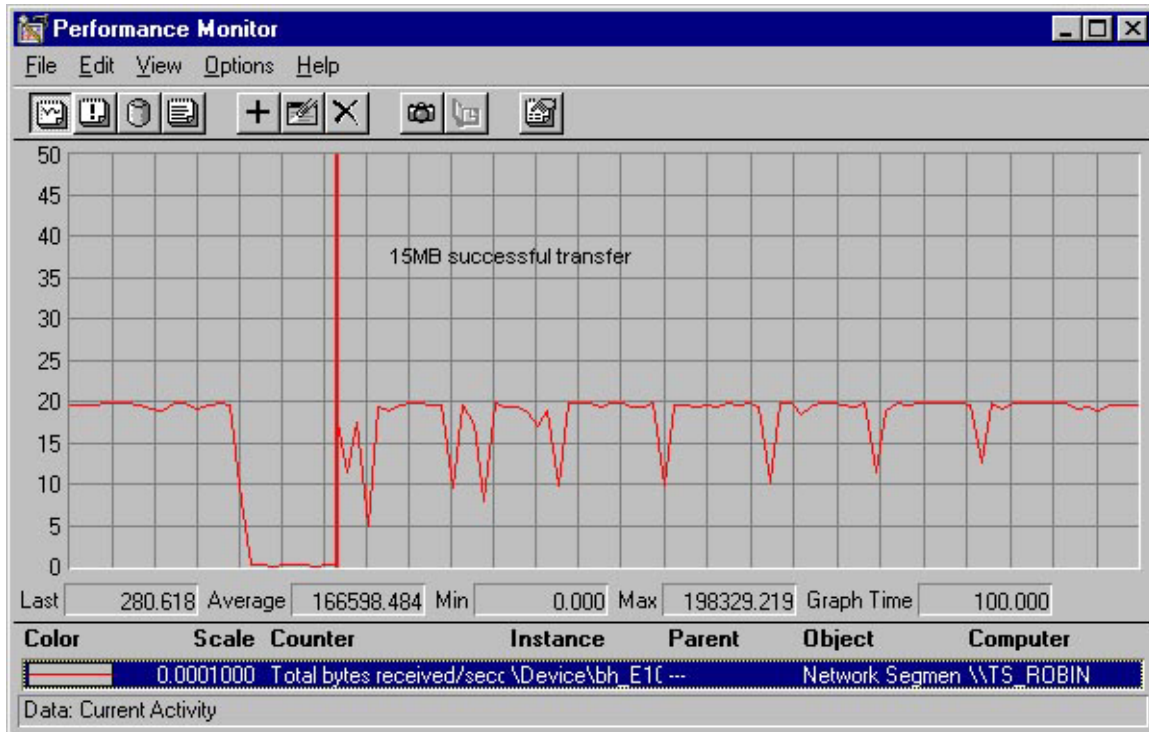


FIGURE D-9: FILE COPY THROUGH A 2-Mbps WIRELESS

In this test, a 15-MB file was copied from a server to the local PC. As indicated in the performance monitor graph (Figure D-9), the sustained throughput averaged 166,598 Bps (~1.33 Mbps). The average displayed is the sample over the 100-second window and was lowered by approximately 10 seconds when there was no network traffic (the drop in the graph before the vertical indicator line). The maximum rate was 198,329 Bps (~1.59 Mbps). This rate was sustained except for the *dips* noted in the graph. The downstream payload on this 2-Mbps store and forward topology was approximately 1.59 Mbps (79.5% of rated capacity).

Note: This type of application utilizes the maximum packet sizes of 1518 bytes for downstream traffic and therefore illustrates the best throughput possible. This does not represent a mixed Ethernet segment carrying Internet traffic, such as web sites or e-mail.

FTP Download from a Web FTP Server

A file download from a web FTP server is a common way for users to obtain software. The FTP protocol first establishes a session via port 21. Upon successful negotiation of the connection, the file is downloaded via higher numbered ports.

