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White Paper: Technical Planning Guide for Fixed Broadband Wireless Internet Access

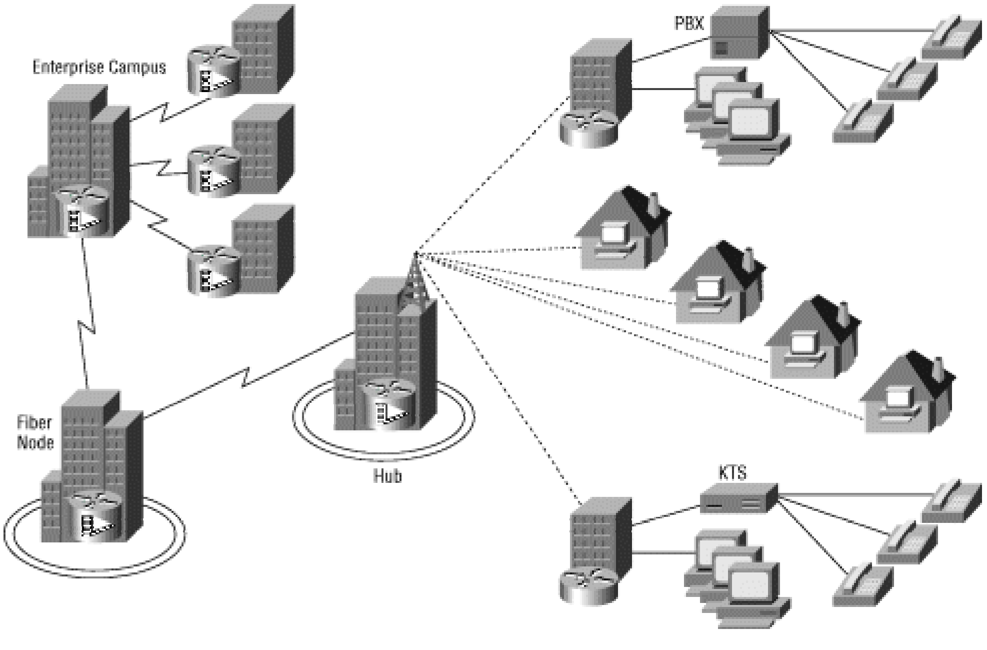
Overview: To provide the reader with a solid understanding of how the Internet is evolving to support Wireless Broadband IP networking and to outline the business steps for construction of a fixed wireless data broadcast and receive station.

Contents:

1. Introduction to Broadband Wireless ……..……………………… page 1
2. Internet Network Basics ………………………………..……… page 2
3. Modem Technology ………………………………………..…….. page 5
4. The Addition of the Wireless Element ………………..……… page 6
    4a. Headend Site Planning Considerations ……………..….. page 6
    4b. Subscriber Equipment Issues …………………………..…… page 15
5. Comparing Fixed Wireless to the Alternatives ……………….... page 19
6. Business Planning …………………………………………..……. page 22
7. Conclusion …………………………………………………..…….. page 24

1. Introduction to Broadband Wireless

The words “Wireless” and “Internet” have gotten a lot of attention recently. They are the two hottest topics in Telecommunications today. To support the anticipated applications and services, major changes are required in both today’s infrastructure and in the radio access networks. But so much of the attention has been for newer cellular phones or pagers and personal digital assistants (PDAs), including Bluetooth enabled e-mail and Internet connections for laptops and other portable devices. These kinds of cellular technologies are mobile and flexible, however they are bandwidth and speed limited. 9600 baud rates are common, and maximum rates are similar to dial-up connections, or 56K. This article is not about those kinds of cellular technologies or mobile phones, rather it is written to help acquaint the reader with a different technology: fixed point to multi-point broadband wireless access (BWA).



BWA networks are capable of 30 Mbps data transmission rates. Actual data throughput speeds are up to 100 times faster than most people are accustomed to, and these services can be compared to traditional cable modem access through the local cable company and xDSL from the phone company. In fact, subscription rates for each of these services should be similar because they are in competition with each other in some of the larger markets. The exception is that BWA services will not have competition from cable or telephone in every city. Small to medium populations, remote locations, and cities with low infrastructure are niche candidates for deployment of BWA (ahead of cable or telephone) because it is easier, faster and has a lower cost of ownership to install, maintain and operate.

Although a wireless cable or digital broadband network operation may be licensed or unlicensed, this article focuses mainly on the former (licensed) operator who already has the rights to some number of 6 MHz channels or groups. The former operator can offer higher qualities of service (QOS) with less chance of being interfered with. Primarily the number of channels in his license limits the former operator’s capacity. On the other hand, the latter (unlicensed) operator will eventually reach a saturated market (subscriber base) over large geographical areas due to interference from other unlicensed operators.

Loma Scientific is using its expertise in data communications and networking technology to assist companies in developing and rolling out new systems that will support present and future needs for connectivity. Broadband fixed wireless solutions provide a major step forward to meet these needs. Evolutions in wireless signal processing technologies now enable information service providers to reach new customers that were not accessible with traditional techniques and expand the available services to existing ones. With the deployment of wireless networks, service providers will benefit from:

- *Improved Revenue Opportunities*---Wireless systems install quickly and provide services in under-served areas in substantially less time than wire-line alternatives.
- *Differentiated Services*---High-speed broadband fixed scalable services such as Internet access and combined data, voice, and video are now possible in non-traditional wireless markets.
- *Competitive Local Loop Bypass*---Broadband fixed wireless solutions make it possible to deploy bypass solutions over existing incumbents providing competitive solutions to the end user.

As demand for information, entertainment, and communications explodes, a broadband fixed wireless network presents the single best medium for delivering these services reliably, cost-effectively, and profitably. In fact, studies propose that the cost for deployment of fixed wireless networks is the lowest of all currently available transport streams and has the potential to provide connectivity solutions to new areas in significantly less time. Technology advances in wireless modulation techniques enable wireless links to provide the scalable multi-megabit services needed to meet today's requirements. And when used as a local loop bypass wireless solutions can significantly reduce or eliminate the recurring cost of leased lines.

2. Internet Network Basics

2a. TCP/IP: Packet Theory

Who ever thought that four or five years ago, the term Internet Protocol (IP) or Transfer Control Protocol (TCP) would mean anything to the general business world or the consumer? IP has been around for years but is just now beginning to give birth to hundreds of applications. To understand the importance of IP's place in the public and private broadband markets, we do not need to discuss all of the technical aspects of IP, but more on the applications of IP with for example: Voice, Data and Video. Let's first define what TCP/IP is in very general terms.

An internet consists of a set of connected networks that act as a coordinated whole. The chief advantage of an internet is that it provides universal connection while allowing individual groups too use whatever network hardware is best suited to their needs. The Advanced Research

Projects Agency developed our technology, called TCP/IP (after the two main protocols). It provides the basis for the global Internet, a large, operational internet that connects universities, corporations, and government departments in many countries around the world. The global Internet is expanding rapidly.

The Internet Protocol (IP) is the method (protocol) which data is sent from one intelligent workstation to another on a network such as the Internet or a Local Area Network (LAN). A TCP/IP internet is a connectionless Packet Delivery Service. Connectionless delivery is an abstraction of the service that most packet-switched networks offer. It simply means that small messages are routed from one machine to another based on address information contained in the message. Because the connectionless service routes each packet separately, it does not guarantee reliable, in-order delivery. Because it usually maps directly into the underlying hardware, the connectionless service is extremely efficient. More important, having connectionless packet delivery as the basis for all internet services makes TCP/IP protocols adaptable to a wide range of network hardware.

2b. Applications of IP for Data, Voice and Video

This section will focus on Internet applications of IP. Workstations can be a PC, Server or Videoconferencing workstation. Each workstation, known as a host, on the Internet has at least one (IP) address that uniquely identifies it from all other intelligent workstations on the Internet. When you send or receive data, voice or video (for example an e-mail or a Web page), the message gets divided into little chunks called packets. Each of these packets contains both the sender's Internet address and the receiver's address.

The first application for IP is data. It is referred to as TCP/IP. TCP/IP (Transmission Control Protocol/Internet Protocol) is the basic communication language protocol of the Internet. It can also be used as a communications language in private networks called intranets or in a public network called the Internet. When set up with direct access to the Internet, your computer is provided with a copy of the TCP/IP program just as every other computer that you may send messages to or get information from also has a TCP/IP address. Think of TCP/IP as your data address, similar to your phone number, which is your telephony address, or your PO Box or street address. Every address including TCP/IP sends and receives information. TCP/IP also uses the World Wide Web's Hypertext Transfer Protocol (HTTP), the File Transfer Protocol (FTP) which lets you logon to remote computers, and the Simple Mail Transfer Protocol (SMTP) which allows you to send and receive email. These and other protocols are often packaged together with TCP/IP as a "suite."

The second application is voice. It is referred to as Voice over IP and IP Telephony.

IP Telephony means exactly what is says. Transmitting voice conversations over IP networks utilizing the personal computer, a server or now a telephone system, Voice over IP has been around since 1996. Its first application was to transmit voice conversations via computers to International destinations for businesses and consumers. An International call over the Public Switched Telephone Network (traditional telephone service) costs on average of a dollar per minute--sometimes as high as $3.00 per minute. With IP Telephony, the cost is $0. This became a very attractive alternative for businesses that had branch offices and customers overseas.

The problem was the quality of the IP Telephony call. Early applications were reminiscent of talking on a two-way radio. The quality and application of IP Telephony has evolved dramatically since 1996. With the increase in bandwidth capability, reduction in costs and major advances by hardware manufactures, IP Telephony now competes with the traditional voice-quality services.

