9 Wireless Local Loops and Satellite Communications

Case Study: Taking the Internet to Rural India

Inhabitants of Pabal, a small village near Pune, India, have been connected to the rest of the world through the World Wide Web. Through the combined initiatives of many government and private enterprises and educational institutes, about 2000 square kilometers around the village are being connected to the Internet through a Wireless Local Loop Technology (WLL). The technology was developed by the Indian Institute of Technology, Chennai, and is marketed by N-Logue.

The project was set up by the Rural Development Through Educational System (RDES) in Pabal to provide technical skills to the rural youth. The idea is to make the Internet as popular and accessible as the cable TV network, which has reached the remotest corners of the country because of the absence of any monopoly, the presence of hundreds of small operators, and the fact that it is a lucrative business opportunity.

A 20-metre-high tower has been constructed at the five-acre Vigyan Ashram, in Pabal. WLL was chosen because the local network lines are clogged and make it impossible for the villagers to log on to the Net. The telephone service providers are not very interested in providing telephone lines in rural areas because of the costs involved. The cost of laying new lines would be roughly around Rs 35,000 (USD 500) for a single connection. This cost would be difficult to recover from the local population. The WLL implementation is so cheap that even if 500 subscribers use the Internet for an hour, at a cost of Rs 20 per hour, the project breaks even. Organizers are making PowerPoint presentations at village gatherings to educate the villagers of Pabal about the Internet and its various applications. These presentations attract a wide audience, including industrial units, professionals such as teachers and doctors, and farmers.

Enterprising farmers are being encouraged to set up kiosks all over the service area. This is expected to be possible at an investment of Rs 50,000 (USD: 800). The kiosks will charge Rs 20 per hour; kiosk owners could earn a little extra money by charging a nominal sum for email services. They could also offer value-added services like updating farmers on market prices and offering the use of webcams.

Sources:

- "Taking Internet to rural India: A case study" – http://www.ciol.com/content/news/trends/102061503.asp
- nLogue Communications Case Study – http://www.digitalpartners.org/nlogue.html

9.1 Introduction

In addition to the wireless LANs and cellular networks, several other interesting developments in wireless communications are worth noting. This chapter gives an overview of the following:

- Wireless local loops that provide broadband wireless services to fixed locations such as homes/offices and wireless service providers
- Free Space Optics (FSO), a competitor to WLL because it can provide high data rates over a few kilometers
- Satellites that support global (also known as celestial) wireless communications between very distant objects
- Deep space communications that are intended for communications that go beyond the earth orbit

Wireless local loops and satellites are playing an important role in the **"*last mile*" –** the area between the subscribers and local exchange carrier's facilities. Although fiber-optic networks are quite popular for the last mile, fiber has several problems – it cannot reach everywhere, takes too long to install, and is quite expensive in underdeveloped countries. The wireless local loops and satellite communications provide an attractive alternative to the last-mile problem, especially in densely populated urban areas and underdeveloped countries. See Section 9.7. This chapter concludes with a few illustrative examples.

Chapter Highlights

- Wireless local loops (WLLs) provide broadband wireless services between fixed locations such as homes/offices and wireless service providers. WLLs deliver data rates between 10 and 50 Mbps. Best known examples of WLLs are:
  - MMDS (Multichannel Multipoint Distribution Service) is an older service that operates in the 2.15 GHz to 2.68 GHz frequency ranges and can offer 27 Mbps over 50 km.
  - LMDS (Local Multipoint Distribution Service) is a newer service for 30 GHz (US) and 40 GHz (Europe) frequency ranges that can deliver up to 37 Mbps within 5 to 8 km distances.
  - IEEE 802.16 is developing standards for WLL.
- Free Space Optics (FSO) is a competitor to WLL because it can provide high data rates over a few kilometers.
  - FSO systems can support data rates between 1.25 Gbps and 150 Gbps (theoretically) with link lengths that can vary from more than 600 feet to about a mile.
  - In practice, FSO networks support around 2.5 Gbps of data, voice and video communications between 1000 to 2000 feet.
- Satellites support global (also known as celestial) wireless communications between very distant objects. Satellites move around the earth in orbits at different altitudes. The altitude of satellite orbits is an important way of analyzing satellites:
  - Geostationary orbit (GEO) are the oldest satellites and operate at altitudes of around 35,000 kilometers (22,000 miles).
  - Medium earth orbit (MEO) satellites operate at altitudes of 5,000 to 12,000 km. They have less delays than GEOs.
  - Low earth orbit (LEO) satellites operate at altitudes of 350 km to 1500 km (in general, less than 2000 km).
- Deep space communications are concerned with communications outside of the earth's orbit.
  - "Deep space" roughly starts at 1.7 million kilometers (about 1 million miles) above the earth.
  - Deep space communication is the general umbrella under which major initiatives such as NASA'a Deep Space Networking (DSN) and "Interplanetary Internet" are being explored.
- Wireless local loops, FSO and satellites are playing an important role in the last mile.

Despite the popularity of fiber-optic networks, these networks cannot reach every potential subscriber. This is where wireless solutions like WLL, FSO, and satellite fill the gap.

The Agenda
- Wireless Local Loops and Free Space Optics
- Satellites and Deep Space Communications
- Examples and Wrapup

9.2 Wireless Local Loops – The Broadband Wireless Networks

9.2.1 Overview

Wireless local loops (WLLs), also called fixed-radio access (FRA), are the wireless metropolitan area networks (WMANs) that are popular with long distance telephone companies to address the last-mile problem. Simply stated, a WLL connects subscribers to the public switched telephone network (PSTN) using wireless communications as a substitute for the wired connection between the subscriber and the local exchange office. WLLs allow long distance carriers to bypass the existing wired local loops owned by local phone carriers. Consider, for example, AT&T long distance services that need to connect a caller in Chicago to a caller in New York. AT&T has to pay the local carriers in Chicago and New York because these carriers own the wirings at the two end points. These charges can add up to $20 billion in the US alone [Varshney 2000]. Figure 9-1 shows a sample configuration in which a local wired loop has been replaced with a wireless local loop. In addition to common carriers, many companies such as Tadiran, Raytheon, Qualcomm, Sanyo, Vodaphone, and Lucent provide WLL services.

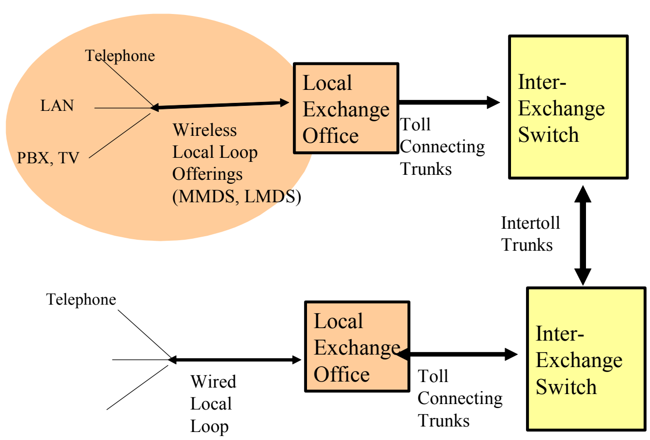

Figure 9-1: Wireless Local Loop

WLLs are quick and cost-effective for quick setup of local phone services. Instead of a wireless setup, imagine laying several of miles of copper or fiber cables to set up a local wired loop. Several technologies exist for WLLs (see Section 9.2.3 for benefits of WLL). The best known examples of WLLs are the LMDS (Local Multipoint Distribution Service) and MMDS (Multichannel Multipoint Distribution Service) systems that deliver data rates between 10 to 50 Mbps.

9.2.2 Wireless Local Loop Configurations

WLLs are ***fixed wireless networks*** where the devices being connected are stationary. Thus there is no need for location services. In addition to WLLs, fixed wired networks are used to set up an office LAN quickly. Consider, for example, a new company that has opened an office in an older building. This building does not have adequate wiring for an office LAN. In this case, a fixed wireless LAN can be set up instead of waiting for the cables to arrive and then be installed.

Frequency bands have been allocated by communication authorities for fixed wireless networks. For example, the FCC in the US has set aside 15 frequency bands between 2 and 40 GHz for fixed wireless services. Although many applications of fixed wireless are possible, WLLs are by far the most active area of work because they compete in the last mile with the traditional copper/fiber wired options that support a combination of ISDN, xDSL, and cable modem services. Wireless local loop (WLL) is increasingly providing two types of services:

- Narrowband as a replacement for existing telephony services
- Broadband for high-speed two-way voice and data service

Figure 9-2 shows a possible configuration for WLL. The switching center, also known as the network operation center (NOC), provides the overall network management and billing services. The switching center is connected to several base stations, typically through a fiber-optic infrastructure. The base station is where the conversion from wired (fibered) infrastructure to wireless infrastructure occurs. Base station equipment includes the network interface for fiber termination, modulation and demodulation functions, and microwave transmission and reception equipment. A base station antenna, mounted on top of a tall building, serves each WLL cell, which consists of residential and business subscribers.

A WLL operator can serve one or many WLL cells from its switching center. The WLL operator houses head-end equipment to transmit the content that is gathered from satellites, terrestrial- and cable-delivered programs, and local services. The satellite and terrestrially delivered formats are remodulated and converted to microwave frequencies for transmission over WLL. Repeater stations can be used to redirect the WLL signals to particular areas.

The customer (subscriber) configurations vary widely depending on the application. All subscriber configurations include outdoor mounted antennas and indoor equipment for modulation, demodulation, control, and interfaces with the subscriber equipment. In general, the subscriber antenna is conditioned to receive the microwave signals, which are then passed through a converter which converts the WLL signal frequencies to the target device frequencies. For example, if WLL is being used to deliver TV content (“wireless cable TV”), then the subscriber converter translates WLL signals to standard cable channel frequencies and feeds them directly to a TV set or a set-top converter box.

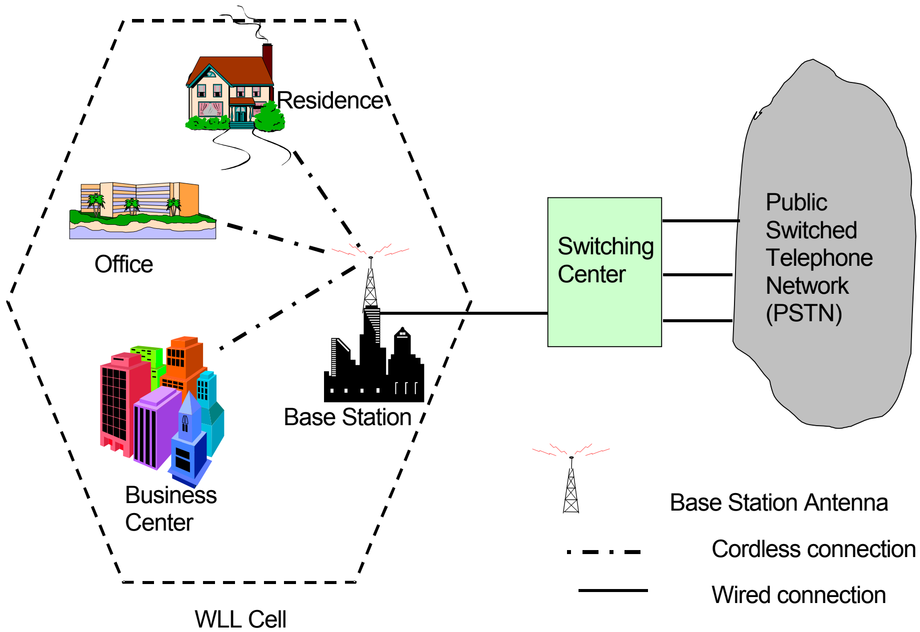

Figure 9-2: WLL Configuration

Within this overall architecture, variations exist (naturally!). For example, each base station may include ***local switching*** so that if two customers connected to the same base station wish to communicate with each other, they can do this at the base station. This implies that billing, authentication and other management functions occur locally at the base station. The alternative is to provide ***centralized switching*** where the switching happens at the switching center and the base station only provides a connection to the switching center. In this scenario, if two customers connected to the same base station wish to communicate with each other, they do so at the switching center. This allows centralized billing, authentication, registration, and traffic-management functions.

9.2.3 Benefits of Wireless Local Loops

WLLs provide an attractive wireless solution to the last-mile problem because it is less capital-intensive and can be deployed faster than the wireline solution. Specific benefits include:

- **Cost.** Wireless systems avoid the cost of cable installation. For example, it may cost around $1000 to provide fiber access to a subscriber due to the labor and other physical expenses. The WLL costs are much cheaper because it only requires antennas on both sides (these costs keep dropping also).
- **Installation time**. WLL systems can be installed in a small fraction of the time required for a new wired system. Due to this, many underdeveloped countries and new offices opt for WLLs. In addition, copper wires are stolen in some countries (see the sidebar, “Using WLL to Save Thefts of Copper Lines”).
- **Selective installation**. Radio units can be installed for subscribers who want service at a given time. With a wired system, cable is laid out in anticipation of serving every subscriber in a given area, because it is not cost-effective for the service providers to provide fiber access to 2 houses in a 20-mile radius. If the service providers invest a great deal of capital to provide, for example, fiber access to an entire area, they are not sure if the residents will be willing to pay for it. In the case of WLL, a large part of a wireless

network's cost is not incurred until equipment is installed on the customer's premises. Thus the network service operator can time capital expenditures to coincide with the signing of new customers.

- **Cost shifting and churn.** In a wireline system, most of the capital investment is in the infrastructure, while with WLL a greater percentage of the investment is shifted to the customer-premise equipment (CPE). Thus the operator expenditures depend on the type and number of customers who sign on. In addition, there is no stranded capital when customers churn.