FTP	Bps Bytes/sec	bps Bits/sec	Ports PC	Ports Host
Server to PC	65,144	521,152	3420	43,606
PC to Server (ACK)	2262	18,096	43,606	3420

TABLE D-6: FTP DOWNLOAD FROM WEB FTP SERVER

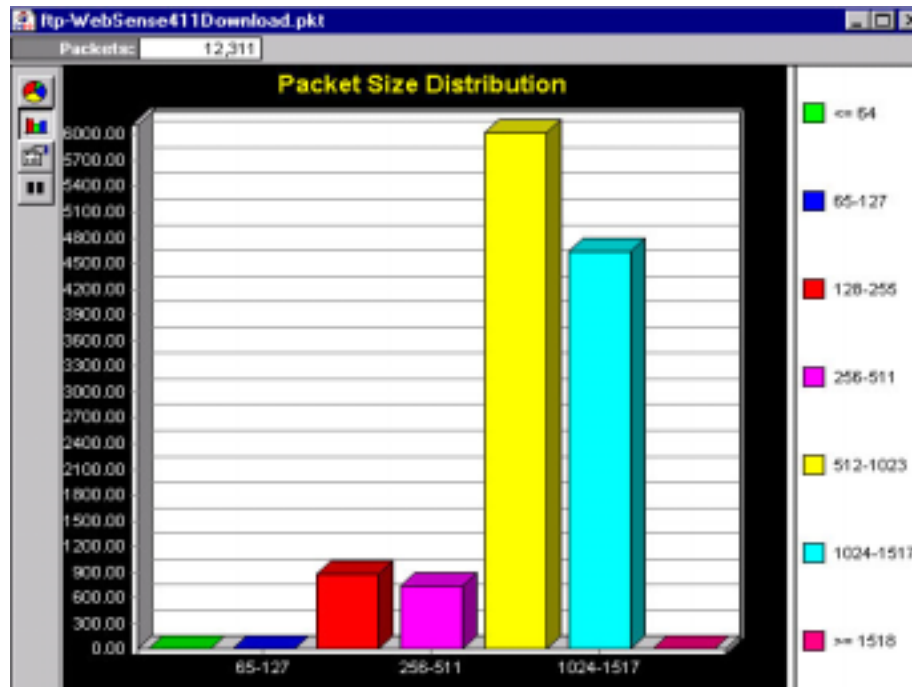


FIGURE D-10: FTP DOWNLOAD FROM FTP WEB SERVER—DOWNSTREAM

- 37.7% of downstream traffic was 1024–1517 bytes; 48.9% was 512–1023 bytes.
- 99.9% of upstream traffic was 64 bytes.
- The total file size of the original download file was 9.036 MB:
 - Total downstream traffic was 9.965 MB.
 - Total upstream traffic was 0.347 MB.

The total downstream traffic was only 110% (9.965 MB + 0.347 MB) of the original file (9.036 MB). The extra 10% accounts for overhead introduced to transfer the file. This illustrates the efficiency of this type of download.

E-mail

Typical e-mail utilizes the SMTP (simple mail transport protocol) and operates on port 25. In many ways e-mail behaves like a file transfer when large files are attached. For this test, a simple text e-mail with large attachments was used. Note that this profile differs significantly from the profile for sending e-mail without attachments.

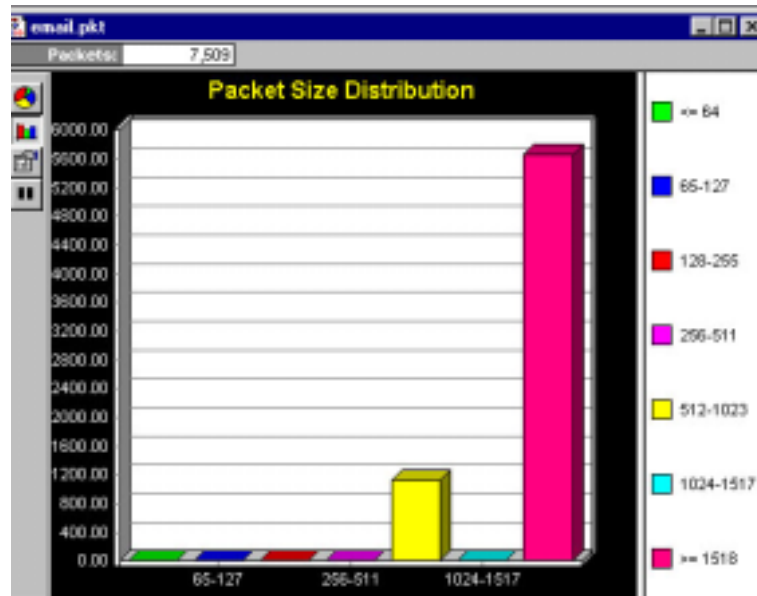


FIGURE D-11: E-MAIL PACKET SIZE DISTRIBUTION

- 83.1% of packets sent were 1518 bytes; 16.6% were 512–1023 bytes.
- 100% of packets received were 64 bytes.
- 25,365 bytes/sec bandwidth being sent; 1176 bytes/sec received.
- Ports 25–1476 were utilized.