IP Telephony not only works on a PC with a sound card and microphone, but also now operates with traditional phone systems, residential telephones and even telephone calling cards. This advanced voice technology poises serious competition to the major long distance companies. Due to the potential of that competition, the major carriers are now beginning to order various forms of IP Telephony applications.

The third application is video. It is referred to as Video over IP or IP Videoconferencing.

This is the newest and most exciting IP application. Traditional videoconferencing over the last ten years used a digital phone line called ISDN (Integrated Services Digital Network).

Traditionally, use of an ISDN telephone line allows video and voice to be compressed and sent over copper telephone lines. However, you can now use IP (or the Internet) to transmit simultaneous voice and video anywhere in the world. This new application significantly reduces the cost associated with traditional videoconferencing. Polycom, a leader in this technology recently announced a product called ViaVideo. This is a complete kit for a desktop Personal or Notebook Computer that provides full-screen, full- motion images transmitted at 30 frames per second and an integrated microphone. ViaVideo is the first product of its kind to offer enterprises of all sizes, as well as telecommuters, affordable, two-way, high-quality video-over-Internet Protocol (IP) networks. This IP video kit can be installed in any computer for around $599.00. It will debut in third quarter 2000, Over the next several years, you will be hearing more about IP technologies because as broadband penetration grows, then IP based applications will in turn grow in popularity.

2c. IP Resources

Each device connected to the Internet must be identified by a unique string of numbers, or "address," so any two computers can find each other over the Net. But just as the proliferation of fax machines, pagers, wireless phones and personal computers triggered a shortage of phone numbers and spawned a wave of new area codes, heavy use of the Internet is rapidly draining the supply of numerical Internet addresses. Of the world's 4.2 billion potential Internet addresses, there could be only a few hundred million left to be taken. And with the Internet doubling in size every nine months, the remaining Internet addresses are rapidly being exhausted.

When the Internet began in the early 1970s, the U.S. government and university researchers were the only ones using the Internet, and they took as many addresses as they wanted. By the mid-1980s, businesses and consumers were beginning to use the Internet. And then by the mid-1990s, the creation of Netscape's Web browser and the emergence of companies like Amazon.com helped trigger the worldwide Internet frenzy. Today, there are 2.6 Internet addresses for every person in North America.

This Internet number crunch has mobilized a loose-knit band of hundreds of computer scientists from the U.S., Asia and Europe: these members of the Internet Engineering Task Force are rewriting the underlying language of the Net. Some of these Internet wizards teach at universities, while technology powerhouses such as IBM or Nokia employ others. Many of them helped create the Internet and now feel a responsibility to fix it. Most of their work is done in massive e-mail discussion groups.

They believe they have a solution: a new Internet language, dubbed IPv6, has the potential of multiplying potential Internet addresses by a factor of 80 octillion, or 80,000,000,000,000,000,000,000,000,000. The hope is that final tests prove them right and that a new Internet protocol can be launched within a couple of years.

Groups Collaborated on Possible Solutions

Thirty years ago when the Internet was in its infancy, worrying about billions of users would have seemed preposterous. The original IPv4 version was devised by Cerf, then a Stanford professor, and Bob Kahn, director of information processing techniques for the Defense Department's Advanced Research Projects Agency. Their design ensured that tiny packets of information could make their way across the many computer networks that constitute the Internet and reach their final destination.

With IPv4, each machine tapping into the Internet has its own numerical address made up of a combination of 32 zeros and ones. But for technical reasons the possible 4.2 billion numerical combinations can't all be used as addresses. For example, Internet addresses must be doled out in blocks of two, four, eight, 16, 32 and other numbers that are a power of two. Therefore, if a company needs 33 Internet addresses, it will get a block of 64, and 31 of them will be wasted. Experts believe that 30% to 70% of all potential addresses will go unused.

Companies and consumers typically get their addresses from Internet service providers, such as EarthLink Network, who in turn receive their allocations from three regional Internet registries that serve the Americas, Asia and Europe. Almost immediately after the impending shortage was discovered, groups of volunteers began collaborating on different solutions. Three competing blueprints soon emerged for a new Internet protocol.

One group backed software maker Novell and wanted this new protocol built upon the foundation of the company's PC networking software. Another proposal came from Internet experts at the National Bureau of Standards, who tossed out IPv4 altogether and created a new Internet architecture almost from scratch. But after two years of "energetic design competition," a design based on IPv4 itself emerged. One advantage was that IPv4 had an entrenched base of hundreds of influential users from universities and federal agencies who were anxious to help with the design and to stick with what they knew. Their blueprint came to be known as IPv6.

The most important feature of IPv6 is that it expands each Internet address from 32 to 128 digits. IPv6 is being tested on 20 computer networks at research centers and Internet service providers. The next step was to get hardware and software companies to embrace the new IPv6 protocol.

Microsoft Windows to Play Vital Role

The most critical role falls to Microsoft, whose Windows software is used on 90% of the world's PCs. The Redmond, Wash.-based software giant hasn't announced any dates yet, though earlier this year Microsoft arranged for some customers to test a piece of Windows that understands IPv6. A full-fledged IPv6 version for Windows is still probably a few years away.

Given that roughly half the computers on the Internet are new to the network in any given year, the protocol should spread across the Internet quickly once software with IPv6 is introduced. Once IPv6 does become widespread, all sorts of devices will be able to connect to the Net on an equal footing with computers.

Ultimately, each home could easily need scores of Internet addresses to accommodate such devices. With IPv6, there will be enough addresses to allow each person to have 64,000 networks in his or her house. Ultimately, the Internet mechanics will know they did their job well if regular Net users don't notice that anything has changed.

3. Modem Technology

Modems can make bridge connections between two remotely located networks or host computers on a Virtual Local Area Network (VLAN). The word “modem” stands for “modulator-demodulator” and it usually converts baseband data signals to and from a leased channel or transmission line. The subscriber modem is connected to the far edge of a Wide Area Network (WAN). Although full duplex modems are commonplace, the basic function of a modem should not be confused with that of network hubs, switches or routers. Asymmetric data rates (i.e. higher capacity in the downstream) and fractional network loading (i.e. not on-line at all times) provide the typical user with a more practical Internet connection. The modem of choice is specifically related to the particular medium of transfer (the network’s “physical layer”) and the usage requirements. All modems share this interface responsibility.

Modems that come preinstalled on “new PCs” are commonly for dial-up services. They interface well with the local Phone Company’s twisted pair copper circuit switched network. Eventually the consumer will be offered additional (or substitute) preinstalled modems on a “new PC”. As with the current day telephone modem, The end-user will not necessarily have to install (or contract to install) internal or external modem models. Newer PCs are now coming with preinstalled Ethernet (10base-T) cards. This makes life easier for the subscriber as well as the service provider. Network service providers (ISPs) may wish or may not wish to do “truck-rolls” for every subscriber during the sign-up phase. This policy can dramatically reduce an operation’s customer service costs. Ultimately, the best situation is when the subscriber has the choice. Thus eventually, internal DSL and cable modems will be preinstalled on newer PCs, while external modems will capably be self-installed (“plug-and-play”).

Currently the wireless modem of choice is a standards based platform with modifications for wireless environments or “enhanced DOCSIS” cable modems. Future modems of choice will be OFDM based providing a more robust wireless network.

Data Over Cable Systems Interface Specifications (DOCSIS)

Also known as CableLabs Certified Cable Modems, DOCSIS is an interface standard for cable modem devices that handle incoming and outgoing data signals between a cable TV operator and a personal or business computer or television set. DOCSIS 1.0 was ratified by the International Telecommunication Union (ITU-TS) in March of 1998. Although "DOCSIS" continues to be used, the newer name emphasizes that the standard is now being used to certify the products of cable modem makers. Cable modems conforming to DOCSIS are now being marketed.

Cable operators whose existing customers have non-standard cable modems can handle them by adding backwards-compatible support to the DOCSIS card at the cable operator's end. As DOCSIS continues to evolve to new versions, existing modems can be upgraded to the newer versions by changing the programming in the cable modem's electrically erasable programmable read-only memory. DOCSIS-compliant cable modems are being integrated into set-top boxes for use with television sets. DOCSIS must also support or converge with the high definition television (HDTV) standard. The set-top box itself follows a standard known as OpenCable.

DOCSIS specifies schemes and the protocol for exchanging bi-directional signals over cable. It supports downstream-to-the-user data rates up to 27 Mbps (megabits per second). Since this data rate is shared by a number of users and because many cable operators will be limited by a connection to the Internet, the actual downstream data rate to an individual business or home will be more like 1.5 to 3 Mbps. Since the upstream data flow has to support much smaller amounts of data from the user, it's designed for an aggregate data rate of 10 Mbps with individual data rates between 500 Kbps and 2.5 Mbps.

Cisco and Microsoft have endorsed DOCSIS. They are collaborating on a DOCSIS-compliant cable hybrid fiber-coax (HFC) system, called the Multimedia Cable Network System (MCNS), that will deliver services to residential, commercial, and educational customers. According to International Data Corporation in August, 1998, there were 67 million cable subscribers in the U.S. There are hundreds of cable TV operators.

4. The Addition of the Wireless Element

4a. Headend Site Planning Considerations

The installation of a wireless network requires much the same basic planning as any wired network. The main difference is that the wireless signal requires some additional planning. This planning includes RF path planning, site preparation, and installation of outdoor components such as outdoor units, antennas, lightning protection devices, and cabling suitable for outdoor conditions. Usually, you also need to investigate the zoning laws as well as Federal Communications Commission (FCC) and Federal Aviation Administration (FAA) regulations.

Although the technology implemented in Loma Scientific's broadband fixed wireless system can reduce the effects of multipath signals, it is important that the characteristics of the path be carefully examined. With this knowledge, components and network requirements can be correctly planned for your specific application.

This section provides insight into the planning necessary to prepare your site for your broadband fixed wireless system.