The main limitation of WLLs is that it can be affected by weather conditions such as rain. In addition, many early implementations of WLLs in the late 1990s were behind schedule on their WLL installations, mainly because of the regulatory issues such as licensing and frequency allocation. Some of the largest potential WLL markets including China, Russia, Mexico and South Africa spent a great deal of time to resolve many of theses regulatory issues in the late 1990s before adopting WLL technology. Besides regulatory issues, WLL implementations have been delayed due to the inexperience of the operators unfamiliar with WLL technology, and the difficulties in network planning and interfacing the WLL radio equipment to the installed switches (see the case study, "Telkom South Africa Deploys Wireless Local Loop" in Section 9.6.1). As the operators have gained more experience, WLL deployments have speeded up.

Using WLL to Save Thefts of Copper Lines

While reading and researching on a topic, every now and then you run into something that is simply too interesting to pass over. Consider, for example, the following quote from the source listed below:

"Telkom (South Africa) also prefers WLL technology in high-theft areas such as the corridor between Soweto and the Central Business District of Pretoria. In this area, copper cables are stolen before Telkom has time to turn on the lines."

I never thought that this could be a benefit of wireless over wired networks, but you never know!

Source: N. Baker, "Telkom South Africa: Case Study in WLL Deployment," *Pyramid Research Report*, www.itu.int/ITU-D/fg7/case_library/ documents/pyr001.doc

9.2.4 Highlights of WLLs

Table 9-1 gives the highlights of WLLs in terms of data rates, distance covered, target applications, frequency allocation, location management, and physical communication considerations.

9.2.4.1 Data Rates and Distance Covered

WLLs deliver data rates between 10 to 50 Mbps. The exact data rate and distance covered depends on the the type of WLL implementation. MMDS (Multichannel Multipoint Distribution Service), an older service, can offer 27 Mbps over 50 km while LMDS (Local Multipoint Distribution Service), a newer service, can deliver up to 37 Mbps within 5- to 8-km distances. See Section 9.2.7 for details and tradeoffs between LMDS and MMDS.

9.2.4.2 Target Applications

WLLs, as stated previously, are competing in the "last mile" with the traditional wired options. Specifically, WLL are increasingly being used to provide: a) narrowband services as a replacement for existing telephony services, b) broadband services for high-speed two-way voice and data service, c) TV content. The end users can get voice, fax, and Internet access over WLLs.

9.2.4.3 Frequency Allocations

FCC in the US has set aside 15 licensed frequency bands between 2 and 40 GHz for fixed wireless services. These frequencies are mostly used by WLLs. The two variations of WLL, LMDS and MMDS, use different frequencies within this range. The frequency band between 2.5 GHz and 2.7 GHz is used by the older MMDS systems, and between 30 GHz (US) and 40 GHz (Europe) for the newer LMDS systems.

9.2.4.4 Location Management

This issue is nonexistent for WLLs because the senders as well as the receivers have fixed locations.

9.2.4.5 Physical Communications

The physical communications, at the lowest layers (layer 1 and 2), deal with many propagation and encoding issues that are unique to WLLs (see Section 9.2.5 and 9.2.6). To allow different users to share the same medium without interfering with each other, the IEEE 802.16 is standardizing on variations of TDMA, FDMA, and even some CDMA for WLL. To deal with different impairments, WLLs use QPSK (Quadratic Phase Shift Keying) for modulation and, of course, forward error correction (FEC) and ARQ for handling errors. Time Division Duplex (TDD), used in the cordless phone systems, is also used in WLLs.

Table 9-1: Highlights of Wireless Local Loops

Factor	Key Points
Data Rate and Distance	10 to 50 Mbps between 5 to 50 km
Target Applications	Broadband wireless communications for the last mile (phone, fax, Internet access)
Frequency Allocations	Licensed band between 2.5 GHz and 2.7 GHz for the older MMDS and 30 GHz (US) and 40 GHz (Europe) for the newer LMDS
Location Services	Not needed because the senders and receivers are fixed (fixed wireless communications)
Physical Communications Considerations	Different variations of TDMA and CDMA Forward error correction, QPSK, Time Division Duplex (TDD).

9.2.5 Propagation Considerations for WLL

Most high-speed WLL schemes use millimeter-wave frequencies (MWF) that range between 10 GHz to about 300 GHz. There are several benefits of using frequencies in these ranges. First, there are wide unused frequency bands available above 25 GHz. Second, at these high frequencies, wide channel bandwidths can be used, providing high data rates. Finally, small transceivers and adaptive antenna arrays can be used. However, undesirable characteristics of

MWF must be taken into account. First, free space losses increase at higher frequencies (roughly with the square of the frequency). Thus, losses are much higher in MWF. Second, above 10 GHz, attenuation effects due to rainfall and atmospheric or gaseous absorption are large. In addition, multipath losses can be quite high because any obstruction at high frequencies can lead to multiple reflections and scatterings.

For these reasons, WLL cells are of limited sizes (a few km in radius) and operate better in dry weather and flat zones with long clear paths and no rain. Thus WLLs in Seattle may be tough to support but work quite well in Saudi Arabia. Specifically, the following propagation considerations are important for WLLs:

- **Clear paths** are needed between the base station antenna and the subscribers. A design issue is: how much space around the direct path between the transmitter and receiver should be clear of obstacles? Detailed calculations involve "Freznel zones" (see Section 9.2.6).
- **Atmospheric absorption** should be minimized because radio waves at frequencies above 10 GHz are subject to molecular absorption. The absorption as a function of frequency ranges is quite uneven, with pockets of low absorption. For example, favorable windows for communication with low absorption rates exist between 28 GHz and 42 GHz and then between 75 GHz and 95 GHz.
- **Attenuation due to rain** is a serious problem because the presence of raindrops can severely degrade the reliability and performance of communication links. The effect of rain depends on drop shape, drop size, rain rate, and frequency.
- **Effects of vegetation**, especially the foliage from tall trees, also needs to be considered. For example, tall trees near subscriber sites can lead to multipath fading. Multipath effects are naturally highly variable due to the wind (the leaves fly around in high winds and obstruct WLL transmissions).

Multiple Access in WLLs: TDMA versus CDMA

The WLL providers reuse the same frequency for different subscribers because, unlike cellular networks, the WLL subscribers are not typically adjacent to each other. This reduces the interference between subscribers of the same WLL provider. However, how are the different users at the same subscriber multiplexed? For example, consider an office as a subscriber with 100 employees who need voice, fax, and data services. To serve these different users at the same subscriber site, some WLL providers use TDMA while the others use CDMA. For example, the WLLs provided by Tadiran and Raytheon use TDMA while the systems by Qualcomm, Sanyo, Vodaphone, and Lucent use CDMA.

Besides the typical TDMA-versus-CDMA tradeoffs considered in cellular networks, the additional consideration in WLL is that the voice services can be directly supported by these configurations. For example, if the people in the office are using GSM (a TDMA-based system), then the WLL system that supports TDMA will be very natural – the subscribers can directly get the WLL service at the handset. Similarly, CDMA-based WLLs are more natural for IS-95 based cellular users.

Source: J. Liberti, and T. Rappaport, *Smart Antennas for Wireless Communications* (Prentice Hall, 1991), pages 12-14.

9.2.6 Determining Clear Space – The Fresnel Zones

An unobstructed line of sight area is needed between the WLL transmitters and receivers because the millimeter waves cannot penetrate obstacles. How much clear space around the direct path between WLL base stations and the consumers is needed? The answer lies in Fesnel zones – a series of concentric circles that lie around the direct line of sight between senders and receivers. Without going through the details of Fresnel zones, let us just highlight the key result: the clear space needed for the signals is determined by 0.6F, where F is the radius of the first Fresnel zone given by:

$$F = \sqrt{\lambda TR/(T+R)}$$

This equation determines the clear space at a point that is at a distance T from the transmitter and R from the receiver; λ represents the wavelength of the signal. Given that T, R and λ are in the same unit, F can be calculated at a certain point and the clear space needed at that point can be determined by multiplying F by 0.6. From a practical point of view, the communication engineers calculate Fs at different points between the WLL transmitters and receivers and then make sure that enough clear space (0.6F) at these points exists along the way for proper transmission. See Stallings [2002] for more details.

9.2.7 Examples of Wireless Local Loop Services – MMDS and LMDS

Several wireless local loops are in operation at present. The best-known examples are MMDS and LMDS, described in this section.

9.2.7.1 Multichannel Multipoint Distribution Service (MMDS)

MMDS is an older service that operates in the 2.15-to-2.68 GHz frequency range. It is also referred to as ***wireless cable*** because it competes with cable TV in rural areas not covered by cable TV. In fact, MMDS is outgrowth of an earlier standard that was intended for broadcast of 6 MHz TV channels. A single MMDS channel can offer 27 Mbps over 50 km. Each channel is subdivided and allocated to different subscribers so that individual subscribers can get data rates from 300 Kbps to 3 Mbps. MMDS is used mainly by residential subscribers and small businesses because of its lower data rates, as compared to LMDS. Although mainly targeted for wireless cable, MMDS is also a good competitor to DSL and cable modems for Internet access.

For wireless cable, the cable provider houses MMDS head-end equipment to transmit the TV content that is gathered from satellites and other sources. This content is re-modulated and converted to MMDS frequencies for transmission. The subscriber antennas receive the signals and pass them through a converter that translates MMDS signals to standard cable channel frequencies and feeds them directly to a TV set or a set-top converter box.

The number of TV channels offered by MMDS networks is limited by the low frequency bands allocated to MMDS. Only 200 MHz of frequency spectrum (between 2.5 GHz and 2.7 GHz) is allocated for MMDS use, thus only 33 TV channels can fit into the spectrum (each TV channel occupies 6 MHz bandwidth). Although higher frequency bands for MMDS have been proposed, this is impractical in the 2.5 GHz spectrum due to the competition from alternative service providers in this low-frequency spectrum.

9.2.7.2 Local Multipoint Distribution Service (LMDS)

LMDS is a newer service for 30 GHz (US) and 40 GHz (Europe) frequency ranges. LMDS can deliver up to 37 Mbps within 2- to 4-km distances. Due to its high data rates, LMDS can support point-to-multipoint communication systems for digital two-way voice, data, Internet, and video. In general, LMDS appeals to larger companies with greater bandwidth demands. However, due to its relatively short distance, the coverage area can be small, or many base stations are needed to cover the same area. Although LMDS could be used to deliver TV services, its limited range of transmission (3 to 5 miles radius), limits its use for wide-area coverage of digital television service.

As the acronym implies, LMDS concentrates on local (i.e., 3 to 5 miles) distribution of services in a multipoint fashion. Thus the signals are transmitted in a point-to-multipoint or broadcast method – the return path, from subscriber to the base station, is a point-to-point transmission. Although the majority of LMDS operators use point-to-multipoint distribution, point-to-point distribution services can be provided within the LMDS system. In a typical LMDS system, base station antennas are mounted on high buildings to minimize obstruction. Recall that the high frequency ranges of LMDS get blocked by buildings and are adversely affected by rain and humidity.

Although LMDS as well as MMDS follow the overall WLL architecture shown in Figure 9-2, LMDS uses more options because of the wider array of services that LMDS can provide as compared to the TV services of MMDS. For example, the switching center as well as the base stations need to handle a wider array of content that includes voice, video, and data. The subscriber equipment also is more sophisticated, with support for time-division multiple access (TDMA), frequency-division multiple access (FDMA), or code-division multiple access (CDMA). In addition, it may be desirable to support local switching at the base stations so that the customers connected to the base station can communicate with one another without entering the switching center.

9.2.7.3 MMDS versus LMDS

The main tradeoff between LMDS and MMDS is that LMDS offers higher data rates but for shorter distances while MMDS offers lower data rates for longer distances (you cannot have everything!). Specifically, the advantages of MMDS over LMDS are:

- MMDS signals have larger wavelengths and can travel farther without losing significant power.
- MMDS is less expensive to support because equipment at lower frequencies is less expensive.
- MMDS signals do not get blocked as easily by objects and are less susceptible to rain absorption.

LMDS, on the other hand, has the following advantages:

- LMDS can offer relatively high data rates.
- LMDS is capable of providing video, telephony, and data services.
- LMDS incurs relatively low cost in comparison with cable alternatives.

In other words, LMDS as well as MMDS services have a place in the wireless technologies heap. It has been proposed to assign a new higher frequency band dedicated to digital MMDS services so that MMDS can also offer higher data rates, but this is impractical.

9.2.8 Standards for Fixed Wireless Development – IEEE 802.16

Due to the interest in WLLs, the IEEE 802 committee started the 802.16 working group in 1999 to develop broadband wireless standards. The objective is to provide standards-based solutions for implementing wireless networks within metropolitan-sized areas. The 802.11-based solutions do not work in the metropolitan-sized networks because 802.11 has performance limitations when supporting larger numbers of users. For example, the cell sizes of 802.11 are small (100 meters) – you will need thousands of 802.11 access points to cover a metropolitan area of 20 to 30 miles. In addition, radio frequency (RF) interference is a problem with 802.11 when covering large areas, because of license-free operation. For example, two competitors may install 802.11 networks which interfere with each other. Due to these limitations of 802.11 to cover metropolitan areas, the IEEE 802.16 was established with the charter to develop standards that:

- Use wireless links with microwave or millimeter-wave radios
- Use licensed spectrum
- Are metropolitan in scale
- Provide public network service to fee-paying customers
- Use point-to-multipoint architecture with stationary rooftop or tower-mounted antennas
- Provide efficient transport of heterogeneous traffic supporting quality of service (QoS)
- Use wireless links with microwave or millimeter-wave radios
- Are capable of broadband transmissions (>2 Mbps)

The first IEEE 802.16 standard, published in April 2002, defines the Wireless MAN Air Interface for wireless MANs. These systems are meant to provide wireless access to homes, small businesses, and commercial buildings. Figure 9-3 shows the abstract reference model that is at the foundation of the IEEE 802.16 specification. The key players, as shown, are a) the core network that represents the telephone system or the Internet, b) the subscriber network that may include an office LAN, c) a subscriber transceiver system that connects the subscribers to the WLL, and d) a base transceiver system that serves the subscribers in the local loop. IEEE 802.16 optionally includes repeaters or reflectors to extend cell coverage by getting around obstacles. The focus of IEEE 806.16, as shown in Figure 9-3, is on the air interface between the subscriber transceiver system (STS) and the base transceiver system (BTS). Other interfaces (SNI and BNI) are included in the reference model for completeness but are not specified explicitly.