Page Print (WinNT 4.0)

To print a page from a Word document to a network printer seems like a simple activity, but printing actually involves many processes and protocols. In an NT environment, a server is usually set up with the print spooling service. The local work station prints to a designated printer but in actuality prints to the print server. The server in turn prints to the network printer. This is accomplished with a variety of TCP protocols (Figure D-12). Printing, as it turns out, is a very verbose set of protocols within NetBIOS and SMB.

Packets received:	4,857
Packets filtered:	2,422
Packets processed:	1,291
Memory usage:	7%

Protocol	Percentage	Bytes	Packets
Ethernet Type 3	0.000%	0	0
IP	0.000%	0	0
TCP	0.000%	0	0
NetBIOS	61.328%	1,158,538	838
Req Ses Req	0.073%	1,374	1
Sess Req	0.073%	1,374	1
10 Dgram	0.088%	1,518	1
20 Dgram	0.083%	1,576	2
1gram Etc	0.153%	2,892	2
SessReq	2.163%	40,870	31
SMB	0.016%	404	3
Class...	0.023%	416	4
Head & X	0.110%	2,074	17
Next...	35.891%	678,042	528

FIGURE D-12: NT WORKSTATION TO SERVER PRINT PROTOCOLS

Work station to server packet sizes (Figure D-13) varied—60% were 1518-byte packets, 31% were 1024-1517 bytes and the remaining packet categories were spread somewhat evenly.



FIGURE D-13: PRINT PAGE PACKET SIZE DISTRIBUTION

If a user were to print over a WAN, the verbose protocols in the bi-directional conversations would become significant since many wireless bridges function in a half duplex.

APPENDIX E

WIRELESS AND FIBRE OPTIONS: PLANNING QUESTIONS

The following preliminary questions are designed to guide decisions on the use and placement of fibre optic cable, microwave wireless and spread spectrum wireless solutions when creating a network.

1. Is there a relatively short distance between sites?
 - If yes, fibre optic cable may be the most effective and cost-efficient solution between these sites—pending access to right of way.
 - If no, a wireless solution may be the only alternative.
2. Do I require a wireless network with a high degree of reliability?
 - If yes, redundancy (fail-over protection) is best achieved using microwave radio networks.
 - If partnering with other agencies, assurance of reliability levels may be a requirement.
3. Am I planning a long-term wireless solution that will meet growing bandwidth needs?
 - For a long-term solution, microwave radio will provide scalability by expanding the number of radios on each hop, as well as through evolving technologies.
 - Spread spectrum networks rely largely on evolving technologies, and scaling upwards requires complete replacement of radio systems.
4. Am I planning a wireless network capable of real-time multimedia applications, videoconferencing, or other interactive applications within the lifespan of the network?
 - If yes, microwave wireless represents a viable solution—particularly given the full duplex nature of this environment.
 - Alternatively, full duplex T1 solutions may be of service, but they have somewhat limited scalability due to costs associated with inverse multiplexing.
5. Am I planning a short-term solution or a solution where economics are the primary consideration?
 - Fibre optic cable networks tend to be more expensive than wireless microwave solutions, and microwave tends to be more expensive than spread spectrum solutions.
 - If short-term economics are the driving criteria, spread spectrum may be the only workable solution. However, there are associated risks and trade-offs.

APPENDIX F

NETWORK PLANNING CHECKLIST

In this checklist of planning activities, the process is iterative. Some points will require more than one visit.