General Considerations

A basic consideration is the physical location of the sites at each end of the link. Because microwave signals travel in a nearly straight line, a clear line of sight between antennas is ideal. Frequently, however, the locations of the desired links are fixed. When a clear line of sight cannot be achieved, you must plan accordingly.

Other general site considerations include:

- Ability to install one or more antennas--Is the roof adequate to support the antenna(s) or will it require structural reinforcement? Will a tower have to be constructed? Are permits required?
- Possibility of future obstructions--Will trees grow high enough to interfere with the signal? Are there plans to erect buildings between the sites that may obstruct the path?
- Availability of grounding--Good grounding is important in all areas of the world, but in areas prone to lightning, it is especially critical.
- Availability of power--Are redundant power systems available if the area is prone to outages?

The planning of a wireless link involves collecting information and making decisions. The following sections will help you determine which information is critical to the site and will be an aid in the decision-making process.

4a.1 Weather

It is important to research any unusual weather conditions that are common to the site location. These conditions can include excessive amounts of rain or fog, wind velocity, or extreme temperature ranges. If extreme conditions exist that may affect the integrity of the radio link, Loma Scientific recommends that these conditions be taken into consideration early in the planning process.

Rain and Fog

Except in extreme conditions, attenuation (weakening of the signal) due to rain does not require serious consideration for frequencies up to the range of 6 or 8 GHz. When microwave frequencies are at 11 or 12 GHz or above, attenuation due to rain becomes much more of a concern, especially in areas where rainfall is of high density and long duration. If this is the case, shorter paths may be required.

The systems discussed in this guide operate at frequencies below 6 GHz, so rain is not a concern.

In most cases, the effects of fog are considered to be much the same as rain. However, fog can adversely affect the radio link when it is accompanied by atmospheric conditions such as temperature inversion, or very still air accompanied by stratification. Temperature inversion can negate clearances, and still air along with stratification can cause severe refractive or reflective conditions, with unpredictable results. Temperature inversions and stratification can also cause ducting, which may increase the potential for interference between systems that do not normally interfere with each other. Where these conditions exist, Cisco recommends shorter paths and adequate clearances.

Atmospheric Absorption

A relatively small effect on the link is from oxygen and water vapor. It is usually significant only on longer paths and particular frequencies. Attenuation in the 2 to 14 GHz frequency range is approximately 0.01 dB/mile, which is not significant.

Wind

Any system components mounted outdoors will be subject to the effect of wind. It is important to know the direction and velocity of the wind common to the site. Antennas and their supporting structures must be able to prevent these forces from affecting the antenna or causing damage to the building or tower on which the components are mounted.

Antenna designs react differently to wind forces, depending on the area presented to the wind. This is known as wind loading. Most antenna manufacturers will specify wind loading for each type of antenna manufactured.

Note For definitions of wind loading specifications for antennas and towers, refer to TIA/EIA-195 (for antennas) or TIA/EIA-222 (for towers) specifications.

Lightning

The potential for lightning damage to radio equipment should always be considered when planning a wireless link. A variety of lightning protection and grounding devices are available for use on buildings, towers, antennas, cables, and equipment, whether located inside or outside the site, that could be damaged by a lightning strike.

Lightning protection requirements are based on the exposure at the site, the cost of link downtime, and local building and electrical codes. If the link is critical, and the site is in an active lightning area, attention to thorough lightning protection and grounding is critical.

Lightning Protection

To provide effective lightning protection, install antennas in locations that are unlikely to receive direct lightning strikes, or install lightning rods to protect antennas from direct strikes. Make sure that cables and equipment are properly grounded to provide low-impedance paths for lightning currents. Install surge suppressors on telephone lines and power lines.

Loma Scientific recommends lightning protection for both coaxial and control cables leading to the wireless transceiver. The lightning protection should be placed at points close to where the cable passes through the bulkhead into the building, as well as near the transceiver.

Coaxial Cable

Because the coaxial line carries a DC current to supply power to the transceiver, gas-discharge surge arrestors are required. Do not use quarter-wave stub or solid-state type surge arrestors.

When the entire coaxial cable, from the building entrance to the transceiver, is encased in steel conduit, no surge arrestors are required. However, local electrical codes require that the conduit be grounded where it enters the building.

When steel conduit is *not* used to encase the cable, each cable requires one surge arrestor within 2 feet of the building entrance, and another surge arrestor within 10 feet of the transceiver.

Control Cable

When the entire control cable, from the building entrance to the transceiver, is encased in steel conduit, no surge arrestors are required. Otherwise, each control cable requires one surge arrestor within two feet of the building entrance, and another surge arrestor within 10 feet of the transceiver.

Note For installations with several radios, it may be more convenient to use a Type-66 punch block with surge arrestors. A Type-66 punch block can accommodate up to 25 conductor pairs.

4a.2 Interference

An important part of planning your broadband fixed wireless system is the avoidance of interference. Effects within the system or outside the system can cause interference. Good planning for frequencies and antennas can overcome most interference challenges.

Co-channel and Adjacent Channel Interference

Co-channel interference results when another RF link is using the same channel frequency. Adjacent-channel interference results when another RF link is using an adjacent channel frequency. In selecting a site, a spectrum analyzer can be used to determine if any strong signals are present at the site and, if they are, to determine how close they are to the desired frequency. The further away from your proposed frequency, the less likely they are to cause a problem. Antenna placement and polarization, as well as the use of high-gain, low-sidelobe antennas, is the most effective method of reducing this type of interference.

Frequency Band Division

Each broadband fixed wireless system is a full-duplex system. Two frequency bands are used to achieve this two-way operation, with the higher frequency band considered the "high" band in the link, and the lower frequency considered the "low" band. The transmitter at one end of the link will use the high band; the transmitter at the other end will use the low band. Interference may affect the high band, the low band or both.

4a.3 Antennas

Antennas focus the radio signal in a specific direction and in a narrow beam. The increase in the signal power (compared to an omnidirectional antenna) when it is focused in the desired direction is called gain.

Antennas are tuned to operate on a specific group of frequencies. The manufacturer also fixes other specific attributes such as beamwidth and gain. Antennas should be selected and placed according to your site and your application.

In general, the larger the antenna, the higher the gain and the larger the mast required. It is best to use the smallest antenna that will provide sufficient protection from interference and enough signal at the far end of the link to provide good reception even with fading.

Other considerations include antenna beamwidth, front-to-side ratios, front-to-back ratios, and cross-polarization rejection. Where interference from other licensees on the same channel or adjacent channels is an issue, narrow beamwidths, high front-to-back and front-to-side ratios, and high cross-polarization rejection are likely to be required. Even when other licensees are not an issue, if you are using a network deployment using the "cell" approach, all these considerations are still important to reduce interference between your own adjacent installations.

Types

Several antenna types are appropriate for the type of installation discussed in this guide. Semi-parabolic grid antennas are usually used where wind loading is an issue. Solid antennas should have the option to add a radome to reduce wind loading, as a means of ice protection, where necessary, and to prevent birds from roosting on the antenna feeds.

For short U-NII links (or links where the appearance of the antenna is a problem) panel, patch or planar antennas might be appropriate. With these antenna types, the front-to-side, front-to-back, and cross-polarization responses are not as good, so it is important to carefully examine interference potential.

Consult your antenna vendor and installer for specific information on the antenna types, their use, and their performance.

Antenna Polarization

The orientation of the antenna will change the orientation of the signal. The transmitting and receiving antennas should be both polarized either horizontally or vertically. Adjacent antennas on different frequencies can be cross polarized to help reduce interference between the two, if your operating license permits this.

Note In licensed bands, such as the MMDS band, the required polarization is specified by the license.

Diversity and VOFDM

When transmitted signals follow several paths between the transmitter and the receiver, a condition called multipath or echo distortion occurs. Signals reflect off buildings, water, and other objects, creating multiple paths to the receiver. On long point-to-point radio links, stratification of the atmosphere can create multiple paths by refracting the signals. Due to their longer path lengths, these reflected or refracted signals take longer to arrive at the receiver, where they can interfere with the main signal. A good strategy for broadband fixed wireless systems is to combine VOFDM technology with spatial diversity to minimize multipath distortion.

Space diversity requires the installation of two antennas separated vertically or horizontally (vertical separation works well for longer free-space line-of-sight links, while horizontal separation works best for partially obstructed or non-line-of-sight links). The signals received by both antennas are combined or sensed to greatly enhance the quality of the signal where multipath exists.

As a rule of thumb, the separation between antennas using this feature should be a minimum of 100 to 200 times the wavelength of the frequency. The greater distances are preferable. Table 4-1 shows some sample antenna separation calculations.

Table 4-1: Sample Antenna Separation Calculations Frequency (MHz)	Wavelength (cm)	Wavelength x 100 (m)	Wavelength x 200 (m)
2500	12	12	24
5000	6	6	12

4a.4 Towers

When planning antenna placement, it might be necessary to build a freestanding tower for the antenna. Regulations and limitations define the height and location of these towers with respect to airports, runways, and airplane approach paths. The FAA enforces these regulations. In some circumstances, the tower installations must be approved by the FAA and/or registered with the FCC.

To ensure compliance, review the current FCC regulations regarding antenna structures. These regulations (along with examples) are on the FCC web site at www.fcc.gov/wtb/antenna/what.html.

4a.5 Path Planning

To get the most value from a wireless system, path planning is essential. In addition to the fact that radio signals dissipate as they travel, many other factors operate on a microwave signal as it moves through space. All of these must be taken into account, because any obstructions in the path will attenuate the signal.

Fresnel Zone

The characteristics of a radio signal cause it to occupy a broad cross-section of space, called the Fresnel Zone, between the antennas. Figure 4-1 shows the area occupied by the strongest radio signal, called the First Fresnel Zone, which is centered on the direct line between the antennas.