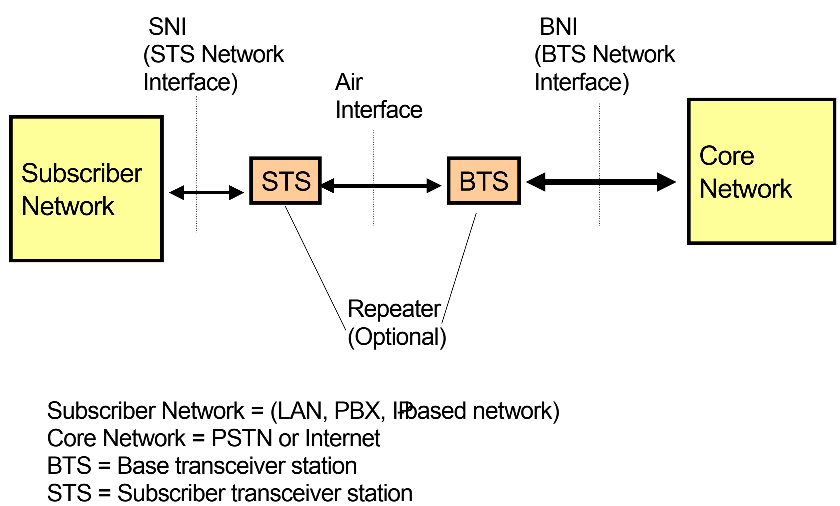

Figure 9-3: IEEE 806.16 Reference Architecture

An industry group, called WiMax, is backing 802.16 developments. Several companies, such as Airspan Networks, Alvarion, Intel, Nokia, Proxim and Wi-LAN – all members of WiMax – are in the process of developing 802.16 products. The wireless 802.16 base station equipment is targeted at under $20,000 and can serve up to 60 customers between 1 to 2 Mbps [Geier 2003]. This is roughly equivalent to the T-1 wired line speed of 1.54 Mbps. Thus 802.16 provides an attractive wireless alternative to the wired broadband Internet access.

The protocol stack of IEEE 802.16 is shown in Figure 9-4. The stack supports point-to-multipoint architecture in the 10-66 GHz range, transmitting at data rates up to 120 Mbps. At these high frequencies, transmission requires line-of-sight, and roofs of tall buildings provide the best mounting locations for base and subscriber stations. The base station connects to a wired backbone and can transmit wirelessly up to 30 miles to a large number of stationary subscriber stations, possibly hundreds. The 802.16 medium access control (MAC) layer supports many different physical layer specifications, both licensed and unlicensed. Through the 802.16 MAC, every base station dynamically distributes uplink and downlink bandwidth to subscriber stations using time-division multiple access (TDMA). This is a much better strategy than the carrier-sensing mechanisms used by the 802.11 MAC. At the highest level of the stack are the following three services:

- IEEE 802.16.1 services that are designed for the 10-to-66 GHz frequency ranges. These services include digital audio/video multicast (e.g., teleconferencing over wireless), digital telephony to replace wired home telephones with wireless ones, wireless ATM and wireless frame relay with necessary QoS characteristics, Internet Protocol to transfer IP datagrams over WLL, and many other services. In all these cases, the WLL must satisfy the delay, synchronization (e.g., synchronizing lip movement with sound for teleconferencing) and QoS requirements that are roughly equivalent to the wirelined networks.
- IEEE 802.16.2 services that specify how the WLL will coexist with other last-mile technologies.
- IEEE 802.16.3 services that are designed for licensed frequencies in the 2 GHz to 11 GHz range. These services support a variety of "bearer" (underlying physical wireless network) functions such as voice transport over packet switching for PSTN, data transport for IP-based traffic, and bridged LAN service for transfer of data between two LANs.

The Convergence Layer adapts the different higher-layer services to MAC- and PHY-layer services. It provides functions such as the following: a) encapsulate PDU framing of upper layers into native 802.16 MAC/PHY frames, b) map upper layer's addresses into 802.16 addresses, c) translate upper layer QoS parameters into native 802.16 MAC format, and d) adapt time dependencies of upper-layer traffic into equivalent MAC services.

The Medium Access Control (MAC) Layer is responsible for sending frames over the air interface. Examples of the functions it provides are a) on transmission, assemble data into a frame with address and error detection fields, b) on reception, disassemble frame, and perform address recognition and error detection, and c) govern access to the wireless transmission medium.

The Physical Layer functions, as can be expected, include encoding/decoding of signals, preamble generation/removal, and bit transmission/reception. The Physical Layer uses different techniques for upstream versus downstream transmissions. For upstream transmission, it uses DAMA-TDMA[1] for multiplexing and QPSK for modulation. For downstream transmission, it uses different techniques to support continuous downstream transmission of bit streams (e.g., audio, video) or burst transmission of data (e.g., IP-based traffic). For continuous transmission, the 802.16 Physical Layer uses a simple TDM scheme for channel access and frequency division duplex (FDD) for duplexing. For burst downstream

[1] DAMA – Dynamic Assignment Multiple Access (see discussion in Section 9.4.14).

transmission, a DAMA-TDMA scheme is used for channel access, and FDD with adaptive modulation, frequency shift division duplexing (FSDD) is used for duplexing.

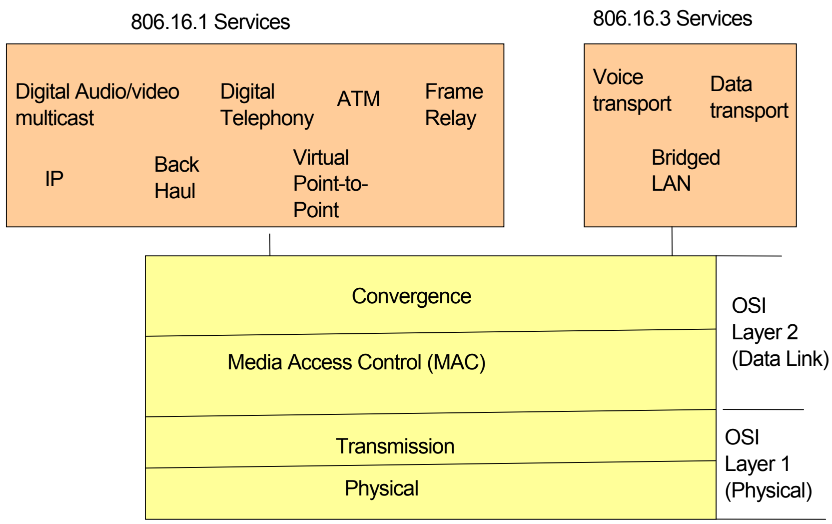

Figure 9-4: 802.16 Protocol Stack

The 802.11 standard is evolving at present. Newer developments (for more details, see the 802.16 website – www.ieee802.org/16) worth mentioning are:

- The initial standard, as indicated above, operates in the 10-66 GHz range which requires line-of-sight transmissions. To accommodate non-line-of-site access over lower frequencies, IEEE published 802.16a in January 2003. IEEE 802.16a operates in the licensed and unlicensed frequencies between 2 GHz and 11 GHz, using orthogonal frequency division multiplexing (OFDM), and does not require LOS transmissions.
- The 802.16 working group is adding mobility to the standard. An 802.16e Study Group on Mobile Broadband Wireless Access has been formed. This group is addressing many different mobility issues, including providing connectivity to moving vehicles within a base station's sector. See http://www.ieee802.org/16/tge/index.html.

Sources of Information for Wireless Local Loops

- Wireless Local loop Forum – http://www.ntia.doc.gov/forums/wireless/
- Tutorial by the International Engineering Consortium – http://www.iec.org/online/tutorials/wll/
- General Site for WLL Developments – http://www.sss-mag.com/wll.html
- Good Tutorial and General Information – www.palowireless.com/wll.asp
- W. Webb, *Introduction to Wireless Local Loop*, Artech House, 1998
- P. Clark, *Wireless Access Networks: Fixed Wireless Access and WLL Networks – Design and Operation*, John Wiley, 2000

9.3 Free Space Optics (FSO) – A Quick Overview

Free-Space Optics (FSO) is a line-of-sight technology that uses lasers for wireless optical communication in a wireless local loop environment. FSO uses lasers to transmit data, but instead of enclosing the data stream in a fiber-optic cable, the data is transmitted through the air (see Figure 9-5). FSO systems can support very high data rates between 1.25 Gbps to 150 Gbps (theoretically) with link lengths that can vary from more than 600 feet up to about a mile. The higher data rates and distances are achieved in clear, dry, and "non-intrusive" atmosphere. Common FSO networks support around 2.5 Gbps of data, voice and video communications between 1000 to 2000 feet. Most FSO equipment vendors supply products providing 100 Mbps, 155 Mbps (OC-3), 622 Mbps (OC-12) and up to Gigabit capacities. FSO transceivers can be located on a rooftop, on a corner of a building or indoors behind a window to support the last mile.

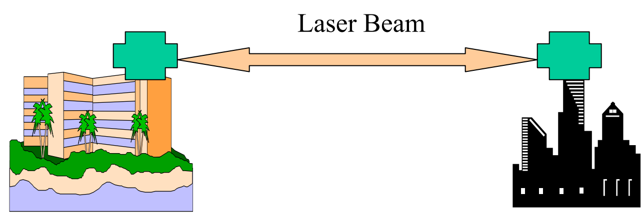

Figure 9-5: Conceptual View of FSO

Free-space optics (FSO) systems could be a viable option for many applications in the last mile. Very few (only 5%) of commercial buildings in the U.S. have fiber optics to their door, although most are within a mile of a fiber-optic connection. FSO fills this "last mile" gap quite well. FSO provides short-term solutions for short distance network bridges, as well as an attractive offering for service providers to deliver all-optical networks. FSO technology operates at layer 1 and so is protocol-independent and can be used with ATM, SONET, Gigabit Ethernet or virtually any network. A major advantage of FSO, as we will discuss, is that it is very secure because laser beams cannot be easily intercepted. In addition, FSO technology requires no frequency-spectrum licensing. See Chapter 10 for a closer look at FSO.

Time to Take a Break

- ✓ Wireless Local Loops and Free Space Optics
- Satellites and Deep Space Communications
- Examples and Wrapup

9.4 Satellite Systems

9.4.1 Overview

Satellites were first launched in 1962 and have ushered in the era of "celestial" and "global" communications. In the initial stages of space exploration and satellites, very few private companies produced satellites because there was no demand beyond NASA (National Aeronautics and Space Administration). However, many entrepreneurs began to realize the potential for these machines rather quickly, leading to very impressive developments in satellite technology over the years. At present, satellites are used in areas such as telecommunications, weather reports, military operations, and scientific exploration. As the uses for satellites increased, so did the demand for them, and not just for government space programs. The private sector also became interested in acquiring satellites. Companies such as Hughes Space and Communications make a variety of satellites for different uses, and large corporations such as IBM, GE, and Walmart own private satellites for corporate use.

At present, communications through satellites is the foundation of global wireless networks in which users communicate with each other over long distances without a physical wire between them. Communication satellites are used in our daily lives for long distance phone calls, international radio and TV broadcasts, and global Internet access. Before satellites, transmissions were difficult or impossible at long distances, especially when it came to stringing cables across oceans and mountains. Wireless signals, which travel in straight lines, could not bend around the Earth to reach a destination far away. Because satellites are in orbit, the signals can be sent directly into space and then redirected to another satellite or directly to their destination. See Section 9.4.2 for a classification of satellites, and Section 9.6 for some real life examples of satellite use.

A satellite is essentially a microwave repeater in the sky which receives signals from transmitting stations on earth and relays these signals back to the receiving stations on the earth or another satellite (see Figure 9-6). From an end-user point of view, satellites can deliver up to 50 Mbps over very wide (global) area networks to the subscribers. The frequency ranges of satellites are 3 to 30 GHz, with a bandwidth of about 500MHz. A satellite system consists of the following components:

- Earth Stations – antenna systems on or near earth.
- Uplink – transmission from an earth station to a satellite.
- Downlink – transmission from a satellite to an earth station (different from uplink, typically faster, can be broad).
- Transponder – electronics in the satellite that convert/amplify uplink signals to downlink signals. There are typically 16 to 20 transponders per satellite, each with 36-50 MHz BW (bandwidth). This is why each subscriber can get up to 50 Mbps service. Typically one transponder supports many telephone and data users by subdividing the 30-50 MHz BW into smaller services instead of allocating the entire BW to one 50 Mbps user.

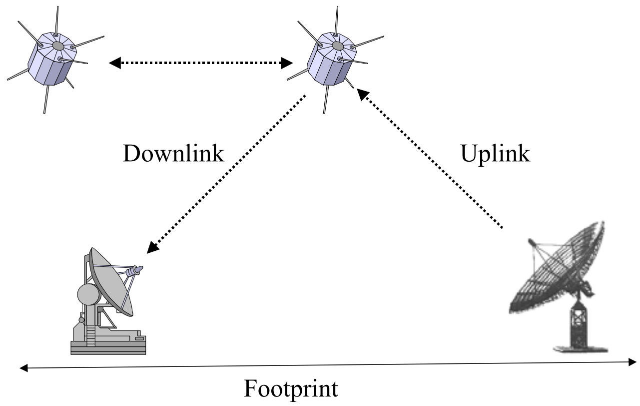

Figure 9-6: Satellite Transmission

A satellite covers a certain area – the higher the satellite, the more area it can cover. The coverage area of a satellite is called the satellite's ***footprint.*** Only receiving stations within this footprint can receive the satellite's signals.