1. Determine design objectives.
 - Assess bandwidth capacity requirements, both current need and future projections. Ensure that you have accommodated anticipated growth patterns due to the evolution of bandwidth-hungry applications.
 - Ascertain availability/reliability requirements (protected/non-protected). Such levels of redundancy are not typically available with spread spectrum systems.
 - Assess application requirements—latency dependence (i.e., voice/video), bandwidth dependence.
2. Determine and produce a preliminary network design.
 - Identify all end nodes within the network.
 - Identify data bandwidth requirements to all end nodes.
 - Map the delivery of bandwidth and solution used to each site.
 - Use point-to-multipoint designs only to serve sites with light bandwidth demand.
3. Contract and work directly with a consulting radio engineer (for all remaining wireless steps).
 - If developing a microwave wireless, ensure the microwave radio engineer has experience with microwave radios and radio paths. A breadth of previous experience working with Industry Canada is an asset.
4. Determine frequency availability and regulatory restrictions.
 - If a microwave radio system, work closely with Industry Canada to identify appropriate frequencies to reach the distances required.
 - If a spread spectrum system, try to ascertain what other spread spectrum systems and frequencies are used or planned in the area.
 - Explore preliminary Ministry of Transport and local governance restrictions.
5. Conduct a path study.
 - Path studies are vital in ascertaining the profile of the geography. Land that looks flat often has surprising rises or falls within a given path.
 - A microwave radio path study identifies topographical considerations and plots the signal across that topography for each radio hop. A microwave radio engineer will lead this step.
 - Spread spectrum path studies tend to have less detail as the radio signal is more *forgiving*.

6. Establish the existence of a line of sight.
 - Visually review each of the paths. Although a path study is an excellent tool for ascertaining paths in light of the geography, such studies fail to accommodate man-made and natural structures that may exist in the path; e.g., silos, trees.
7. Meet with various interested parties, engage in public relations and communicate with stakeholders.
 - School jurisdiction personnel can play a vital role in communications.
 - Consider partnerships with other agencies.
 - Spend time with town/city and municipal administrative staff; discuss the project and its benefits to students. Support from residents and municipal or town administration may be key to receiving approvals for rights of way and tower construction.
 - Discuss various preliminary path and tower considerations with town and municipal administrators.
 - If laying fibre optic cable, discuss right-of-way processes and considerations.
8. Develop a detailed network design.
 - Identify the network topology, possibly a star design, a ring design or some hybrid of these.
 - Detail the bandwidth delivery to each site and the upstream requirements.
 - Consider the protocols required on the network (IP, ATM, IPX).
 - What type of quality of service (QoS) features will be required?
 - Identify preliminary network layer (Layer 2 and Layer 3) solutions that also achieve the QoS requirements.
 - What type of routers will be used—dedicated router, routing with the radio, routing via a server? Does the solution provide the level of throughput (packets per second) to meet the planned bandwidth requirements?
9. Identify specific networking equipment required to meet the design requirements.
 - Ensure that the networking equipment has appropriate interfaces to work with the wireless gear.
 - Ensure that the networking equipment accommodates sufficient throughput (packets per second).
 - Ensure scalability of the networking gear.
10. Redraft the network design.
 - The process is iterative. A change in frequency may suggest changes in the original network design. A change in line-of-sight findings can require you to identify a new path. A change in wireless products may require changes in routing equipment. Each of the items on the checklist is often tightly interwoven with other items.

APPENDIX G

WIRELESS AND NETWORKING GLOSSARY

10Base-T:

An adaptation of the Ethernet standard that runs over unshielded twisted-pair wiring and provides data transfer rates of 10 Mbps.

100Base-T (Fast Ethernet):

A high-speed network standard based on Ethernet that provides data transfer rates as high as 100 Mbps.

802.11:

An industry standard for wireless Ethernet communications as defined by the Institute of Electrical and Electronic Engineers (IEEE).

802.3:

An IEEE standard for wired Ethernet.

Access Point:

The point of interface between a wireless radio system and the wired Ethernet LAN.

Asynchronous:

Transmission by individual bytes not related to specific timing on the transmitting end.

ATM Asynchronous Transfer Mode:

The name of a network technology designed to make it easy to build high-speed hardware. ATM is interesting because it can be used as the basis for LANs or WANs. ATM provides for guaranteed Quality of Service (QoS) levels and is extremely scalable.

Backbone:

A high-speed connection within a network that connects shorter and usually slower circuits. Also used in reference to a system that acts as a *hub* for activity.