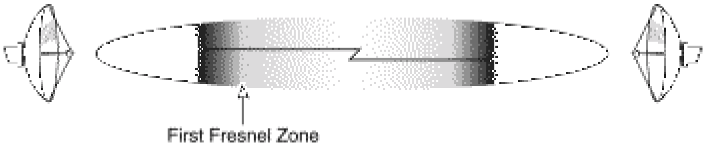


Figure 4-1: First Fresnel Zone

Due to the shape of the First Fresnel Zone, what appears to be a clear line-of-sight path may not be. Because of this, it is often necessary to calculate the width of this zone at the path midpoint. The following formula is used to calculate it:

$W = 43.3 * (D / 4F)^{0.5}$

where
W = Width of the First Fresnel Zone (in feet)
D = Distance between the antennas (in miles)
F = Frequency in GHz
^0.5 = square root

It has been found that if 60% of the First Fresnel Zone is clear of obstructions, the link behaves essentially the same as a clear free-space path.

Earth Bulge

When planning for paths longer than seven miles, the curvature of the earth might become a factor in path planning and require that the antenna be located higher off the ground. The additional antenna height needed can be calculated using the following formula:

$H = (D^2) / 8$

where
H = Height of earth bulge (in feet)
D = Distance between antennas (in miles)
^2 = squared

Total Antenna Height

The total antenna height at each end of the link for paths longer than seven miles (for smooth terrain without obstructions) is the height of the First Fresnel Zone plus the additional height required to clear the earth bulge. The formula would be:

$H = 43.3 * (D / 4F)^{0.5} + (D^2) / 8$

where
H = Height of the antenna (in feet)
D = Distance between antennas (in miles)
F = Frequency in GHz

4a.6 Calculating a Link Budget

A link budget is a rough calculation of all known elements of the link to determine if the signal will have the proper strength when it reaches the other end of the link. To make this calculation, the following information should be available:

- Frequency of the link
- Free space path loss
- Power of the transmitter
- Antenna gain
- Total length of transmission cable and loss per unit length at the specified frequency
- Number of connectors used
- Loss of each connector at the specified frequency
- Path length

Free Space Path Loss

A signal degrades as it moves through space. The longer the path, the more loss it experiences. This free space path loss is a factor in calculating the link viability. Free space path loss is easily calculated for miles or kilometers using one of the following formulas:

$$Lp = 96.6 + 20 \log_{10} F + 20 \log_{10} D$$

where
Lp = free space path loss between antennas (in dB)
F = frequency in GHz
D = path length in miles

Antenna Gain

Antenna gain is an indicator of how well an antenna focuses RF energy in a preferred direction. Antenna gain is expressed in dBi (the ratio of the power radiated by the antenna in a specific direction to the power radiated in that direction by an isotropic antenna fed by the same transmitter). Antenna manufacturers normally specify the antenna gain for each antenna they manufacture.

Cable and Connector Loss

There will always be some loss of signal strength through the cables and connectors used to connect to the antenna. This loss is directly proportional to the length of the cable and generally inversely proportional to the diameter of the cable. Additional loss occurs for each connector used, and must be considered in planning. Your cable vendor can provide you with a chart indicating the loss for various types and lengths of cable.

Sample Link Budget Calculation

The example below is based on the following assumptions:

Frequency	2.5 GHz (MMDS)
Length of Path	10 miles
Free Space Path Loss	124.6 dB
Transmitter Power	30 dBm
Cable Length	50 feet 1/2 inch Andrew Heliax at each end (1/2 inch Andrew Heliax has ~ 4 dB loss per 100 ft. at 2.5 GHz)
Number of Connectors Used	4 (~ 0.5 dB loss per connector)
Antenna Gain	19.5 dBi transmit, 19.5 dBi receive
Receiver Threshold	-90 dBm
Required Fade Margin	20 dB (minimum)

i.

The following formulas can be used to determine if the fade margin meets the requirement:

fade margin = received signal – receiver threshold

ii.

The received signal can be calculated with the formula:

received signal = transmitter power – transmitter cable loss - transmitter connector loss + transmitter antenna gain - free space path loss + receiver antenna gain – receiver cable loss – receiver connector loss

iii.

Based on the assumptions in the example, the formula becomes:

received signal = 30 dBm - 2 dB (50 ft) - 1 dB (2 connectors) + 19.5 dB - 124.6 dB + 19.5 dB - 2 dB (50 ft) - 1 dB (2 connectors) = -61.6 dBm

iv.

The fade margin is then calculated as follows:

fade margin = -61.6 dBm - (-90 dBm) = 28.4 dBm

v.

A fade margin of 28.4 dBm is above the required fade margin minimum (20 dB) specified for this example.

Note The previous link budget calculation is only an example. The actual figures and requirements will vary with the installation.

4a.7 Availability

Availability represents the quality of a link. It is the ratio of the time that the link is available to the total time. This serves as a guide to the service that you can expect, on average, over a period of one year. Table 4-2 shows how percentage availability relates to outage time per year.

Table 4-2: Link Availability and Outage Time Availability	Outage Time	Outage Per Year
99.9%	0.1%	9 hours
99.99%	0.01%	1 hour
99.999%	0.001%	5 minutes
99.9999%	0.0001%	30 seconds

Your application determines what availability is required. A critical application where down time adversely affects business and revenue requires a high percentage of availability. Somewhat lower availability might be acceptable by an application used to gather data, where occasional outages can be tolerated.

Availability is largely a function of fade margins and the amount of signal fading. Paths obstructed by trees have larger fades than paths with no trees. Longer paths tend to have more fading than shorter paths. Larger fade margins yield better link availability.

The International Telecommunications Union (ITU) publishes a reference for link planning, which is available at www.itu.ch. ITU-R Recommendation G.826 contains definitions for "availability" and related terms used to describe link quality. It also contains recommendations for link quality objectives. ITU-R Recommendation P.530 contains information on how to plan for high reliability in clear, line-of-sight links.

Availability is much more difficult to predict for non-line-of-sight links. It is best determined by field measurements.

Note One can lower the BER, resulting in greater reliability. However, the resultant compromise is a reduction in the data throughput and an increase in the latency.

4a.8 Licensed and Unlicensed Frequencies

Permission to use a licensed frequency band has to be obtained from the host government. In the US the FCC issues licenses for the MMDS band at auction. Current license holders, or those holding leases from these license holders, are the only operators permitted to use radios on those frequencies. The band has channels or segments, so multiple systems can be installed in a geographic area without interference. The MMDS band in the US has 31 licensed channels in the main part of the band. Each channel is 6 MHz wide. The MMDS "response" channels, from 2686 to 2690 MHz, may also be aggregated to create an additional 4 MHz of spectrum for data communication.

An unlicensed band, such as the U-NII band, is a band of frequencies that can be used by anyone without having to obtain a license. However, you must use radio equipment that is "type approved" by the FCC for use within the specific band. If you are installing a U-NII band link between two buildings, across a parking lot or across town, you will find that this type of system is much simpler to implement than licensed systems. By using very directional antennas in the installation, you are not likely to experience interference.

MMDS Band / Channel Plan Selection

For MMDS installations, the frequency you will be using is based on what has been licensed or leased to you. Use the tables below to determine which channel designation is appropriate for your allotted frequencies. Table 4-3 defines the starting, center, and end frequencies along with channel designations for 6-MHz MMDS channels. Table 4-4 defines the frequencies and channel designations for 12-MHz MMDS channels.

Table 4-3: MMDS Frequencies and Band Plans: 6 MHz MMDS Channel (US)	**Start (GHz)**	**Center (GHz)**	**End (GHz)**	**MMDS Channel (US)**	**Start (GHz)**	**Center (GHz)**	**End (GHz)**
A1	2.500	2.503	2.506	E1	2.596	2.599	2.602
B1	2.506	2.509	2.512	F1	2.602	2.605	2.608
A2	2.512	2.515	2.518	E2	2.608	2.611	2.614
B2	2.518	2.521	2.524	F2	2.614	2.617	2.620
A3	2.524	2.527	2.530	E3	2.620	2.623	2.626
B3	2.530	.2.533	2.536	F3	2.626	2.629	2.632
A4	2.536	2.539	2.542	E4	2.632	2.635	2.638
B4	2.542	2.545	2.548	F4	2.638	2.641	2.644
C1	2.548	2.551	2.554	G1	2.644	2.647	2.650
D1	2.554	2.557	2.560	H1	2.650	2.653	2.656
C2	2.560	2.563	2.566	G2	2.656	2.659	2.662
D2	2.566	2.569	2.572	H2	2.662	2.665	2.668
C3	2.572	2.575	2.578	G3	2.668	2.671	2.674
D3	2.578	2.581	2.584	H3	2.674	2.677	2.680
C4	2.584	2.587	2.590	G4	2.680	2.683	2.686
D4	2.590	2.593	2.596				

Table 4-4: MMDS Frequencies and Band Plans: 12 MHz MMDS Channel (US)	**Start (GHz)**	**Center (GHz)**	**End (GHz)**
A1/B1	2.500	2.506	2.512
A2/B2	2.512	2.518	2.524
A3/B3	2.524	2.530	2.536
A4/B4	2.536	2.542	2.548
C1/D1	2.548	2.554	2.560
C2/D2	2.560	2.566	2.572
C3/D3	2.572	2.578	2.584
C4/D4	2.584	2.590	2.596
E1/F1	2.596	2.602	2.608
E2/F2	2.608	2.614	2.620
E3/F3	2.620	2.626	2.632
E4/F4	2.632	2.638	2.644
G1/H1	2.644	2.650	2.656
G2/H2	2.656	2.662	2.668
G3/H3	2.668	2.674	2.680

4b. Subscriber Equipment Issues

A number of technical issues effect the performance of subscriber antennas and transceivers. These issues are briefly discussed below.