The oldest example of satellites is the Geosynchronous ***(GEO)*** satellites that are in wide use providing international and long distance communication services for government institutions, businesses and the general public. GEO satellites are placed in the earth orbit at 22,300 miles, a region called the Clark Belt after the famous science-fiction writer who first envisioned satellites in 1945. Once placed in the Clark Belt, the satellite rotates at the same speed as the earth's rotations so the satellite does not appear to move (this is called geosynchronization). Thus the sending and receiving dishes can stay pointed to the satellite without any readjustments. For example, once placed above Chicago, the satellite always stays above Chicago.

GEO satellites can provide high communications capacity and can support several thousand voice channels. However, each satellite message encounters a 0.25-second delay because of the distance a message has to travel between a sender and a receiver. Satellite systems have gone through several advances over the years. In addition, to GEOs, some MEOs and LEOs (medium and low earth orbits) have been also launched for commercial use. These offer lower delays (see Sections 9.4.4, 9.4.5, and 9.4.6 for a discussion of GEOs, LEOs, and MEOs, respectively).

Satellite communications has several unique qualities; it is terrain-independent and it provides an efficient model for broadcasting. Satellites provide global coverage for audio, video and other communications traffic. Satellite networks can also augment terrestrial and wireless communication networks in areas where terrestrial infrastructure is poorly developed, nonexistent, or not cost-justifiable due to low population density. In many cases, satellite remains the only means of communication available. Despite these benefits, the number of customers signed up for satellite systems, especially LEOs and MEOs, has been less than impressive due to costs (the initial cost can be $1000 and the per-minute charge can exceed $50). In addition, the use of satellites, especially for the broadcast services, presents serious security problems which require extensive encryption/decryption, such as scrambling and highly protected keys. See Section 9.4.11 and 9.4.12 for the benefits and limitations of satellite communications. Due to the special characteristics of satellites, they compete with fiber optics and cellular phones (see Section 9.4.13).

In a satellite communication system, the transmission cost is independent of the distance between the sender and receiver (two stations 100 miles apart or 1000 miles apart still have to travel thousands of miles to and from the satellite). Because of this, satellite communication systems are used to broadcast, i.e., send a message to several receivers simultaneously. Satellite communications present unique issues in frequency allocation, multiple access and location management (see Section 9.4.14).

9.4.2 Highlights of Satellite Communications

Table 9-1 captures the key points about satellite communications in terms of the data rates and distance covered, target applications, frequency allocation, location management, and physical communications.

9.4.2.1 Data Rates and Distance Covered

As a communication facility, a satellite can technically deliver around 500 Mbps. This capability is usually subdivided so that subscribers can have around 50 Mbps data service. There are several exceptions to this. For example, Teledesic (www.teledesic.com) launched satellites to provide "fiber type" data rates of up to 622 Mbps. A typical Teledesic user could get up to 64 Mbps service. From an end-user's point of view, each satellite provides a link (a 40 MHz channel) that can be allocated to the following users:

- One 50-Mbps data stream that is enough to support one T3 line (44 Mbps)
- 16 to 20 T1 lines (1.544 Mbps each)
- 400 to 600 lines of 64 Kbps each
- 1200 voice channels

For example, a company may support many telephone and low-speed Internet access lines over one satellite link.

For distances, a single satellite can easily cover between 250 km and 10,000 km. The exact distance to be covered by one satellite, called the satellite footprint, depends on the altitude of the satellite – GEOs have bigger footprint (almost 1/3 of the earth's surface) than the LEOs. For longer distances, satellites send information to other satellites, thus building a multi-hop network in the sky.

9.4.2.2 Target Applications

Typical applications of satellites are radio and TV broadcasts and long-distance communication services between continents. For example, radio, television, telephone, and Internet transmissions can be sent live anywhere in the world by using satellites. From an end-user point of view, a satellite provides a long-distance link at about 50 Kbps that can be used by any voice, video and data applications just like any other 50 Kbps line. Between two earth stations, a satellite can be a fixed service satellite (FSS) that provides point-to-point service, mainly for military purposes, or a broadcast service satellite (BSS) that is used for TV and radio broadcasts. As we will see later, other type of satellite configurations also exist for different applications.

9.4.2.3 Frequency Allocations

The frequency ranges of satellites are 3 to 30 GHz with a bandwidth of about 500MHz. The frequency range of 3-30 GHz is subdivided into frequency bands. For example, GEO has a 500 MHz BW, subdivided into channels of 40 MHz each. The frequency bands used by satellites are regulated by the ITU (International Telecom Union) and other bodies. Table 9-3 shows the most commonly used frequency bands available for satellite communications (see Section 9.4.14.4 for a discussion of the frequency bands). The two bands used most frequently are the C-band (4 to 8 GHz) and the Ku-band (12 to 18 GHz). The X-band (8 to 12.5 GHz) is used mainly in deep space communications.

9.4.2.4 Location Management

Location management issues in satellite communications are unique because the satellites are moving around the earth while the satellite dishes are typically fixed at one location. In the case of GEOs, the dishes can stay stationary, but special considerations are needed for LEOs and MEOs. Instead of having the earth dishes keep track of the satellites, enough LEO and MEO satellites are launched so that as soon as one moves out of the range, another appears on the horizon. See Sections 9.4.3 through 9.4.7 for details.

9.4.2.5 Physical Communications

Due to the long distances and the severe attenuations and delays involved in satellite communications, forward error correction (FEC) becomes extremely important. A combination of PSK and FSK are commonly used for modulation.

To allow multiple earth stations to share the same satellite, special issues in allocation to earth stations of the same frequency bands (channels) arise because of long turnaround delays (270 ms). For example, it is virtually impossible to poll users that are 22,000 miles away just to see if they are doing anything. Although TDMA and FDMA are commonly used for multiplexing purposes, special techniques such as FAMA and DAMA are used due to the long distances involved,. In FAMA (fixed-assignment multiple access), the assignment of capacity is distributed in a fixed manner among multiple earth stations, and in DAMA (dynamic assignment multiple access), the capacity assignment is changed as needed between different earth stations based on demand. See 9.4.14 for additional details.

Table 9-2: Highlights of Satellite Communications

Factor	Key Points
Data Rate and Distances	Typically a 50 Mbps link per user over long distances that may range up to 12,000 miles (around the globe)
Target Applications	Typical applications: broadcasting in very broad areas Long haul applications that require very long range communications
Frequency Allocations	3-10 GHz or higher at 300 – 500 MHz BW. The satellite frequencies are subdivided into different bands, e.g., C, X, and K, that are used for different types of applications
Location Services	Unique issues because the satellites are moving around the earth
Physical Communications Considerations	Forward error correction extremely important due to long delays, variations of FSK and PSK techniques. Typically FDMA and TDMA with special considerations such as FAMA and DAMA

9.4.3 Satellite Systems – Classifications and Terms

There are several ways to categorize communications satellites:

- **Altitude:** Satellites move around the earth in orbits at different altitudes. The altitude of satellite orbit is an important way of analyzing satellites:
  - **Geostationary orbit (GEO)** – altitude of around 35,000 Killometers
  - **Medium earth orbit (MEO)** – altitude of 5,000 to 12,000 km
  - **Low earth orbit (LEO)** – altitude of 350 to 1500 km (in general, less than 2000 km)

- **Coverage area (footprint)**: Satellites can provide coverage at global, regional, or national levels. For wide areas of coverage, transponder beams can cover up to 10,000 km. For narrow coverage, the transponders beams may be limited to 250 km. For transmission, each antenna aims at a transponder, sends a few frames, and then aims at another area. The time spent by an antenna while aimed at a satellite is known as dwell time.
- **Service type**. A satellite can be a ***fixed service satellite (FSS)*** that provides point-to-point service. This option may be used for military purposes. A satellite may also be a ***broadcast service satellite (BSS)*** that sends information to homes. An example of BSS is the Public Broadcasting Service TV satellite. Other categories are the ***mobile service satellite (MSS)*** that sends and receives information from mobile users, and ***Digital Audio Radio Service (DARS)*** for satellite radio.
- **General usage**: Satellites may be used for commercial, military, amateur, or experimental purposes. We use satellites in our daily lives to make long distance phone calls, watch TV broadcasts of international events, send emails to friends around the globe, and access websites at far-off places. From a satellite provider point of view, a satellite can have a passive role in communications, like bouncing signals from the earth back to another location on the earth. But satellites also carry transponders that receive, amplify, and re-broadcast signals to the earth.

Types of Orbits. Satellite orbits may be circular, with the center at the earth's center, or elliptical, with the earth's center at one of the two foci of the ellipse. A satellite may orbit around the earth in different planes – such as an equatorial orbit above the earth's equator, a polar orbit passing over both poles, and other orbits. Let us briefly look at these orbits (see Figure 9-7):

- **Equatorial or Polar Orbits.** Most GEOs orbit above the earth's equator. A polar orbit is a particular type of Low Earth Orbit. The only difference is that a satellite in polar orbit travels in a north-south direction, rather than the more common east-west direction. Polar orbits are useful for viewing the planet's surface. As a satellite orbits in a north-south direction, the earth spins beneath it in an east-west direction. As the earth rotates to the east beneath the satellite, each pass monitors an area to the west of the previous pass. These "strips" can be pieced together to produce a picture of a larger area. As a result, a satellite in polar orbit can eventually scan the entire surface. For this reason, satellites that monitor the global environment, like remote sensing satellites and certain weather satellites, are almost always in polar orbits. No other orbit gives such thorough coverage of the earth. Polar satellites also circle at a much lower altitude (about 530 miles, 850 km), providing more detailed information about violent storms and cloud systems.
- **Circular and Elliptical Orbit**. Circular orbits move around the earth in a circle while the polar satellites follow an oval-shaped elliptical path. One part of the elliptical orbit is closest to the center of the earth and the other part is farthest away. Like polar orbits, elliptical orbits move in a north-south direction. Elliptical orbits are used to provide polar coverage because the footprints of GEO satellites do not cover the polar regions of the earth. So communications satellites in elliptical orbits cover the northern and south polar areas that are not covered by GEO satellites. In addition, elliptical orbits can be used to cover one larger area without having to travel larger areas. For example, one elliptical satellite can cover the entire North American continent by circling higher above it while having a lower orbit over the rest of the earth (recall that higher altitude of a satellite gives broader coverage).

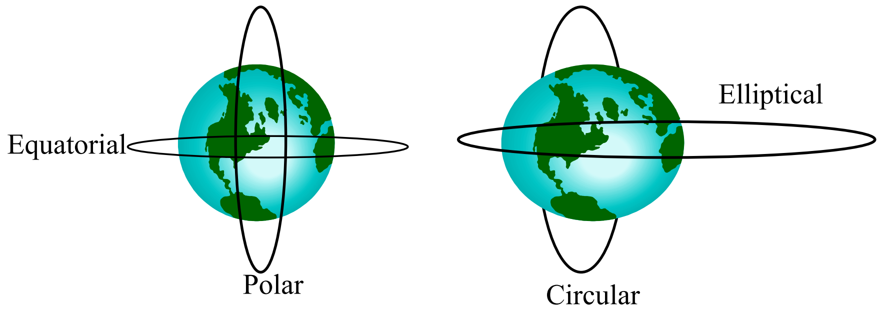

Figure 9-7: Polar, Equatorial, Circular, and Elliptical Orbits

9.4.4 GEO Orbit and GEO Satellites

Geosynchronous satellites are in wide use, providing international and long distance telephone services (to stationary users) and broadcasting services. The GEO satellites are placed in the earth orbit at 22,300 miles (35,000 kilometers), a region called the Clark Belt, so that the satellite rotates at the same speed as the earth's rotations. Thus the sending and receiving dishes can stay pointed to the satellite without any readjustments.

Geostationary satellites transmit photographs to the receiving system on the ground as soon as the camera takes the picture. A succession of photographs from these satellites can be displayed in sequence to produce a movie showing cloud or other movements. For weather applications, this allows forecasters to monitor the progress of large weather systems such as fronts, storms and hurricanes. Wind direction and speed can also be determined by monitoring cloud movement. For military applications, troop movements can be monitored.

GEO satellites are located directly above the equator, exactly 22,300 miles out in space. At that distance, it takes the satellite a full 24 hours to circle the planet. Since it takes the earth 24 hours to spin on in its axis, the satellite and the earth move together. Thus, a satellite in GEO always stays directly over the same spot on Earth – if it is placed above Moscow, it always stays above Moscow. Conversely, once your antenna points at a GEO, you will always have direct contact with the satellite. This is why geosynchronous orbits are also called Geostationary Orbits. Many communications satellites travel in geosynchronous orbits, including those that relay TV signals into our homes.

GEO satellites can provide high communications capacity and can support several thousand voice channels. However, each GEO satellite message encounters a 0.25-second delay because of the distance a message has to travel between a sender and a receiver. In a satellite communication system, the transmission cost is independent of the distance between the sender and receiver (two stations 100 miles apart or 1000 miles apart still have to travel 22,300 miles to and from the satellite).

Satellites have to be placed 2 degrees apart from each other to minimize interference. In other words, roughly 180 satellites are placed in Geospace to avoid interference (there are 360 degrees in the equatorial plane). Once placed in the orbit 35,000 km above the earth (the Clark Belt), GEO satellites appear stationary. The main advantages of the GEO satellites are:

- There is no problem with frequency changes between senders and receivers because the satellite is practically stationary.
- Tracking of the satellite is simplified because once your antenna is pointed to a Geo, you are done.

- Each satellite has a very high coverage area. For example, one GEO satellite can cover 120 degrees (almost 8,000 miles). Thus 3 satellites can cover the entire earth, although the coverage on the poles is not very good.

However, there are several potential disadvantages of the GEO orbit:

- High delay (240 to 270 ms) is encountered between a dish on earth and a satellite that is 35,000 km above the ground.
- Signals become weak after traveling over 35,000 km .
- Polar regions are poorly served .