Bandwidth:

The amount of usable data transfer, or the maximum data rate of a system.

Beamwidth:

The maximum angle of a usable radio signal provided by a radio/antenna combination.

Boot Protocol (BOOTP):

A standard for assigning IP addresses.

Bridge:

A network device used to connect two separate networks. Bridges operate at the MAC layer of the OSI model.

Broadband:

A transmission method in which the network's range of transmission frequencies is divided into separate channels, and each channel is used to send a different signal. Broadband transmission is often used to send signals of different kinds simultaneously, such as voice and data.

Broadcast Storm:

An incorrect packet broadcast on a network that causes most hosts to respond all at once, typically with wrong answers that start the process over again.

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA):

An Ethernet algorithm defined by the 802.11 (wireless) Ethernet standard.

Carrier Sense Multiple Access with Collision Detection (CSMA/CD):

An Ethernet algorithm defined by the 802.3 Ethernet standard.

Dipole:

A small directional antenna.

Direct Sequence Spread Spectrum (DSSS):

A type of spread spectrum radio system that spreads data across a wide RF band.

Directional Antenna:

An antenna that emits RF in a specific, constrained directional pattern.

DS-0:

Digital signal Level 0. The bandwidth of a digitized PCM voice signal, 64 Kbps. May carry voice or data.

DS-3:

Digital signal Level 3. A multiplexed 44.736-Mbps digital signal comprised of seven DS-2 or 28 DS-1 signals. Contains 672 DS-0 channels.

Digital Signalling Unit (DSU):

A device that connects a terminal (router, computer, etc.) to a digital line.

Dynamic Host Configuration Protocol (DHCP):

A standard for assigning IP addresses from a central automated system.

EIRP:

Effective isotropic radiated power (EIRP) is a measure of signal strength that combines broadcasting power (measured in watts) with the effect of antenna signal gain (measured in decibels).

Ethernet:

The standard LAN topology/system in use today. A 10-million bit per second networking scheme originally developed by Xerox Corporation. Ethernet is widely used for LANs because it can network a wide variety of computers; it is not proprietary, and components are widely available from many commercial sources.

Fade Margin:

A design allowance to accommodate the fading of a signal. Fade margin is expressed as the difference between the available signal and the desired signal in decibels. The higher above the minimum value expected, the more the fade margin, and hence reliability that the radio path accommodates.

Frequency Hopping Spread Spectrum (FHSS):

A type of spread spectrum radio system that encrypts data across multiple random frequencies with a specified range.

Fresnel Zone:

The Fresnel zone for a radio beam is an elliptical area immediately surrounding the visual path. It varies in thickness depending on the length of the signal path and the frequency of the signal. The necessary clearance for the Fresnel zone can be calculated, and it must be taken into account when designing a wireless link.

Full Duplex (FDX):

The use of two separate communications channels for one circuit. Where the endpoints are *A* and *B*, one channel is transmitted from *A* and received at *B*, while the other channel is transmitted from *B* and received at *A*.

Gain:

The concentration of signal strength in a given direction is known as signal gain. Signal gain is measured relative to the strength of a theoretical antenna type called an isotropic radiator.

Gigahertz (GHz):

One billion cycles per second: a measure of frequency.

Hertz (Hz):

The unit for the measurement of frequency, where one hertz equals one cycle per second.

High Frequency (HF):

A portion of the electromagnetic spectrum, typically used in short-wave radio applications; frequencies approximately in the 3–30 MHz range.

Half Duplex (HDX):

The operation of a communications channel where transmission and reception occur in both directions, alternately based on an established channel control protocol.

Institute of Electrical and Electronic Engineers (IEEE):

An institution that sets standards and guidelines regarding electrical and electronic applications and systems.

IP:

Internet protocol.

Ka Band:

Portion of the electromagnetic spectrum; frequencies approximately in the 12–30 GHz range.

LAN (Local Area Network):

Any physical network technology that operates at high speed over short distances (up to a few thousand metres).

Line of Sight:

A visual straight line between two geographic points.

Media Access Control (MAC) Layer:

Media access control layer of the Ethernet standard.

Medium:

The material used to support the transmission of data. This can be copper wire, coaxial cable, optical fibre or electromagnetic wave (as in microwave).