Using multiple modems with a single transceiver

Linearity of the upstream transmitter chain has a great impact on system performance. Although QPSK upstream signals are very forgiving to degradation in linearity, there are a number of circumstances where linearity becomes much more critical. Generally, these involve the use of a single transceiver to transmit multiple upstream carriers simultaneously (as is required when using a single transceiver attached to multiple cable modems in an MDU, each using different frequencies, or if more complex multi-carrier modulation formats are employed). In order to isolate other system issues from an evaluation of a transceiver's capability, the best measure of linearity of the transmit chain is output IP3, measured using a two-tone test. This measure provides an "apples-to-apples" comparison of various transceivers. Low power transceivers provide a transmit output IP3 of +36 dBm to +40 dBm.

Coverage

Transmit power is a key parameter which determines the coverage which can be expected in a deployment for a given architecture. In general, the higher the transmit power, the better the coverage. The best measure of the transmit power over temperature is the output 1 dB compression point (P1dB) and gain variation over temperature. These measures eliminate other variables such as modulation and modem performance from the evaluation of a transceiver's impact to coverage. Typical low power MMDS transceivers provide an output P1dB of +25 dBm to +28 dBm, with low gain variations over temperature.

Frequency Stability

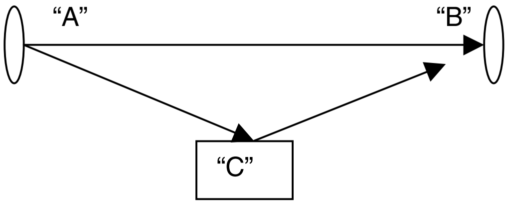
Upconversion frequency stability differs between various available transceivers. The typical broadband wireless modem or cable modem has very relaxed requirements for downstream frequency stability, but has much tighter requirements for upstream stability. Modem systems vary in their upstream frequency stability requirements, based on the ability of the upstream burst receiver to track out frequency variations. Specifications among different products vary between +/- 20 kHz and +/- 100 kHz. The best transceivers utilize temperature compensated oscillators (TCXOs) or oven controlled oscillators (OCXOs) to provide sufficient stability to work with wireless modems in use today. Some transceiver suppliers have chosen to incorporate the use of GPS timing references in order to achieve the ultimate stability. Although this approach provides frequency stability of better than +/- 1 kHz over all effects, this approach adds substantial cost to customer premises equipment, and reduces reliability due to increased circuitry and reliance on an external system.

Power Blanking

Power blanking is the ability of the transceiver to turn off its output power amplifier stages when the unit is not actually transmitting data. The reason that this feature is very important is that network coverage can be substantially reduced in a large market. Without power blanking, the sum total of the upstream noise floor from a large population of transceivers would be a combination of varying noise sources with varying microwave transmission path losses of near and far transceivers. This would create a buildup of broadband noise interference. The typical point at which the noise floor from such transceivers (BB Noise) exceeds the thermal noise floor, for example, is –117dBm and 700 subscribers. For this reason, it is critical to ensure that the power amplifier stage blanks (turns off) when the transceiver is not transmitting data.

Multipath

Multipath, as mentioned in the headend antenna (Section 4a.3) above, is the phenomenon where an intended receiver sees not only the desired signal, but reflections of the signal, delayed in time, due to the differences in transmission path length between the direct reception path and the reflected reception paths. The figure below shows how multipath is caused.



The transmitter sends a signal to the receiver over direct line-of-sight path A-B. However, due to the radiation patterns of the antennas, the receiver also sees the same signal reflected off a nearby building (path A-C-B). The length of path A-B is 10 miles, while the length of A-C-B is 11 miles. Due to this increased path length, the signal that traveled path A-C-B has been delayed 5.4 microseconds relative to the direct path A-B. If the power of the reflected signal is close to that of the direct path signal, this delay will effectively cancel any information contained at frequencies of approximately 100 kHz. In this example, a 100 kHz carrier is combined with one of equal strength, delayed by 5.4 microseconds. As shown, the resulting signal is substantially lower in amplitude than either the directly received signal or reflected signal and the phase of the result is altered. Complex modulation schemes such as QAM, which encode information in the amplitude and phase of the signal, are particularly affected this by multipath. On a typical digitally modulated waveform, the signals at a select set of frequencies are attenuated, thus reducing the ability of the receiver to demodulate the signal. It is therefore important to reduce the effects of multipath as much as possible.

The primary methods of addressing multipath include:

a. improving transmit antenna performance so the transmitter sends less energy in directions which may cause reflections (see antenna performance)
b. improving receive antenna performance so the receiver does not see as much energy from the reflection (see antenna performance)
c. signal processing whereby the receiver attempts to identify the time delay and magnitude of the echo and cancel it mathematically, prior to demodulation

Generally, signal processing to eliminate multipath follows one of four approaches: antenna diversity, adaptive equalization, frequency diversity, and coding diversity. Antenna diversity, the simplest and most expensive of the approaches involves the use of multiple receive antennas. The receiver monitors the signal reception characteristics from these antennas and determines which is best to use. The drawback of this approach is that in order to be effective, the antennas must be physically separated sufficiently to provide different multipath characteristics--generally on different portions of the customer premises building. This approach increases cost substantially, not only in the cost of multiple antennas, but also the cost to install these antennas.

A second approach to reducing effects of multipath involves adaptive equalization. This approach takes delayed versions of the received signal and adds them to the received signal with appropriate weighting (or taps) in order to reduce the effects of reflections. In essence this approach simulates reflections in order to eliminate their effect. Generally, the key parameter that describes the effectiveness of adaptive equalization is length, usually expressed in the number of IF filter taps or the time delay in nanoseconds. Using this basic premise, the optimum length of the adaptive equalizer for a given transmit and receive antenna can be calculated.

Frequency diversity relies on the fact that certain offset frequencies are affected more or less by multipath than other adjacent frequencies. A drawback is a requirement for multiple transmitters and the need to obtain another licensed frequency. The same concept is built into complex modulation schemes, such as the Orthogonal Frequency Division Multiplexing (OFDM) format that creates signals with many different carriers and varying frequencies. Through error correction, and tagging and avoidance of frequencies which are most affected by multipath, this modulation format compensates for frequency selective fades caused by reflections. When combined with adaptive equalization, this modulation provides extreme robustness against multipath. Since the demodulator for an OFDM modem must simultaneously demodulate a large number of channels, and correct for missing signals, until this technology is integrated into commercially available modem chips, its use is better suited for commercial applications and ones involving low data rates.

In direct sequence spread spectrum (DSSS) modulation, reflections are essentially canceled by the despreading sequence in the demodulator. However, with this type of modulation, it is possible to actually use the energy found in large reflections by adding a second or even third despreading demodulator and adding the outputs of the two, delayed by the appropriate amount. This is essentially the equivalent of adaptive equalization for DSSS modulation formats.

Although all of these methods are used in wireless communications today, adaptive equalization and its spread spectrum variant are the only ones which have been deployed in sufficient volume to bring down the cost to consumer levels. The incremental cost of adaptive equalization is very small because equalizers are normally integrated directly onto the modem integrated circuits utilized in broadband wireless access systems.

Cellular Environment

Wireless access using frequencies in the 2 GHz to 4 GHz range requires line-of-sight for reliable service. This means that if the receiver cannot "see" the transmitter, then the link is impaired, thus limiting coverage in an intended service area. Although new modulation formats such as Orthogonal Frequency Division Multiplexing are emerging which claim to provide service without line-of-sight, they rely on a combination of frequency diversity, high transmit power and receiving signals off reflections to get at least a portion of the signal to its intended reception site. Despite advanced signal processing, receiving signals through obstructions such as hills or buildings is not possible.

For point-to-multipoint wireless access systems, one approach to overcoming line-of-sight constraints and increasing coverage is to use multiple cells where any customer premise has a number of hub sites which can be accessed for service. This approach substantially increases the probability that the customer premises equipment will achieve line-of-sight with at least one hub within its range.

This approach generally utilizes a combination of frequency diversity and polarization diversity to minimize interference between cells. Despite these efforts, there are instances where a single customer will "see" multiple hubs where an undesired signal will interfere with the intended link. The figure to the right depicts this scenario. In such instances, the only method for addressing such issues is through the use of well designed customer premise antennas. Through narrow beamwidths, low sidelobes and high front-to-back ratios, the antenna must reject undesired signals, while providing robust reception of desired signals.

Antenna Performance

The most effective method of reducing or eliminating multipath effects and self interference from nearby cells is through proper antenna design. Use of a highly directive transmit antenna will reduce the energy transmitted at angles not directed at the intended recipient. Similarly, use of a highly directive reception antenna prevents the antenna from seeing reflections. Hypothetically, the reception (point B) of a directly transmitted signal from point A is compared to the reception of a reflected signal from point C using two antennas. Both antennas receive the directly transmitted signal adequately. However, the more directive antenna attenuates the reflected signal by approximately 10 dB more than the less directive antenna.

Although in theory, using a highly directive antenna seems like an ideal solution, a few realities stand in the way of solving any concerns regarding multipath:

In a point-to-multipoint system, generally the antenna at the hub is used to communicate with a large number of subscribers. Therefore, hub antennas generally have wide beamwidths ranging from 360 degrees for omni-directional coverage to 20 degrees for narrow sectorization plans. Generally, antenna size and directivity are related. At microwave frequencies such as MMDS, highly directive antennas are large and difficult to install. Specifically, an antenna with a 10-

degree beamwidth is approximately 2 ft square. Contrast this with a 12 in square antenna that provides approximately a 20-degree beamwidth. The cost (antenna, mounting hardware and installation labor) for a large, narrow beamwidth antenna is substantially greater than that of a small, wider beamwidth antenna.