9.4.5 LEO Satellite Characteristics

Most of the satellites before 1990 were GEOs. Motorola changed this by filing an application with FCC in 1990 for 77 LEOs. This project was called Iridium because element 77 is Iridium. In reality, only 66 satellites were launched. Since then, launching LEO satellites has been an active area of work, with many companies launching their own LEOs.

How do LEOs work? The basic idea is that many LEOs are launched in a particular orbit that is between 350 km to 1500 km above the equator. These LEOs move around the globe with a high speed relative to the earth objects (a disadvantage of not being in the Clark Belt). When one LEO satellite is out of view of a dish, the next one takes over just in time. This works well because the transceiver dishes transmit and receive in bursts separated by moments of "silence." Thus if the LEO satellite system was designed in such a manner that a satellite was in sight whenever a dish needed to transmit/receive, then everything works fine.

Because they orbit so close to the earth, LEOs must travel very fast; otherwise gravity pulls them back into the atmosphere. Satellites in LEO speed along at 17,000 miles per hour (about 27,000 kilometers per hour)! They can circle the earth in about 90 minutes. The main advantage of LEOs is that round-trip signal propagation delay is less than 20 ms as compared to about 250 ms for GEOs. LEOs move around in a circular/slightly elliptical orbit that is under 2000 km in altitude. An orbit period ranges from 1.5 to 2 hours and the diameter of coverage is about 8000 km. Due to their high speed, maximum satellite visible time is up to 20 minutes. Thus an earth station communicates with a satellite in bursts of 20 minutes and then uses the next one that comes into sight.

The LEO satellites are usually capable of both voice and data communications and use the 26.5-to-40 GHz frequency bands, known as Ka bands, that require smaller antennas. These satellites can communicate directly with handheld devices on earth. The communications equipment of a LEO satellite behaves much like the cell site of a cellular system. The satellite gets the call from the earth and usually passes it to an earth-based switching system (a cellular MTSO or a PSTN switching center). Because the satellites move very fast, they frequently hand off a particular call to a second satellite just moving into the zone. This is similar to a cellular system – but *the cell site is moving rather than the subscriber*.

LEOs can be further categorized as:

- **Little LEOs** that use frequencies below 1 GHz in a 5MHz bandwidth. This bandwidth is subdivided into data rates up to 10 Kbps for applications aimed at paging, tracking, and low-rate messaging. LEO One and Orbcomm are examples of Little LEO satellite systems.
- **Big LEOs** that use frequencies above 1 GHz and support data rates up to a few megabits per second. Big LEOs offer the same services as little LEOs in addition to voice and positioning (GPS) services. Iridium and Globalstar are examples of Big LEO satellite systems.

Broadband LEOs, another class of LEOs, use mixtures of Little and Big LEOs to deliver high-speed data and voice applications. Examples are the Teledesic and Skybridge satellites.

LEO satellites have several advantages over the other satellite systems. There is less propagation delay and costs for launches are lower. In addition, LEO-based networks are more reliable because many LEOs are required for global coverage – if one LEO fails, the entire network does not go down. Some of the limitations of LEO satellites are that they have to cope with large Doppler effects[2] and attenuations due to rain and other atmospheric conditions. In addition, the maximum satellite visibility time is limited to 20 minutes; thus many handoffs between satellites are needed for longer communications.

9.4.6 MEO Satellite Characteristics

MEOs are circular orbits at an altitude in the range of 5000 to 12,000 km. The orbit period of a MEO is 6 hours and the diameter of coverage is 10,000 to 15,000 km. Due to the distance, round trip signal propagation delay is less than 50 ms. Maximum satellite visibility time for a MEO is a few hours.

Why use MEO satellites? The main reason is that they have fewer handoffs than LEOs, even though they have more turnaround delay and require more power than LEOs. MEOs fit very well where less turnaround delay than GEOs and fewer handoffs than LEOs are needed.

Satellite Launches and Operation at a Glance

Launching and operation of satellites is an intricate undertaking. The main steps in launching of a satellite are:

- The launch vehicle carries a satellite into space.
- Once in space, the satellite is separated from its carrier.
- Once on its own, the satellite is directed by its propulsion systems to reach the correct orbit.
- Once in the correct orbit, the satellite is considered successfully launched but not operational.
- To be operational, the satellite goes through a series of tests and system activations.
- Once operational, the satellite starts serving its users.
- Operational satellites have to respond to operational failures of on-board components such as transponders, solar panels, and propellant systems. Redundant hardware is usually installed in satellites for fault tolerance. In addition, satellites are built with technology that takes into consideration harsh space conditions.

To guard against failures, insurance services are available for unsuccessful launches and operational problems. Improvements in satellite technologies are producing over 90% success in the launching and operation of current satellites.

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[2] The Doppler effect, briefly reviewed in Chapter 5, shows how the radiation emitted by an object moving toward an observer is squeezed, giving the appearance that its frequency appears to increase. In contrast, the radiation emitted by an object moving away is stretched, giving the appearance that its frequency is decreasing. A common example to illustrate the Doppler effect is that of an ambulance approaching you – its signal appears to get louder and louder as it approaches you but drops off significantly as it passes you.

9.4.7 VSAT (Very Small Aperture Terminal) Systems

Satellites are commonly used to provide point-to-point as well as broadband communications between senders and receivers. For example, a military station in Washington can use a satellite to directly send information to a NASA station in Houston (point-to-point model) and a TV station in New York can broadcast content to all other TV stations in the US (broadcast model).

A VSAT configuration, shown in Figure 9-8, is a variation on the earlier models. In this case, a hub is used to provide communications between various user sites. VSATs (Very Small Aperture Terminals) are small, software-driven earth stations (typically with 3- to 8-foot antennas) used to set up a satellite-based communications network. The VSAT earth stations are organized as cells and one cell acts as the hub. Each user site is interconnected with the hub station via the satellite – the hub controls the operation of the network. All communications between the user sites are first transmitted to the hub station, which then retransmits the traffic via the satellite to the other user VSATs. A VSAT can easily handle data rates of 56 Kbps, and higher data rates are now available.

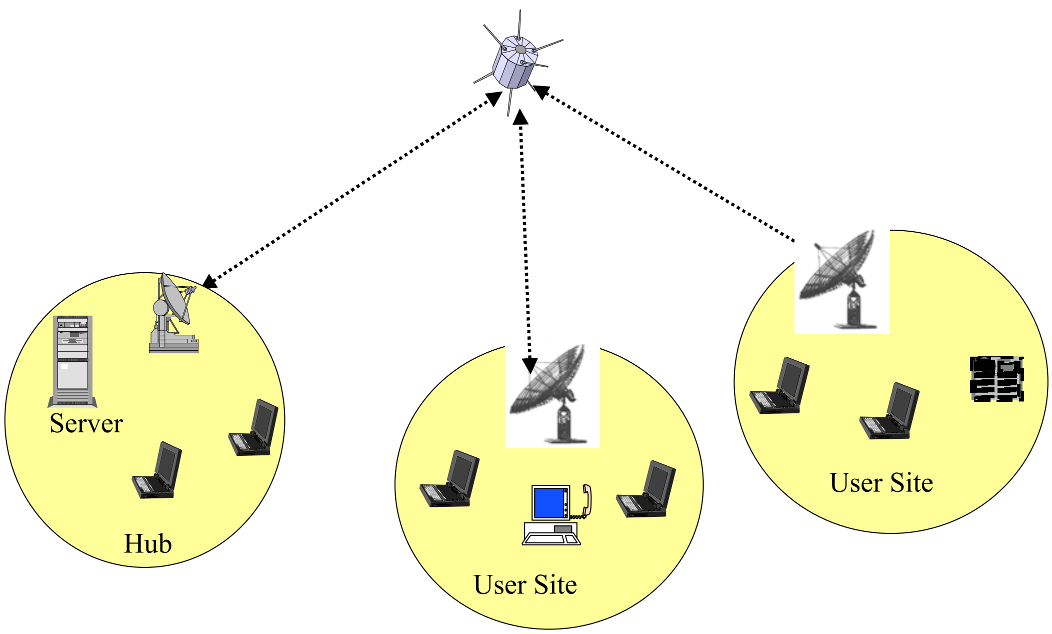

Figure 9-8: A Sample VSAT Configuration

Each VSAT cell houses a VSAT earth station – a transceiver that is placed in direct line of sight to the satellite. The transceiver is connected to the end user's communications device, such as a PC or a point-of-sales (POS) terminal, through wired or wireless connections. The hub may house a server that contains common information. A hub may also be the corporate site in a multi-site organization. Because of the central role of the hub, a VSAT can be a common website for a particular application such as a distribution center. Due to their large coverage areas, VSATs can be used for very large wide area networks. VSATs are used commonly in retail store chains such as WalMart and Kmart. In these cases, the retail headquarter serves as a hub and each retail store acts as an user site. The point-of-sales (POS) equipment at each user site reads a bar code label and then sends this information to the central site (the hub) for prices, etc. The communication between the retail stores and the hub is supported by the satellites.

The main advantage of VSATs is that they provide two-way satellite-based Internet access and provide both data transmission and reception without depending on a terrestrial network. This is extremely useful in many satellite applications, because many satellites provide one-way communication – mainly to download the content. Many distance learning (DL) applications, for example, require content delivery as well as two-way Internet access (see the case study in Section 9.6.4). For example, the Lehigh University DL uses VSATs. Lehigh clients find that VSATs are affordable, and easy to install and use [Collins 2000]. However, in most VSAT implementations, a VSAT is fixed on one satellite and is able to receive signals only from that particular satellite. In case of problems with that satellite, the communications fail. A dedicated VSAT dish that can switch from one satellite to another in case of a problem is more reliable.

Several improvements in VSATs have been introduced over the years. This has resulted in higher data rates as well as the use of smaller-sized antennae. For example, VSATs at present can provide 2 Mbps data rates as compared to the 512 Kbps and 54 Kbps data rates in 2002 and before. The VSATs also support smaller-sized antennas that are cheaper and can be mounted on walls instead of rooftops, thus reducing rental costs. For example, the antenna diameter limits are reduced to 2.4 meters from 3.8 meters in some cases.

For additional information on VSATs, visit the Global VSAT Forum (GVF) website (www.gvf.org).

9.4.8 Examples of Satellite Systems

Satellite systems have gone through several advances over the years. Due to improvements in antenna design, signal reception, and other related technologies, it is becoming possible to provide mobile services using satellites. Several such projects are under different stages of implementation. Some examples are:

- Teledesic, funded by Microsoft and McCaw Cellular, is a $9 billion LEO satellite project. The project originally planned to launch 840 LEO satellites but that number has been scaled down to 288. The satellites are supposed to provide "fiber type" data rates – 155.52 Mbps to and from the ground and 622.08 Mbps to and from other satellites. A typical Teledesic user will operate at 64 Mbps downlink and 2 Mbps uplink. In February 2002, Teledesic announced it's planning thirty MEO satellites. Visit the website (www.teledesic.com) for more information.
- Iridium, initiated by Motorola, is another LEO project that uses 66 satellites to provide mobile communications to every point on earth and within 50 miles above it. Iridium is designed to handle different mobile customer needs that may range from global roaming to adding new coverage to an existing service. Iridium services were offered in 1999 but the reception has been lukewarm due to complaints about high cost and technical problems. At the time of this writing, the Iridium project has been closed by Motorola but new deals and news about the project appear in the press on a regular basis. See www.iridium.com for details.
- Western Union satellites have been used regularly by PBS (Public Broadcast System) to broadcast TV programs to a wide range of viewers across the US.
- Many other satellites from large corporations (GE, Hughes, AT&T, IBM) have been launched for company business.
- ICO (for Intermediate Circular Orbit, another term for Medium Earth Orbit) was originally foormed by Inmarsat before being spun off into a separate company. In

addition to several MEOs, ICO offers a limited telephone service from a GEO satellite. See the ICO website (www.ICO.com) for details.

- Several VSAT (Very Small Aperture Terminals) use satellites on a regular basis for point-of-sale applications. For example, WalMart uses VSATs at each store, that communicate directly with suppliers via satellite. VSATs have a 1-meter antenna and operate at 19.2 Kbps for uplinks and 512 Kbps for downlinks. Due to their small size, VSAT signals are weak, so they use a hub to reinforce signals and coordinate users.

Although many LEOs, and some MEOs as well as GEOs, have been launched successfully, the number of customers signed up for satellite systems has been less than impressive due to costs (the initial cost can be $1000 and the per-minute charge can exceed $50). Satellite systems to support mobile users should meet the demands of cellular users in many countries and regions with poor cellular services or none.

It should be noted that orbital arcs are controlled by the FCC and other agencies. The FCC was formed in 1934, long before satellites came into existence in 1960s. The FCC started controlling satellites after the Communications Satellite Act of 1962.

Weather Satellites

Satellites show weather patterns which cannot be seen from the ground. Recall that the weather satellites are either Polar Orbiting Satellites (POES) which orbit around the earth, or Geo-Stationary Orbitting Satellites (GOES) which stay in a fixed location 22,300 miles above the equator. Each satellite is equipped with cameras which send back photographs of clouds, and additional equipment such as light and heat sensors, recorders, and a radio receiver/transmitter. The first weather satellite, TIROS I, was launched in 1960. It circled the earth every two hours at heights of 420-900 miles and sent back pictures of cloud and snow cover. Since then, TIROS has been replaced with newer, more sophisticated satellites and several new weather satellites have been launched. The satellite pictures we all see on TV weather reports are mostly from GOES satellites.

9.4.9 Global Positioning System (GPS)

The GPS is a global radio navigation system consisting of two dozen satellites and their corresponding ground stations. The GPS components are used to calculate positions accurate within a few meters – a more advanced form of GPS can estimate positions with less than a centimeter margin of error. GPS was initially designed for the United States military; however, the technology is now available for commercial or private use. For example, GPS technology is now appearing in planes, cars, boats, construction equipment, movie-making gear, farm machinery, and laptop computers. GPs technology, as discussed in previous chapters, is also used for location-based services in cellular networks.