Multiplex:

The division of a single transmission medium into multiple logical channels supporting many simultaneous sessions.

Multiplexer (MUX):

A communications device that multiplexes (combines) several signals for transmission over a single medium.

Microwave:

The portion of the electromagnetic spectrum above about 890 megahertz. Also, a line-of-sight, open-air radio transmission of a radio beam of energy within the microwave frequency band that is used as a carrier for multiple communications channels.

Node:

A computer or device that is attached to a network.

OFDM:

Orthogonal frequency division multiplexing—a frequency hopping technology used by Wi-LAN Inc.

Omni-directional Antenna:

An antenna that spreads its signal across a 360-degree pattern.

(OSI) Open Systems Interconnection Reference Model:

A seven-layer model for data communication that is the standard network architecture developed by the International Organization for Standardization (ISO). The layers are as follows: physical, data link, network, transport, session, presentation and application.

Overhead:

In communications, all information, such as control, routing and error checking characters, in addition to user-transmitted data. Includes information that carries network status or operational instructions, network routing information and retransmissions of user-data messages that are received in error.

Packet:

The base unit for transmission of data. A packet generally contains the source (from) and destination (to) information along with the payload or actual data being sent.

Parabolic:

A concave or dish-shaped antenna used to focus a radio signal into a narrow beam.

PBX—Private Branch Exchange:

A private telephone network used within an enterprise. PBX users share a certain number of lines that they can use to make external telephone calls.

Protocols:

A formal description of message formats and rules that two computers (or systems) must follow to exchange messages. Protocols specify the formatting, timing, sequencing and error checking of data transmission.

PVC—Permanent Virtual Circuit:

A continuously available communications path that connects two fixed end points. A PVC is similar to a leased line.

Radio Frequency (RF):

A generic term describing radio technology.

Range:

The distance a radio signal can travel and still provide reliable data transmission.

RJ-45 Registered Jack-45:

An eight-wire connector commonly used to connect a computer onto a LAN, particularly an Ethernet LAN or native T1 interface.

Router:

A dedicated computer (or other device) that sends packets from one place to another, paying attention to the current state of the network. Routers work at Layers 3 and 4 of the OSI model.

Scalability:

The ability to be made larger or smaller. Scalability describes whether a hardware or software system can adapt to increased demands.

Signal to Noise Ratio:

Relationship of the magnitude of a transmission signal to the noise of a channel; measurement of signal strength compared to error-inducing circuit noise, given in decibels.

Simple Network Management Protocol (SNMP):

A network standard for management of IP (Internet protocol) devices.

SONET—Synchronous Optical Network:

A high-speed network technology that provides data transfer rates from 51.8 Mbps to 2.48 Gbps. SONET often uses fibre optic cable to support high-speed digital traffic.

Spread Spectrum:

A generic term for encoding radio signals to provide robust and secure data transmission.

Star Topology:

A network configuration in which each node is connected to a separate line, and all lines lead to the same central hub. Through the hub, a line can be connected to any other line. An example is a PBX (private branch exchange).

Synchronous:

Describes a mode of data transfer in which information is transmitted in blocks (frames) of bits separated by equal time intervals. Synchronous data transmission allows for guaranteed levels of service. See also **Asynchronous**.

T1:

A dedicated telco standard connection supporting data rates of 1.544 Mbps. A T1 line actually consists of 24 individual channels, each of which supports 64 Kbps. Each 64-Kbps channel can be configured to carry voice or data traffic. Use of just some of these individual channels is known as fractional-T1 access.

TCP/IP (Transmission Control Protocol/Internet Protocol):

A set of protocols, resulting from ARPA efforts, used by the Internet to support services such as remote login (telnet), file transfer (FTP) and mail (SMTP).

Throughput:

The net data transfer rate between an information source and destination.

WAN (Wide Area Network):

A network spanning hundreds or thousands of kilometres, generally linking smaller LANs (local area networks).

W-OFDM:

Wide-band orthogonal frequency division multiplexing—an emerging (1999) spread spectrum encoding technique that can utilize multiple high-speed signals on diverse frequencies. W-OFDM provides for high-speed data transmission that is resistant to interference from other radio signals or multi-path distortions.

Yagi:

A small directional antenna.