It is therefore important to select a properly designed antenna, where the maximum directivity is achieved with the minimum size. Directivity is generally specified by three parameters: beamwidth, sidelobe level and front-to-back ratio. Sidelobe level and front-to-back ratio are measures of how much an antenna sees outside its main beam, while beamwidth is a measure of how much the antenna sees through the main beam. Typically, a well-designed antenna will provide sidelobe suppression of 20 dB and front-to-back ratios of 25 dB. Performance better than this can be achieved, but usually at the expense of overall antenna gain. Beamwidth is generally related to gain of the antenna: the higher the gain, the narrower the beamwidth.

On a given antenna, performance changes over frequency. While an antenna may be optimized to operate at a specific frequency, it is more difficult to achieve good performance over the entire band of interest. Therefore, it is crucial to investigate performance over the entire band of interest. An easy method of doing this is to review the worst case performance over frequencies of interest. The worst points on patterns for all frequencies of interest are used to generate a mask, representing the overall performance of the antenna. This mask, indicated by the "Worst Case" plot, is then used to calculate the expected performance of the antenna with respect to multipath and interference.

FCC Type Acceptance

The Federal Communications Commission (FCC) places requirements on products that intentionally transmit signals. The FCC rules limit the amount of power that may be transmitted in-band and out-of-band, when that power may be transmitted, and other restrictions related to interference issues. The only certain way to ensure that the products you are using meet these requirements is to purchase FCC Type Accepted products. However, when an industry launches new applications, such as broadband wireless access, type accepted equipment might not be available for initial deployments. Therefore, the FCC allows the use of non-type accepted equipment under a limited set of circumstances, usually under developmental licenses. Generally, non-type accepted equipment may not be used, unless your license specifically permits it.

The requirements for type acceptance of equipment are as follows:

a. spectral mask of the transmitted signal
b. maximum signal transmit power for a single carrier
c. maximum signal transmit power for a single piece of equipment
d. restrictions on transmission
e. power turn off capability when unit is not intending to transmit signals
f. inability for equipment to transmit tones

Spectral Mask

The FCC defines the spectral mask requirements for transmission using MDS, MMDS and ITFS spectrum as follows:

> "21.908 (d) The maximum out-of-band power of a response station using all or part of a 6 MHz channel and employing digital modulation shall be attenuated at the 6 MHz channel edges at least 25 dB relative to the maximum authorized power level of the response station, then attenuated along a linear slope from that level to at least 40 dB at 250 kHz above the upper and below the lower channel edge, then attenuated along a linear slope from that level to at least 60 dB at 3 MHz above the upper and below the lower channel edge, and attenuated at least 60 dB at all other frequencies."

Transmitting Power

The FCC places the following limitations on the maximum power and EIRP that a response station may transmit:

a. A response station may not transmit in excess of 33 dBm of power.

b. A response station may not have an EIRP in excess of 63 dBm per 6 MHz channel, prorated for the occupied bandwidth transmitted. For example, for a 200 kHz channel, the maximum EIRP is 63 - 68 + 53 = 48 dBm, which can be achieved with a 25 dBi antenna and a transceiver transmitting 23 dBm output power.

With careful consideration of the above subscriber equipment issues, the operator of a fixed broadband wireless access network can make the best business decision ahead of time, prior to the system launch date.

5. Comparing Fixed Wireless Solutions to the Alternatives

In the next several years, all of the different data access technologies will play a role in subscription services for video, voice and data, over private networks and the Internet. Each of these technologies will yield particular benefits from differing standpoints of the various local operators. A given application will tend to yield to the most suitable solution; however, trade-offs will make some solutions unsuitable. The individual operator will need to consider other transport alternatives (see Table 5-1).

Table 5-1. Transport Alternatives

Platform	Current Availability for Business	Maximum Data Rate	Symmetrical or Asymmetrical
Broadband Fixed Wireless	Low	44Mbps	Symmetrical
Twisted Pair Copper	High	56 kbps	Symmetrical
Enhanced Copper (xDSL)	Low	1.5Mbps downstream 64 kbps upstream	Asymmetrical
Fiber-in-the-Loop	High	2.5Gbps	Symmetrical
Hybrid Fiber Coax (HFC)	Low	30Mbps downstream 10Mbps upstream	Asymmetrical
Broadband Satellite	Medium	400 kbps downstream Phone line Upstream	Asymmetrical
Very Small Aperture Terminal (VSAT)	High	2 Mbps	Symmetrical

The transport stream decision involves more than just data rate limitations. Certain basic features must be considered. For example: although twisted pair copper is available to 99% of all users, its data rate is unacceptably low for broadband applications of video or combinations of data, voice and video. On the other hand, twisted pair copper does provide lifeline services, in that power to run the system is provided over the network connection.

Enhanced copper concepts such as xDSL have the potential to be made available to very large audiences, since they use the twisted pair line. Unfortunately for DSL, deployment to complete populations is limited by the subscriber’s physical distance to the nearest central office

(CO) or POP. This distance is proportional to electrical delay and it is limited to approximately three (3) miles for xDSL.

Fiber appears to be the best solution for symmetrical high-speed data. Gigabit speeds are readily available on fiber-optic cable. Additionally, it is being installed in most large businesses today. Fiber capable of OC-3 rates can be installed relatively cheaply inside new or existing facilities. However, the installation of fiber outside the facility can be expensive and require substantial time to complete due to the amount of underground work required.

Hybrid fiber coax (HFC) provides asymmetrical data via a combination of fiber in the backbone network structure and a hybrid coax/fiber cable to the end user. Cable is currently seeing an increase in usage in the business market but at present is primarily a residential access technology and runs to relatively few businesses. Additionally, since this is not a dedicated bandwidth solution, actual upstream and downstream rates will vary with the number of subscribers on the system at any given time.

Satellite technologies such as broadband satellite and very small aperture terminal (VSAT) provide asymmetrical data flow to the user. Although a single satellite can cover a wide footprint for point-to-multipoint solutions, the usage has not expanded according to expectations, possibly because, in the case of broadband satellite, the downstream path is from the satellite while the upstream path is via conventional twisted-pair phone lines requiring multiple modems.

Although each of the methods listed above has its advantages, broadband fixed wireless solutions bridge several of the disadvantages of the others and bring unique advantages. Providing symmetrical, fiber-quality, high-data-rate information in a variety of situations, broadband fixed wireless solutions are quick to install, with no external construction required. Leading-edge technology enables the use of unobtrusive rooftop antennas, eliminating the need for trenching in cable and fiber solutions and costly towers in previous wireless products. This makes broadband fixed wireless solutions perfect alternatives when high speed, high quality and quick time to market are critical to success.

The unavoidable convergence of multiples of voice, video and data applications is real. As we continue to see the need increase for connectivity, service providers will be required to look for alternatives to doing business the old fashioned way. The new Internet economy demands that high-quality service be available to all that want it. In the near future, it will no longer be acceptable to ignore a facility (or a single customer within a facility) because the facility has no access. Customers are demanding service. The amount of time from a customer call to when they expect service will be counted in hours not weeks or months. This requires that service providers have at their disposal a variety of alternatives to solve a customer's need for connectivity quickly and efficiently. These alternatives must provide cost-effective, scalable solutions that not only result in acceptable solutions to the end user but also enable profitable revenue streams for the service provider.

Packet-based broadband fixed wireless networks provide the service provider with that answer. Broadband fixed wireless networks provide the flexibility to quickly install new links in any part of the network where connection is needed. Wireless access provides the service provider with a cost-effective solution that minimizes the up-front investment, enables the service provider to activate new links with little or no recurring cost, and provides the service providers with the product differentiation that sets them apart from the competition.

Understanding Wireless Network Performance

What is the speed on an Expressway? The 65-mph speed posted at the roadside, the 5-mph that the traffic moves during rush hour or the 55-mph that the cars in the HOV (high-occupancy vehicle) lane experience at the same time?

Even though it is slower than the 65-mph rated speed, the HOV (high-occupancy vehicle) lane has the advantage. While the actual speed is lower, constant flow and fewer vehicles mean that more traffic passes in a given period. The same can be true for high-speed or broadband Internet access. Even though some service providers quote a lower-rated speed, data throughput may exceed that of a competitor with higher advertised speeds.

It is important to understand the key differences between advertised performance and the actual speed delivered. The variance can be due to many factors. The speed discrepancy debate starts to take shape in wireline systems. A 56K dial-up modem does not give the advertised file transfer rate of 7 kbps. Something in the range of 0.2 kbps to 2.0 kbps is more common. T1 and DSL exhibit similar differences between advertised and true performance. T1, for example, claims 1.544 Mbps. The reality is a connection somewhere in the range of 1.2 Mbps to 1.4 Mbps.

The speed of a DSL line depends on the distance from the central office (CO). It is not only the direct measured distance, but the length of the actual connection route between a point A and a point B. Other significant factors include the quality of the copper, bundle cross talk, the number of splices in the line, bridge taps and load coils. These factors contribute to a common scenario in which users a few miles away get only a 100-kbps to 200-kbps connection.

With fiber to the desktop, download speed is limited by many external factors including the hardware interface between the PC and the fiber link, the operating system, and application software controlling the transfer. The PC itself, including its CPU and bus speeds, disk access time, and amount of RAM are also factors. The connection between the PC and the link may be a LAN, so factors such as other LAN traffic, congestion, router performance and the speed of the network interface card can produce bottlenecks.

The speed of the server providing the data can also be a major factor. Tests have demonstrated significant differences in performance between servers running Windows and Linux, as well as for different controlling software applications. Moreover, latency induced by the server or client hardware, including disk access time and RAM size, can become the overriding limitation on ultimate link speed.