The GPS technology has gone through several enhancements over the years, but the basic idea is quite simple. The system uses the angular arrival at the satellite to measure distance using the time travel of radio signals. The travel time is measured using very accurate timing techniques. To assure accuracy, the GPS satellites are carefully monitored so that observers know exactly where they are in space. Adjustments are made for delays the signal may experience as it travels through the atmosphere.

9.4.10 Satellites Talking to Satellites – The "Satellite Constellations"

One satellite only covers part of the world at any time. For global or near-global coverage, many satellites are needed so that at least one satellite can be seen from almost every point on the earth at least once. The term "satellite constellation," coined by Lloyd Wood[3], represents a collection of satellites with coordinated coverage and control so that their coverage areas (or footprints) overlay the world. Satellite constellations imply that the satellites could talk to each other directly via inter-satellite links (ISLs), without the signal hopping to and from an earth station. The two main applications of satellite constellations are:

- **Routing in the sky**. In this configuration, each satellite behaves as a router in the sky that forwards traffic directly from one satellite to another. For example, if three satellites were handling traffic from three different states, then the inter-state communication traffic is routed between the satellites. This represents a very-very-very wide-area wireless network.
- **Handoffs in the sky**. In this configuration, commonly found in LEOs, one satellite hands off a particular call to another satellite. This happens frequently in LEOs because the LEOs move very fast and do not have enough exposure to the ground stations to complete a call. For example, if a cell call lasts 40 minutes but the LEO moves out of sight in 20 minutes, then the call has to be handed off to another satellite just moving into the zone. As stated previously, this is similar to a cellular system – but the *cell site* is moving rather than the *subscriber*.

Several constellation-based schemes are being used at present. Voice communications is one area, with companies such as Globalstar, ICO, and a host of other "Big LEO" providers. These focus on voice as the main market, but can provide fax, paging, and 56 Kbps data services. Unfortunately, telephony is a legacy application, and GSM has most of the planet tied up; finding a market is a problem. ICO seems to be reinventing itself as a data service. Another area is satellite radio, by which North American drivers can listen to radio broadcasts from Europe and other parts of the world. Another possibility is broadband networking with players such as Teledesic and Skybridge. Constellations are already being used for messaging, with companies such as Orbcomm launching much of its constellation for messaging applications. Naturally there are satellite constellations for military and government applications.

For additional information and ongoing developments in this area, see the Lloyd Wood site (http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/).

Abandoned Satellites – The "Space Junk"

Many satellites have been launched into space over the years and abandoned by their owners due to "down to earth" reasons (pun intended) such as bankruptcies and lack of funds. With these orphan satellites, along with other satellites and debris flying around in orbit, there is a risk of orbital collisions. There are the doomsday scenarios of these collisions creating debris that flies off and collides with other satellites, which breaks into debris that collides with others, and so on, and so on. This chain reaction is known as the "satellite cascade effect." Concerned people, including politicians (who else?) have raised the possibility of denying access to space. Considerations of this nature have affected the satellite insurance sector.

[3] Lloyd Wood maintains a very interesting site on satellites with a great deal of discussion on constellations (http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/).

9.4.11 Key Benefits of Satellite Communications

User Mobility. Satellites cover very broad areas, thus customers can transmit or receive signals from moving vehicles, mountains or mid-ocean ships. As compared to cellular networks that may not have enough base stations to cover many areas, satellites provide real mobility for users in very large areas. Thus they eliminate the geographic location barriers and provide terrain independence. Due to their coverage, they can equally serve metropolitan areas or deserts.

Broadcast Model. Satellites cover vast geographical areas for broadcast and multipoint communications. A single GEO can simultaneously broadcast signals to an area as large as one-third of the earth's surface. A very complex and expensive terrestrial network consisting of hundreds of fiber links would be needed for broadcasting to an area much smaller than one third of the earth. In comparison, satellite broadcasts are more reliable and less expensive because they can broadcast information to an almost infinite number of dispersed sites simultaneously.

Minimum Hops. Satellite technology can be used to distribute content directly to the end user or closer to the edge of a network to reduce the number of terrestrial router hops. Each hop can lose packets or cause additional delay and degrade quality of service.

Relative Quick Deployment. A satellite communications network can be deployed in two to three years, starting from scratch (construction and launch of a new satellite). While this is not rapid deployment, it is still less than the time required to deploy an equivalent terrestrial network. The installation time for satellite networks is decreasing as technology advances.

Customization. Satellite transponders can be used in whole or in part to service one location while the rest of the transponder is serving the remainder of the region. Satellites can also be easily customized to accommodate different uplink and downlink data rates for Internet users.

9.4.12 Limitations of Satellite Communication

High Latencies. This is the biggest limitation. Because of the long distances (around 22,000 miles both ways), typical GEOs suffer latency of a quarter of a second. This results in a noticeable impact. LEOs are more attractive because their latency is comparable to terrestrial networks.

Risks of Failures. Launching of satellites is an intricate and error-prone process (see the sidebar, "Satellite Launches and Operation at a Glance"). Any of the steps in launching can fail. And even after being fully operational, a satellite can crash due to failures of on-board components such as transponders, solar panels, and propellant systems. Although the reliability of satellites is improving due to better technologies, they are much more complex than the terrestrial networks.

Shaky Business Models. Several satellites launches have been technically successful but business failures. The main problem is that the initial cost of launching satellites is high, so the satellite service providers have to charge high usage fees to break even. As a result, many commercial satellites did not become very popular, thus leading to business failures. Well-known examples are the failing satellite business models of Iridium and Globalstar. Thus it seems to be easier to successfully put a satellite into operational orbit than to make it a business success.

Too Many Regulations. Satellite communication operators have to deal with many more regulations and controls as compared to the terrestrial networks (see the sidebar "Regulations in Satellites"). These regulations make it difficult for new players to enter the marketplace.

Regulations in Satellites

Satellite communications are subject to a wide range of regulatory controls. Since satellites can be used for national espionage, they are subject to national security regulations. In addition, installation of earth stations requires landing rights permission. In many countries, satellite licenses to foreign operators are prohibited unless they have partnerships or alliances with local companies. These regulations for operation are in addition to the frequency regulations that exist in cellular and other wireless networks. The good news is that many of the regulations are being relaxed and monopolistic agencies and companies are being replaced with multiple competitors, each using its own satellite for its business. In particular, deregulation and privatization is stimulating the demand for satellite services from multiple suppliers.

9.4.13 Satellite versus Fiber Optics and Cellular Phones

We have looked at the general benefits and limitations of satellites. Let us now briefly review satellite communication versus its principal competitors: fiber-optic and cellular networks.

Satellites were favored before 1984 for long-distance communications. However, the breakup of AT&T resulted in development of fiber and broadband communications that created competition for satellites. While considering fiber versus satellites for long-haul communications, fiber has far more bandwidth (BW) than many satellites. For example, the BW of one fiber link is around 2,000 MHz, while the BW of one satellite transponder is about 15 MHz. Even with 20 transponders per satellite, the total BW of a satellite is around 300 MHz – much smaller than that of a fiber link. On the other hand, fiber cannot reach every home – the well-known last-mile problem. Although fiber does have advantages over satellites, several niches for satellites have been found. Consider, for example, a user who needs 50 Mbps access. The user can use a T3 line or a satellite link. In this case, satellite is a good choice if messages need to be broadcasted (which is tough with fiber), or if you cannot lay cables due to hostile environment.

Competition between satellites and cellular networks is commonplace. Although many satellites support applications such as forestry, aviation, mining, maritime and defense that cannot be addressed with cellular networks, other applications such as Internet access can be provided by both. The main tradeoff is in coverage. In particular, several LEOs have been launched to provide wider coverage than cellular networks. A key benefit of the satellite systems so far has been global connectivity. But the availability of tri-band GSM phones that can work across Europe, America and Asia provides as much coverage as satellites. Given the same coverage area, the cellular networks have the advantage that the cellular phones are light and inexpensive as compared to the large and expensive phone equipment (brick size telephones) needed for the satellite networks. However, satellites are favored in less-developed countries of Africa and Latin America where it may be cheaper to use the satellite phones than wired phones, with the only other alternative being no phones.

In reality satellites co-exist very well with fiber-optic and cellular networks. For example, satellite networks are commonly used as links between regions that are individually supported by fiber-optic or cellular networks.

9.4.14 Satellite Design Issues

9.4.14.1 Overview

Numerous technical design issues arise in the development, launching and use of satellites. For example, satellite launching is a complicated task that requires a great deal of effort. In addition, keeping the satellites healthy and operational while they are up there is non-trivial (they tend to crash and burn every now and then). Basically, a satellite is a complex machine with several sub-systems that work together as one large system to help the satellite achieve its mission. Discussion of these topics is beyond the scope of this chapter. Details can be found in books such as Inglis [1997] and Elbert [1999]. Technical details about inner workings of satellites can be found at the websites (http://www.thetech.org/exhibits_events/online/satellite/) and (http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations).

Our main concern here is how the satellites are used once they have been launched and are operational.

A serious problem in satellite design is capacity allocation to different users. Typically a GEO will have 500 MHz BW, subdivided into channels of 40 MHz each. You can possibly allocate one complete satellite channel for a single TV channel or a fast data service (50 Mbps or higher). However, in most cases, a satellite channel needs to be subdivided among many users (see the sidebar, "Example of Alternative Uses of Satellite Channels"). Special issues in multiple user allocation to these channels arise because long turnaround delays (270 ms) are not suitable for polling and detecting collisions, etc. It is, for example, virtually impossible to poll users that are 35,000 km away. Thus, the LAN-type protocols for satellites simply do not work. Variants of Alloha allocation schemes have been proposed, but most satellite allocation schemes use either frequency division multiple access (FDMA) or time division multiple access (TDMA) techniques. These techniques are briefly reviewed here. Detailed discussion can be found in Stallings [2002].

Example of Alternative Uses of Satellite Channels

One 40 MHz satellite channel can be allocated to the following users:

- One 50-Mbps data stream
- 1200 voice-frequency (VF) voice channels
- 16 channels of 1.544 Mbps each
- 400 channels of 64 Kbps each
- 600 channels of 40 Kbps each
- One analog video signal for TV users
- Six to nine digital video signals

Source: Stallings [2002]

9.4.14.2 Distance and Coverage

Figure 9-9 shows the basic geometry of satellite distance and coverage. An important parameter is the elevation angle (A) of the earth station, which is the angle from the horizontal to the point on the center of the main beam of the antenna when the antenna is pointed directly at the satellite. For maximum coverage, the elevation angle should be as small as possible. However, the following factors affect the minimum elevation angle of the earth station's antenna:

- Buildings, trees, and other terrestrial objects block the line of sight.
- Atmospheric attenuation is greater at low elevation angles.
- Electrical noise generated by the earth's heat near its surface adversely affects reception.

9.4.14.3 Frequency Allocations in Satellites

Satellite signals are only transmitted on certain frequency bands. The International Telecommunication Union (ITU) assigns the specific bands to be used. Each band consists of an uplink band and a downlink band. The band's reception on earth is subject to an inverse relationship between frequency and wavelength. When frequency increases, wavelength decreases. The larger the wavelength, the bigger the antenna (satellite dish) necessary to receive it. In other words, the radius of dish r is given by the following formula:

$$r = k \cdot w = k/f$$

Where k = constant, w = wavelength and f = frequency. Thus, the higher the frequency, the smaller the satellite dish. Table 9-3 shows the most commonly used satellite frequencies. The two bands used most frequently are the C band and the Ku band. The X band is used mainly in deep space communications and the Ka band is a relatively new band.

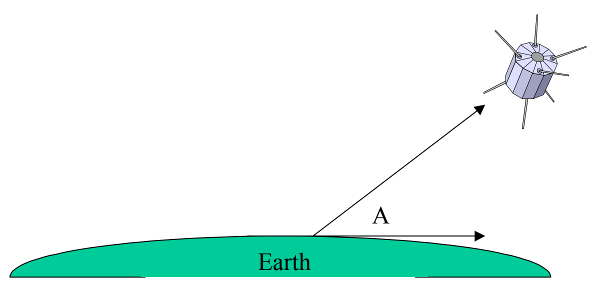

Figure 9-9: Angle of Elevation

The **C band**, commonly used in first-generation satellites because it was the first band to be exploited by commercial satellites, is crowded because terrestrial microwave links also use these frequencies. The C-band range of frequencies extends from 3.4 GHz to 6.7 GHz, with an uplink frequency of 6 GHz and a downlink frequency of 4 GHz. As the signal strength is relatively weak, larger antennas are needed to receive the signal. The minimum size of an average C-band antenna is approximately 2 to 3 meters in diameter. C band is a particularly popular choice in Africa and the Arabian countries because its lower frequencies are less affected by weather than the higher frequencies of the Ku or Ka band.

The **Ku band** has an uplink frequency of 14 GHz and a downlink frequency of 11 GHz. Based on the discussion above, Ku bands have much smaller antennas. The smallest of these antennas can be 18 inches in diameter. This is the type of antenna used with home entertainment satellite dishes. Ku-based satellites, permitting smaller antennas on the ground and the ability to deliver over 200 television channels, provide an attractive alternative to Cable TV programming. The Ku band is generally considered to extend from 12 to 18 GHz.

However, many satellite communication engineers use the term “Ku band” to refer to an extended frequency range from 10.7 GHz to 18.4 GHz. This frequency range actually includes part of the X band (8-12 GHz). In fact, many Ku-band systems include X-band frequencies.

The **X band** is used very frequently in deep space communications (see Section 0). For example, the Mars rovers communicate with earth stations by using the X band.