All these limitations influence dedicated point-to-point links with no networking overhead. When the link is part of a shared network, multipoint system, networking overhead also comes into play. One of the best features of wireless networks is how easily and naturally a shared, multi-user network can be created in the air interface. As with any multiple access network scheme, time delays in the grant of bandwidth to an individual user can and will decrease throughput.

Wireless Discrepancies

Wireless vendors often advertise what is known as "signaling" rate (the rate at which bits are sent over the air interface) as the link speed, which can be misleading. The actual throughput may be significantly less due to overhead from a variety of sources. One source is header information, which consists of addresses, routing information, signal control, forward error correction and QoS bits. Often, this information is added to every packet of data transmitted.

High speeds alone are not enough to create a truly fast link if latency is high. Even in a predominately one-way transmission, such as an FTP (File Transfer Protocol) download, the uplink contains return acknowledgments. The downlink cannot stream more data until the uplink return acknowledgment has been received. Such latency translates into gaps or dead time in the total payload transmission. In a highly asymmetrical link, the slow uplink will serve to limit any FTP download speed. This is true, for example, in a "megabit/second" wireless downlink with a telephone line return such as that used in many LMDS or MMDS systems.

Changing the network access scheme, effectively making the payload packets longer so the overhead is a smaller percentage of the total, can reduce overhead. However, the longer a streaming transmission is, the longer the latency is for other users wanting to gain access.

Any network can be optimized for good throughput for streaming applications, but then be proven far less than optimal for thin client-server transactional applications. Because reducing latency is the key element for transactional data transfer, a compromise must be struck. So, when comparing throughput, look closely at the conditions under which performance is measured. Look especially at the assumed packet sizes and number of users on the test network.

Networks designed for metropolitan area applications must account for the speed of light. As swift as it is, the speed of light is slow enough to contribute to overhead. Range delay can produce a hesitation of about 150 milliseconds at a distance of 25 miles. Half-duplex turnaround time is another overhead drain. Most low-cost wireless systems are half-duplex (they cannot transmit and receive simultaneously). The time it takes a system to switch modes adds to the overhead and reduces payload time. When combined with range delay, it can become even more significant.

Range delay must also be considered in the design of multiple access networks. As anyone who has tried to stretch a wireless LAN system beyond a mile can attest, the efficiency of a listen-before-talk access scheme degrades drastically as the range delay increases. This increases the probability of packet collision. And as packet collision increases, throughput decreases dramatically.

All wireless links have an associated BER (bit error rate) that varies with signal strength. Inevitably, some packets must be retransmitted; these retransmissions further reduce throughput and effective speed. A vendor that equates or advertises signaling rates as throughput is ignoring this very real condition. If high speeds can only be achieved under ideal conditions, and very high signal-to-noise ratios, then the end user will never see those rates or the wireless link installation could become prohibitively expensive.

Moreover, how retransmission is handled, or ignored, can severely affect performance. The control logic of TCP/IP interprets lost packets as congestion and subsequently causes the controller to throttle back transmission speeds. If retransmission responsibility is passed to the higher layers of TCP/IP control, the link might only end up attaining half the rated speed even under modest retransmission rates.

Some unlicensed wireless networks use frequency-hopping technology. The tuning time, the time it takes to "hop" a signal from one frequency to another, must be considered in the calculation of overhead. A product with a high signaling rate may have a slow tune time. Even with the advantage of digitally tuned synthesizers, achieving tune times in the range of 10 microseconds to 100 microseconds can be expensive. Many lower cost products have tune times from 100 microseconds to 1 millisecond. Depending on how often the system hops, this millisecond of essentially dead time can chew up a significant percentage of time that could be allocated to data transmission.

Compression should be another warning sign along the road of overstated bandwidth. Beware of the vendor claiming speeds based on assumptions of data compression by the link equipment. Claims of substantial speed savings through compression are unrealistic in today's networking environment because most large data files are already compressed. Attempting to compress data that is already compressed sometimes actually results in a slightly larger payload.

Wireline verses Wireless

Broadband wireline and wireless technologies share a common challenge: overhead. The difference between the speed expectations created by marketing departments and the actual speed delivered by network operations is due to limitations in network equipment and network architecture. This is in addition to whatever may be created by the end user's own equipment. But regardless of what marketing departments proclaim, the only relevant issue to the end user is the effective throughput experienced while on the Web.

Providing this broadband throughput is something that wireless provides very efficiently and, compared to dedicated access and xDSL options, wireless networks can also deliver substantial savings in infrastructure investment. By sharply reducing provisioning time while providing greater market coverage, wireless broadband access will increase exponentially over the next few years.

Wireless providers will come knocking with many exciting new flavors, business models, and service levels. Remember to distinguish between hype and reality. If you are a carrier or provider, avoid potential backlash from customers whose expectations and real experience don't match because of the overhead inherent in any system.

6. Business Planning

6a. System Starter Kit

Some Wireless Cable Operators plan to build from revenues when total savings or complete investment funding is not available. These Service Providers must begin on a limited start-up budget. The following list of equipment includes enough of the RF and high speed routing equipment to begin with one downstream and one upstream channel. What is not included below is the Internet backbone connection equipment and LAN servers that will support value added Internet services.

Headend Equipment List

- Downstream Router
- Upstream Router
- Management System
- Software License
- Fast Ethernet Switch
- RF Transmitter, Transmission Line and Antenna
- RF Receiver, Transmission Line and Antenna

Subscriber Base (Terminal) Equipment List

- Client Modems (multi-user)
- Client Modems (single-user)
- Transceivers and Antenna/Transmission Line Kits
- Network Interface Cards (NICs) for End-User PCs (A/R)

6b. Service Launch Period Commitments

Marketing and Engineering time of approximately six months is needed during the crucial first year of operations. The Service Provider should start deploying terminal equipment early. Pre-launch and post-launch involve the following key issues:

i. Field testing
ii. Capacity adjustments and multipath corrections
    - "Starter Kit" (beta test)
    - Maximize QoS and minimize truck rolls
    - Redesign or reconfigure sub-systems if necessary
iii. Web site - customer service hotline
iv. Advertise (e.g. comparative download speeds)
v. Announce future applications (e.g. IP telephony)

A key element in any new service launch is to quickly establish credibility with the customer base. In the case where this is an entirely new service, reduced price and delayed payment starts may be necessary to overcome buyer inertia. Establishing an attractive web site is an essential part of a successful plan, as most of the customer base (early adopters) will be pre-existing Internet users. A strategic way to begin advertising is one that emphasizes the high-speed connectivity offered and what it means in comparative download times. In the future, IP telephony, video IP and video download will be offered as attractive hooks.

A sound technical plan should be followed, which is to build on standard protocols such as TCP/IP, Ethernet (10Base-T), ATM switching and forward error correction (FEC). This way the initial system will function reliably and future offerings will be added easily.

6c. Capacity Management Procedures

A dynamic and well-maintained network has no undesired limits. In order to avoid unforeseen slowdowns or bottlenecks, the design has to be flexible. When a new system launches it is expected to work quite well, initially. As the number of users increases, a single T1/E1 connection to the Internet will become a real bottleneck. This is where advanced planning plays a significant role in customer satisfaction. Upgrading to a T3, E3 or equivalent circuit at the right time (and later an OC3 or equivalent) will reduce dissatisfaction and churn. Deployment of multiple headend antennas (sectorization) and/or secondary nodes (cellularization) may be necessary. The key is to do so before the overall data throughput has bogged down to unacceptable levels. In other words, the Service Provider’s goal should be to stay ahead of the curve.

Instead of assuming that one downstream and one upstream channel is enough for future growth, multiple channels might be necessary. Applications for licensing of two additional channels should be in process, at least initially. That is, a more flexible use-of-spectrum plan is for a minimum of two channels in each direction, downstream and upstream. As alluded to above, the system may need to be segmented using hybrid fiber coax (HFC) networks and frequency re-use, but these options can be planned for, and they can be added later. With frequency re-use the same downstream and upstream frequencies can be used for data transmission throughout the system, but each node or cluster of nodes will have different data on its respective downstream and upstream channels.

Another important aspect of capacity management is not to set customer expectations too high, then find it necessary to reduce throughput later. A good plan is to set effective data throughput for basic services at a baseline, e.g. 128kbps. [Note: Data throughput and data transmission rates are not the same thing. Data transmission rates can still be 10Mbps (megabits per second), even though data throughput is being managed at lower values.]

One other piece to the capacity management puzzle is the so-called back office, and includes the Provider's network operations center (NOC), customer help desk, billing, marketing and general business operations. As the data modem service grows, so too, must the back office.

7. Conclusion

Multichannel Multipoint Distribution Service (MMDS) provides several advantages over competitive terrestrial Internet access methods because it effectively utilizes full duplex service provisioning. Despite its flexibility, however, the technology, also known as Wireless Cable, has some important technical drawbacks (discussed below) compared to DSL and cable modems.

MMDS traditionally comprises (8) 6 MHz channels in the E and F Group from 2596 MHz to 2644 MHz. When the rights are licensed in conjunction with the remaining (23) ITFS/OFS channels (Groups A, B, C, D, G and H) the operator is able to choose among (31) channels from 2500 MHz to 2686 MHz for downstream data and video delivery. There is also a bank of (31) 125-KHz response channels available from 2686.0 MHz to 2689.875 MHz assigned for upstream, voice and data applications. Typically however, an operator would rather use one or two of his MMDS/ITFS/OFS channels, or he may even have the rights (or license) to use one or two channels in the Multichannel Distribution Service (MDS) band from 2150 MHz to 2162 MHz for upstream data traffic. By using a standard such as MDS for upstream the cost of subscriber transceiver equipment is reduced. And, for a large number of subscribers, the transceiver choice can dramatically effect the bottom line.

The technology's upstream and downstream specifications reveal some technical advantages over competitive technologies. MMDS systems broadcast downstream data in a TDM format to subscriber modems, a plus given the asymmetric nature of Internet traffic. Multiplexing techniques therefore play an indispensable role in handling Internet traffic given its bursty nature; the average downstream and upstream rates can vary as much as 5:1 to 20:1. MMDS's ability to broadcast this traffic directly to subscribers via RF (radio frequency) waves instead of passing it through the switched network is particularly advantageous. While cable modem systems are also able to dedicate transmission to Internet data, many have to be built from scratch to provide full duplex usage and are more costly to implement.

MMDS systems have distinctive data rate and bandwidth specifications. These systems provide a downstream raw data rate of 30 Mbps and an attainable speed of 27 Mbps, which factors in FEC (forward error correction). MMDS's downstream bandwidth capability utilizes 6-MHz channels that, for example, can allow up to 540 users to access the system simultaneously at 50 kbps (see Figure 6-1). If the Internet traffic is particularly bursty and there is a sudden upsurge in demand, the system can handle up to 2700 subscribers, a loading factor of five times the typical capacity. The ratio of upstream to downstream subscribers in typical 6-MHz channels is approximately 3:1. Upstream, MMDS consists of 48 channels that are each 125 kHz wide. These transmissions have a data rate of 200 kbps with no FEC. The capacity is at least at 36 percent of the MAC (media access control) efficiency of 72 kbps, which translates into 38 active simultaneous users uploading data at an average rate of 38.4 kbps. Upstream transmissions can accommodate up to 187.5 subscribers at a five times loading-factor in heavy traffic (Figure 6-1).

Upstream
48 channels each 125 kHz wide
Raw data rate 200 kbps
Capacity 36% MAC efficiency
37.5 active users, 38.4 kbps average rate with burstiness of 20x
187.5 subscribers @ 5x loading-factor
48 channels accommodates 9,000 subscribers per 6 MHz TV channel
Downstream
64-QAM 6 MHz channel
Raw digital rate 30 Mbps
540 simultaneous users @ 50 kbps throughput rate
2700 subscribers @ 5x load factor
The ratio of U/S to D/S in a 6 MHz channel is approximately 3:1

Figure 6-1: Two-Way MMDS Example Service Specifications.

MMDS systems utilize innovative technologies to compensate for their shared bandwidth infrastructure. MMDS data is sent as packets of address and payload data that requires each subscriber's modem to monitor the downstream flow and screen for information specifically intended for that particular user. The shared nature of the downstream flow requires an algorithm--most commonly MAC--to separate the upstream and downstream bandwidth resources among subscribers, especially when Internet traffic is heavy. The upstream traffic is sent to the POP, which typically constitutes the software and hardware used by the local ISP (servers, modems, and gateways) and connects to the headend and consumer via RF wireless broadcast signals (see Figure 6-2).

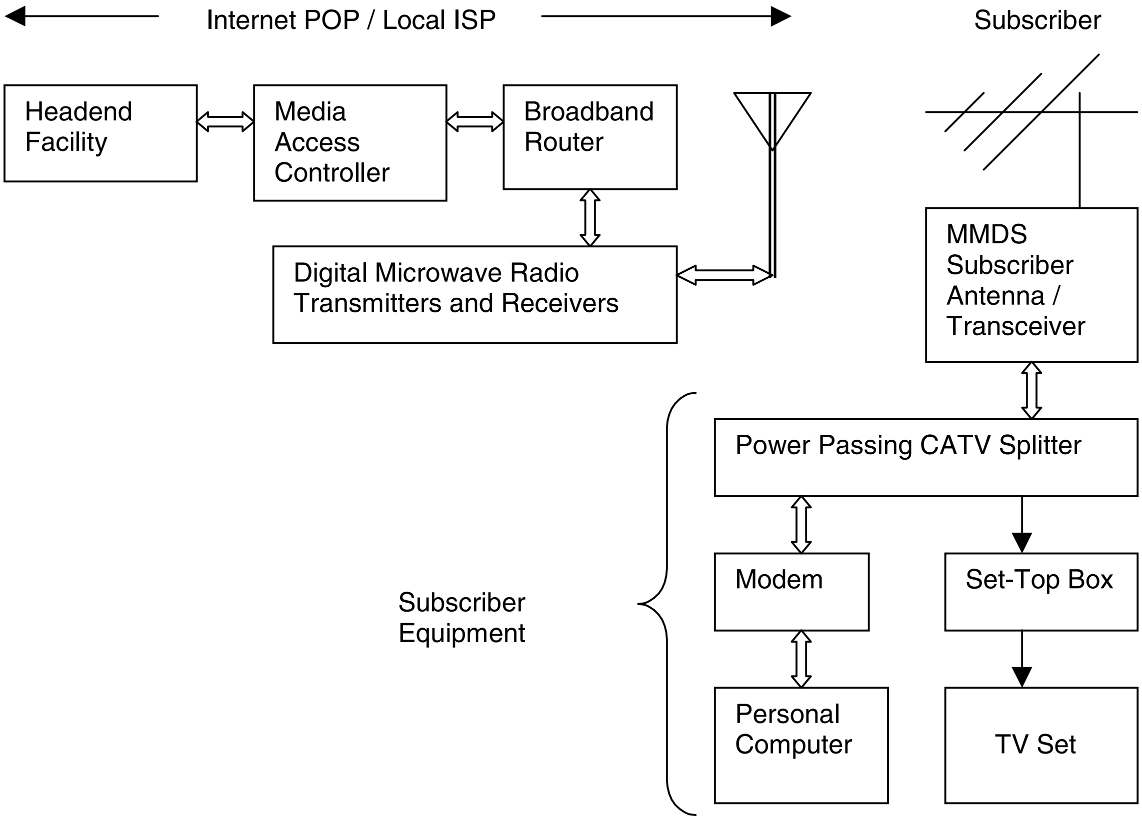


Figure 6-2: Internet Services over MMDS – RF Return Link

This RF upstream and downstream MMDS system is preferable to competing technologies, especially SDSL (symmetric DSL), in that its asymmetric broadcast capabilities allow it to be more responsive to two-way technical requirements and usage patterns. Perhaps the most compelling reason is that two-way RF systems specifically deployed to handle Internet traffic are the most flexible in meeting the distinct patterns of Internet users because they do not have to accommodate telephony-related traffic. In addition, these systems can operate entirely from the headend without feedback from the subscribers to prevent heavy data users from monopolizing the downstream channel capacity.

MMDS is taking advantage of spectral efficiencies of digital video compression to increase the number of RF channels per system and is closing the capacity and speed gap with DSL and cable. For example, cellularization techniques utilize multiple hub sites to offer signals to geographically dispersed groups of subscribers. This augments capacity by sending different information from different cell sites using the same RF channels. Because the frequency is reused, users can send more bandwidth-intensive graphical and audio files while simultaneously conserving bandwidth.

While the limitations of DSL and cable modems have been well documented, MMDS has its own technological disadvantages. One is a line-of-sight constraint, which can pose difficulties for MMDS users in some topographies. Once the signal comes into contact with a physical barrier it rapidly diffuses or attenuates, and the data is lost. A second disadvantage is that xDSL generally offers faster upstream data rates. While MMDS might have a comparatively impressive downstream rate of 27 Mbps, the upstream is relatively inadequate at 200 kbps.

Coaxial cable systems offer other advantages over MMDS, including greater user capacity and available bandwidth as well as the absence of the line-of-sight constraint. Cable provides more bandwidth, especially in terms of downstream spectrum, which is in the 50-MHz to 550-MHz range. MMDS, on the other hand, only offers (31) 6-MHz channels in comparison. Even in terms of upstream capability some cable modem systems can far exceed MMDS. For example, while optimal coaxial systems offer upstream transmissions in the 5-MHz to 35-MHz range, wireless cable is typically limited to (2) 6MHz channels with 125 kHz wide subchannels. Cable systems were better designed to accommodate video capacity requirements, which is particularly useful for innovative high-end Internet use such as transmitting high-definition pictures and video files. However, cable systems were not designed to carry full duplex traffic, and much of the existing cable plant must be upgraded or replaced to offer this functionality.

MMDS two-way RF broadcasting proves to be more flexible than DSL or cable to route Internet data. This is because the specifications of MMDS systems can be uniquely defined and dedicated to Internet use. The technology is more effective and efficient than xDSL, which often funnels its traffic, at least part of the way, through the PSTN. MMDS does not burden networked corporate users with high infrastructure costs associated with updating cable systems. While the technological specifications and factors involved with MMDS are highly dynamic and complex, MMDS is the most appropriate emerging technology for two-way Internet applications.

A large volume of people simply cannot all be served by Cable or by DSL. Fiber can only go some places, and DSL can only reach so far. This leaves a big hole in the middle for large bandwidth needs and creates an even playing field (or advantage) for the wireless broadcaster. Fixed wireless is the perfect kind of thing to fill this gap: it beats fiber into the home, in terms of availability, speed, cost and delivery.

The true value for fixed wireless solutions is in its ability to supplement other technologies that can provide high-data-rate services. As mentioned earlier, key areas for expansion of fixed wireless solutions will be in under-served markets such as small to medium-sized business where high-speed fiber alternatives are prohibitively expensive due to right-of-way issues, have limited accessibility, or are not feasible to the incumbent due to limited return on investment.

Loma Scientific wireless solutions allow Service Providers to quickly deploy high quality data links to deliver Internet services as well as bypassing wireline networks or even expanding their existing fiber, cable or DSL plants. Operators can also benefit from new operating efficiencies, peer-to-peer IP-based architecture for scalability, and IP standard interfaces to billing and customer care.

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