The **Ka band**, a relatively new band, extends from 27 GHz to 40 GHz. Many Ka-band satellite systems typically employ the 27.5-30.0 GHz frequency range for uplink transmissions and the 17.7-20.2 GHz range for downlink transmissions. The satellite dishes for Ka-band systems are very small. Once again, satellite communication engineers use the term “Ka band” rather loosely.

Table 9-3; Satellite Frequency Allocations

Band	Frequency Range	Total Bandwidth	Typical Applications
L	1 to 2 GHz	1 GHz	Mobile satellite service (MSS)
S	2 to 4 GHz	2 GHz	NASA, deep space research, MSS
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	Mobile satellite service (MSS) and deep space communications
Ku	12 to 18 GHz	6 GHz	Mobile satellite service (MSS)
Ka	27 GHz to 40 GHz	13 GHz	Many short distance, high data rate applications, WLLs

Since satellite links can operate in different frequency bands, there are several tradeoffs. The frequency allocations at C, Ku, and Ka bands offer effective bandwidths of one gigahertz (GHz) or more per satellite, facilitating a range of broadband services. The current band usage trend is toward the higher frequencies of the Ka and Ku bands, which allow use of small earth-station antennas. There are two main consequences when moving from the C band to the higher frequencies of the Ka band. The first is that the beam becomes more concentrated at the Ka band, providing higher gain and a narrower beam width. This reduces the dish size but as a consequence of the narrower beam width, the susceptibility to antenna pointing errors increases. The second consequence is that the effects of the weather become more severe at the higher frequencies and also the distance traveled is reduced. It is the task of the system designer to balance these advantages and disadvantages.

The scarcity of frequency ranges applies particularly to geostationary satellites that are commonly used for communication services. Due to the constraints on the limited number of slots that can be allocated in the GEO orbital plane, unoccupied slots are becoming scarce, particularly the ones offering viable commercial services over certain geographic coverage. Applying for new slots is a complex and time-consuming process. Frequency bandwidth is strictly regulated and allocated for use in each country, and the deployment of a satellite service involves a lengthy process of frequency coordination. The consolidation of satellite fleets, such as SES Global Satellite Fleet (www.ses-global.com/fleet/), is partly due to this limitation.

9.4.14.4 Frequency-Division Multiple Access (FDMA)

FDMA subdivides a logical channel by allocating different frequency ranges to the users. The factors which limit the number of subchannels provided within a satellite channel via FDMA include thermal noise, intermodulation noise, and crosstalk. FDMA is used in two forms for satellites:

- **Fixed-assignment multiple access (FAMA).** The assignment of capacity is distributed in a fixed manner among multiple stations. Since logical links between stations are preassigned, multiple stations access the satellite by using different frequency bands. This scheme is simple but may result in significant underuse of capacity because demand may fluctuate and some subchannels may not be used at all.
- **Demand-assignment multiple access (DAMA).** Capacity assignment is changed as needed to respond optimally to demand changes among the multiple stations. The set of subchannels in a channel is treated as a pool of available links. For communication between two earth stations, a pair of subchannels is dynamically assigned on demand. Demand assignment is performed in a distributed fashion by the earth station. DAMA is more complicated than FAMA but can support many more users.

9.4.14.5 Time Division Multiple Access (TDMA)

TDMA allocates users to channels by using time slices (one time slice per user). Although many satellites at present use FDMA, TDMA is becoming more popular because it uses digital communications. As mentioned in previous chapters, digital communications are attractive because the cost of digital components continues to drop, you can use sophisticated error correction and encryption techniques, and the quality of signals is better.

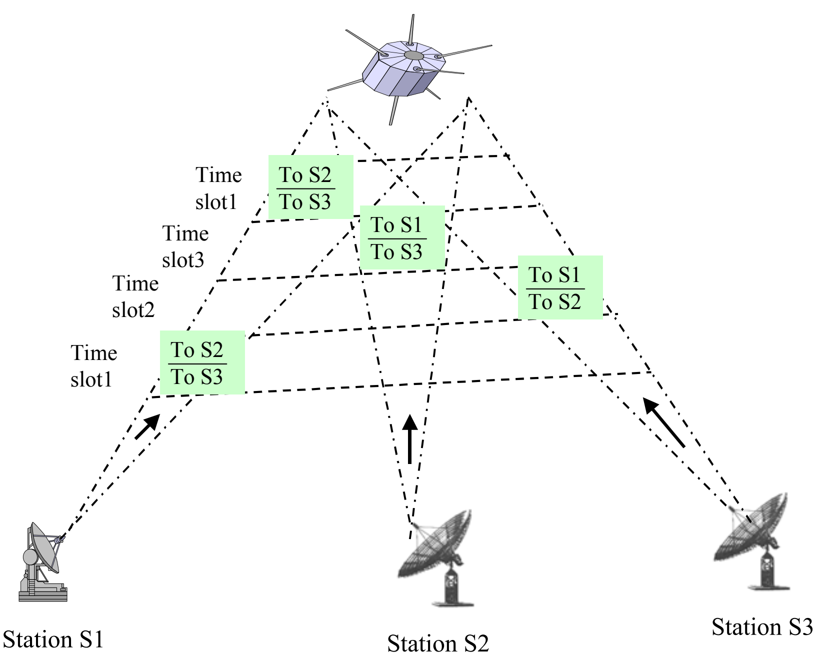

Figure 9-10: TDMA-FAMA Uplink

TDMA can also operate as FAMA where fixed time slots are allocated to users, or as DAMA where the duration of time slots is adjusted based on demand. Once again, TDMA-FAMA is simple but wastes bandwidth, while TDMA-DAMA is complex but is more efficient. Figure 9-10 shows a TDMA-FAMA uplink where stations S1, S2, and S3 broadcast information to each other. Time slot1 is used by S1 to “uplink” information intended for S2 and S3, time slot2 is used by S3 to uplink information intended for S1 and S2, and so on. Figure 9-11 shows the TDMA-FAMA downlink where the information is downloaded by the satellite to the various earth stations in different time slots.

9.4.14.6 TCP/IP and ATM Over Satellites

It is important to run TCP/IP over satellite links to support the Internet over global networks. There has been some discussion about TCP/IP running properly over satellite (see the article "Wireless multimedia and internet via satellite," by Mark Sturza and Farzad Ghazvinian, at the website http://www.teledisc.com/. This article claimed that the TCP/IP reference implementation's 4K buffer size limits the data throughput to only 64 Kbps. TCP buffer size S is determined by the following equation:

$$S = W.D$$

where W = bandwidth and D = expected delay. Thus with a limited buffer size, a longer end-to-end delay could decrease the throughput of a TCP connection. However, the work done on larger buffer sizes for TCP in RFC 1323 addresses this problem. At present, TCP handles GEO delays quite well and individual high-bandwidth GEO TCP links are possible.

Another issue is ATM support over satellites. ATM was developed for a tree of permanent, high-bandwidth, fixed, error-free fiber links. Use of ATM in lower-bandwidth satellites with rapidly changing positions in bursty-error space is not easy. ATM has to be modified heavily to efficiently support satellite links. This increases the complexity of ATM, an already complex protocol.

For discussion and opinions, see the website (http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/general.html#tcp).

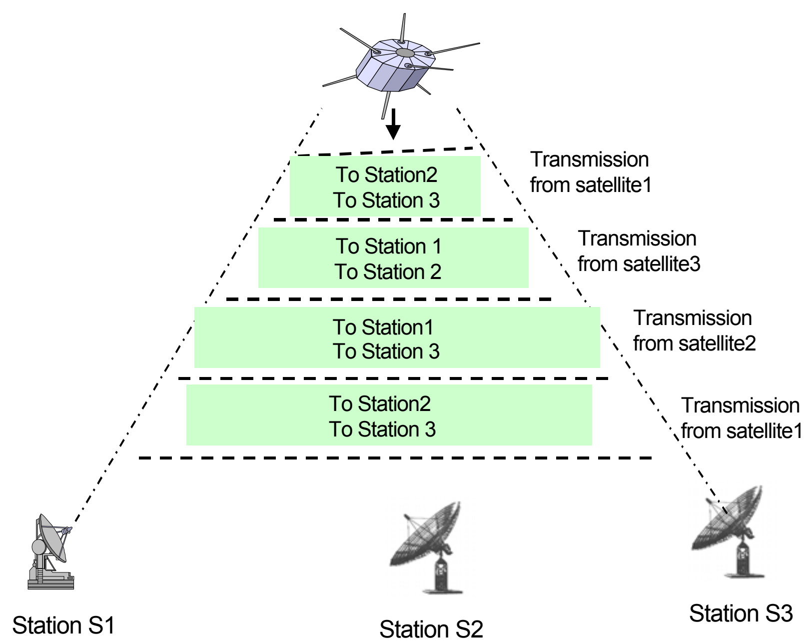

Figure 9-11: TDMA-FAMA Downlink

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- General information site: http://www.thetech.org/exhibits_events/online/satellite/
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- http://www.satcoms.org.uk/ -- UK website for satellite communications
- Lloyd Wood's website – http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations
- *International Journal of Satellite Communications*, John Wiley (for deeply technical topics).
- Reference list for satellites: http://www.cse.ohio-state.edu/~jain/refs/sat_refs.htm

9.5 Deep Space Communications and Interplanetary Internet[4]

9.5.1 What is Deep Space Communications?

The discussion of satellites so far assumes communications in the orbit of the earth. Deep space communications are handled by spacecraft beyond earth's orbit. "Deep space" roughly starts at 1.7 million kilometers (1.05 million miles) above the earth (see Figure 9-12). Although an active area of work by NASA for several years, communications into deep space again received national attention on January 14, 2004, when President Bush announced to the nation a new vision in space exploration that highlighted the task of sending humans to Mars and other planets.

Among the many questions that must be answered to make these missions a success is that of how all of these spacecraft – and in the near future, human explorers – will communicate with earth during their journeys. Deep space communication is the general umbrella under which major initiatives such as NASA'a Deep Space Networking (DSN) and "Interplanetary Internet" are being explored.

It is interesting and educational to look at deep space communication systems in a book on wireless because in deep space, wireless is the *only* option (it is technically infeasible to run a million-mile fiber cable up in the sky). In addition, deep space communications use a mixture of the fundamentals of wireless communications, such as signal modulation, data encoding, error correction, and many other techniques we have discussed so far (it is reassuring to know that somewhat similar techniques are useful at even over such large distances). Furthermore, as we will see, problems in deep space communications are much harder than those on earth; thus solving these problems could lead to solving some future problems on earth. For example, the somewhat far-off notion of Interplanetary Internet is leading the research in delay tolerant networking which has many "down to earth" applications.

[4] This discussion is largely based on a "Deep Space Communications" presentation by Raymond Ciarcia and Greg Kuperman.

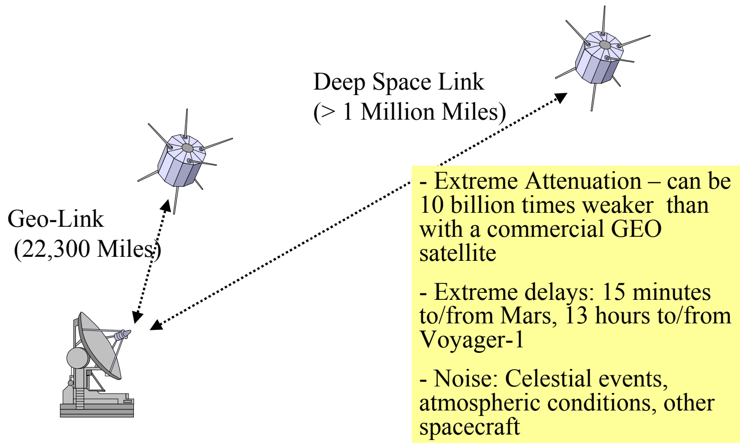

Figure 9-12: Deep Space Communications Challenges in Deep Space Communications

Many of the challenges that are faced when communicating in deep space are similar to those seen on earth – except taken to the extreme. Here is a quick summary:

- **Extreme Attenuation.** While all wireless systems face signal attenuation, the attenuation faced when communicating on the interplanetary scale is astounding. This is because received signal strength is related to the inverse of the square of the distance, i.e., signal strength is proportional to $1/d^2$ where d is the distance. Thus, a signal in the region of the outer planets (Neptune, Pluto) is approximately 10 billion times weaker than with a commercial GEO satellite.
- **Extreme Delays**. Delays are similarly excessive, ranging from minutes to communicate with spacecraft on Mars to hours to communicate with spacecraft further from Earth. For example, delays of 15 minutes to/from Mars becomes 13 hours to/from Voyager-1. In such conditions, many typical protocols become extremely inefficient. Particularly, it is critically important to minimize retransmission of data. Thus considerable onboard autonomy is required. Interplanetary Internet, as discussed later, is a paradigm under which the effects of extreme delay are being investigating and addressed.
- **Noise and Line of Sight.** Noise comes from other spacecraft and also from the surrounding environment. Celestial events on top of a noisy background due to other spacecraft, as well as atmospheric conditions on earth, make the incoming signal more difficult to recover. It is not uncommon to see frequent and sometimes extended breaks in communication due to a celestial event or even rain over the receiving ground station. In addition, Doppler shifts – the combined movement of earth and spacecraft – distorts signals. The line-of-sight problems are also complicated because base station placement must account for the earth's rotation and the location/rotation of other planets. The challenge is well summarized by analogy: "Successfully sending a DSN signal into Voyager-2's receiver is like throwing a baseball across thousands of miles of ocean into a porthole of a moving cruise ship."[5]
- **Low Power**. Batteries must be lightweight and last for years or decades. Because the spacecraft must be light and contain a great deal of other hardware, power is generally very limited. Battery use must always be carefully weighed against future considerations because, when the battery dies, the mission is over.
- **Specialized Hardware**. Equipment is exposed to extreme temperatures, radiation, and physical shock. As a result, hardware must be fault-tolerant and redundant. Space

[5] Source: http://www.spacetoday.org/SolSys/DeepSpaceNetwork/DeepSpaceNetwork.html

communications hardware is also much more expensive than equivalent non-space-bound hardware because of the extra layers of protection and redundancy that must be incorporated into the design. In addition, once deployed, a spacecraft's hardware cannot be upgraded to use newer technology. If the spacecraft is designed to communicate over the next forty years, as has been the case in some missions, then the communication system it uses must be supported over the entire mission duration.

9.5.2 What is DSN (Deep Space Network)?

Simply stated, Deep Space Network (DSN) is a NASA initiative to handle communications with spacecraft outside of earth's orbit. The origin of DSN is an Army project to support the communications of Explorer 1, the US's first successful satellite in the 1960s. With emphasis on space exploration at that time, DSN dramatically grew in scope and capability as new dishes, technologies, and worldwide stations were added. Currently, DSN is a large project, managed by NASA's Jet Propulsion Laboratory (JPL) and manned by thousands of people for the daily operations of the network. DSN does not support the space shuttle and most earth-orbiting satellites, such as the Hubble telescope – it is exclusively devoted to communications beyond earth orbit. The DSN is responsible for telemetry, monitoring and control, and scientific explorations in space farther than one million miles above the earth.

DSN uses a variety of sophisticated technologies. Ground-based dishes for DSN, for example, are equipped with precision motors to closely track a spacecraft. In addition, to avoid retransmissions at almost all costs, DSN uses the latest in error-correcting codes, with much current work focused on Turbo codes [Guizzo 2004]. Thanks to these coding techniques, the chance of requiring a retransmission on a typical mission is less than one in a million. For details, see http://www.astrosurf.com/lombry/qsl-mars-communication2.htm.

DSN currently supports a wide range of frequency bands, from 2.3 GHz up to 90 GHz. Though current missions largely use the X band at 8 GHz, the S band supports older spacecrafts that still communicate with earth, and many bands are designated for active and anticipated research. The DSN data rates are relatively low due to extremely large distances. The current deep space data rate at Jupiter of about 600 Kbps is equivalent to 250,000 Gbps at the altitude at which geo-synchronous satellites orbit the Earth!

While there are many spacecraft still in flight that use older technologies, the X band is currently the standard means of communication for today's DSN-supported missions. The X band uses two separate bands for uplink (earth to spacecraft) and downlink (spacecraft to earth), with the downlink band slightly larger than the uplink. Phase-shift keying is used for both links. and 8PSK is under development in hopes of significantly raising downlink capabilities. With current technologies, the upper limit on X-band capability is around 200 Mbps, though it is hoped new modulation and coding techniques can raise this figure to as high as 600 Mbps. Because retransmission delays are near intolerable, a forward error correction based on Turbo codes is an area of intense research. To provide communication to multiple spacecraft, the X band (and most other DSN bands) use a form of TDM.

Optical communication has the promise to become the new standard for DSN communication and to offer higher data rates, perhaps up to 10^7 or 10^8 bps (based on Jupiter location). While the goal of using optical techniques is to increase communications' data rates, there are some additional advantages. One major advantage of using optical communications is that less power is required. While current technologies like X band require around 15 to 20 W to transmit, optical equipment would require only 5 W. Furthermore, the ground station dishes necessary to receive signals need not be as large as conventional dishes, perhaps as small as 10 meters in diameter to receive signals from the vicinity of Mars.

Table 9-4: Highlights of Deep Space Networks

Factor	Key Points
Data Rate and Distances	Typically low data rate (600 Kbps) per user over 1 million miles or more
Target Applications	Deep space explorations and Interplanetary Internet
Frequency Allocations	Frequency bands from 2.3 GHz up to 90 GHz. Many use X band: – Uplink: 7.145 to 7.235 GHz – Downlink: 8.40 to 8.50 GHz
Location Services	Unique issues because the satellites are moving around the earth.
Physical Communications Considerations	- FEC with possibility of turbo codes - Phase-shift keying (PSK) and improvements used for modulation - Each mission given non-overlapping time slots for transmissions (TDM)

9.5.3 Interplanetary Internet – Internet in the Sky

The idea of an Interplanetary Internet was proposed by Vinton Cerf, Chief Internet Scientist for Worldcom, in 1998 and was later refined and presented in 2001 by a team under his leadership. Currently, an Interplanetary Internet Study is funded by DARPA's Next Generation Internet Initiative (www.ngi.gov). Simply stated, Interplanetary Internet (IPN) is trying to use the Internet technology in DSN such that the various satellites and exploratory devices on the surface of far-off planets, for example, would have IP addresses (see Figure 9-13). The primary goal of the study is to investigate how terrestrial Internet protocols and techniques may be extended and/or used as is, in the exploration of deep space. The main driver is to establish deep space infrastructure to support the communication needs of multiple missions into the indefinite future. This is different from the current ad hoc deep space communication performed by individual exploration spacecraft.

IPN could offer many benefits to explorers who travel great distances in future missions. For example, it would provide a standard by which, for example, astronauts could use tele-robotics to directly control the operation of vehicles before landing on the Martian surface. It could also provide a means by which astronauts could directly send and receive emails to and from friends and family directly over the Internet, making long journeys more bearable. For the rest of us, there are some benefits too. The IPN may provide a standard by which explorers can interact directly with spacecraft without undertaking a space trip. New visualization and control applications could allow scientists to participate in real time as discoveries are made, and thus influence the direction of research. Students from high schools and colleges could undertake interesting projects and explore truly unknown territory, rekindling interest in science.

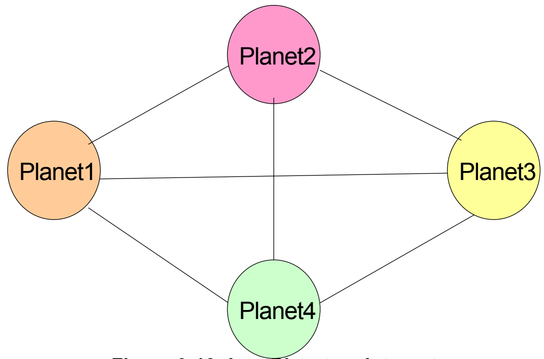

Figure 9-13: InterPlanetary Internet

9.5.4 Delay Tolerant Networking

The IPN study has sparked research in Delay Tolerant Networking (DTN) – i.e., how do you build a network where the propagation delay between a sender and a receiver can be several hours or even days? These networks also have relatively low data rates (8-256 Kbps) and suffer from intermittent connectivity possibly due to schedules of operation (a satellite may transmit or receive only a few hours a day). Under these conditions, reliable Internet protocols perform poorly, and unreliable protocols (e.g. UDP) require application-layer support to provide acceptable service. Thus higher-layer request/response applications can time out and lose data due to excessive delays and "off" periods. The objective of DTN protocols is to provide a robust application-layer overlay to handle these special conditions.

There are many possible earthly applications of delay-tolerant networking, such as the following:

- Some communication resources (e.g. satellites, helicopters, and fixed-wing aircraft) in military and emergency operations are highly mobile and hence only intermittently available. Additionally, delays within connected portions of the network may be extremely variable due to the harsh working environments.
- Wireless sensor networks (WSNs), discussed in a previous chapter, may have similar discontinuity and large delay problems caused by sensors dying due to battery limitations and a highly variant communication environment (a sensor, for example, may be installed on the tire of a moving vehicle).
- Location Services such as "OnStar" provide very limited real-time satellite connectivity between vehicles and monitoring sites. Services of these nature are also intermittent and could benefit from DTN research.

Delay Tolerant Networking tries to solve the problems posed by extreme environments by first dividing up the network into "regions" where each region could be a planet. For example, earth would be one region and Mars would be another. The communication between regions is handled by introducing the following approaches:

- Store-and-forward messaging system that can retain messages for several days
- New "Bundle" layer to handle the network differences between regions
- Custody transfers between regions
- "Network of Internets" to tie different Internets in different regions

Store-and-forward operation is a common technique that is used to deliver messages over long-haul networks (see Figure 9-14). IP networks also use store and forward but there is an assumption that the "storing" will persist for a short time to allow for queuing and transmission delay. DTN architecture stores a message, called a "bundle" as we will see, for a long time until a link does become available.

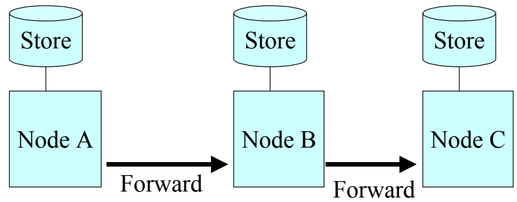

Figure 9-14: Store Forward Message Processing

The core of the DTN architecture is a new protocol layer, called the bundle layer, that resides on top of region-specific lower layers (see Figure 9-15). This layer implements long store-and-forward message switching and several other DTN-specific features. The bundle layer stores and forwards entire bundles between nodes and ties together the region-specific lower layers so that application programs can communicate across multiple regions. A single bundle-layer protocol is used across all regions of a DTN. By contrast, the layers below the bundle layer (the transport layer and below) are chosen for their appropriateness to the communication environment of each region. The DTN bundle layers communicate between themselves using simple sessions with minimal or no round trips, to take into account the long delays.

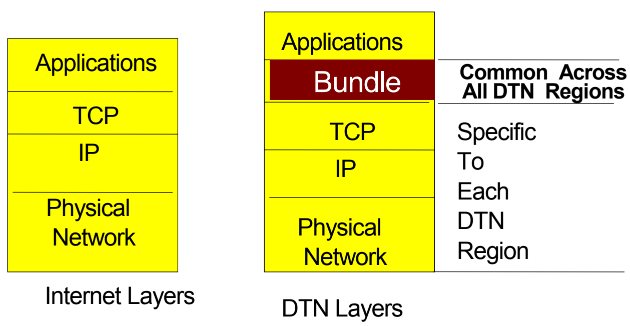

Figure 9-15: Delay Tolerant Network Architecture

Custody transfers are used by the bundle layer to support node-to-node retransmission. A bundle custodian must store a bundle until another node accepts custody. Custody transfers move points of retransmission progressively forward toward the destination. The advance of retransmission points minimizes the number of potential retransmission hops. This frees the resources of the previous node and lowers network congestion.

DTN supports a "Network of Internets" to tie different Internets in different regions. Each individual regional network has similar transport layer protocols. For example, TCP/IP may be used on earth, a protocol resembling TCP/IP may be used on Pluto, but the network between the two has a totally different lower-layer protocol stack to handle long delays and outages. Thus each of these three networks will have homogenous protocols underneath the bundle layer, but different from each other. The lower-layer protocols that support bundle-layer exchanges between regions may be like TCP or something completely different. DTN gateways may be needed to move the messages between regions.

9.5.5 Concluding Comments about Deep Space Communications

Deep space communications is an interesting area of research that may seem far removed, but could have, as discussed above, interesting terrestrial applications. Another question is: are there intelligent beings elsewhere in the universe who are trying to communicate with us (wirelessly, of course!) An institute called SETI (Search for Extraterrestrial Intelligence) was established to ponder this possibility. A major project of the institute has been to actively search for intelligent signals from deep space using the Arecibo radio observatory in Puerto Rico. To support the massive signal processing that must be done to analyze the collected data, a creative distributed computing solution known as SETI@home was developed. The idea behind the solution was that many personal computers around the world spend much of their time simply sitting idle. SETI@home provides PC users with a screen saver such that, when the computer would otherwise be idle, it is instead used to process data from Arecibo.

Sources of Information about Deep Space Communications

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- Challenges: http://tmot.jpl.nasa.gov/Program_Overview_Information/Unique_Deep_Space_Environment.pdf
- Heavy traffic: http://www.space.com/businesstechnology/technology/dsn_future_020529-1.html
- Interplanetary communuications: http://www.spacetoday.org/SolSys/DeepSpaceNetwork/DeepSpaceNetwork.htmlVoyager mission: http://voyager.jpl.nasa.gov/news/profiles_dsn.html
- New exploration goals: http://www.whitehouse.gov/space/renewed_spirit.htmlSETI: http://www.seti.org/,

Time to Take a Break
✓ • Wireless Local Loops and Free Space Optics
✓ • Satellites and Deep Space Communications
• Examples and Wrapup

9.6 Short Case Studies and Examples

9.6.1 Telkom South Africa Deploys Wireless Local Loop

Telkom South Africa (SA) was one of the first operators in the world to begin deploying large-scale WLL networks in July 1997. Telkom SA awarded contracts to Alcatel and Lucent

Technologies in April 2000 for the supply of 420,000 wireless local loop (WLL) lines to be installed over two years. Telkom SA decided to use WLL technology for several reasons: a) WLL is suitable for densely populated areas in which the operator is unsure of exactly where the customers will be located, b) WLL is preferred because Telkom need to install only the amount of equipment that will be needed, and c) WLL is preferable in high-theft areas where copper cables are stolen before Telkom has time to turn on the lines. All of the wireless local loop lines ordered by Telkom were based on the European DECT standard.

But Telkom SA was behind schedule on its WLL deployments and had only connected 75,000 subscribers – instead of 420,000 – by the end of August 1999. Many other operators like Telkom SA were also behind schedule on their WLL installations at that time, mainly because of the regulatory issues such as licensing and frequency allocation. Some of the largest potential WLL markets, including China, Russia, Mexico and South Africa, spent a great deal of time to resolve many of theses regulatory issues in the late 1990s before adopting WLL technology. Since then, more and more WLL contracts have been awarded, but still the number of lines actually installed is much less than the number of lines contracted. This discrepancy is due to the inexperience of the operators unfamiliar with WLL technology and the difficulties in network planning and in interfacing the WLL radio equipment to the installed switches. The specific obstacles Telkom SA faced were:

1. Delays in planning due to the decisions about antenna selection. Different types of antennas are available for WLLs, and the operators have to decide based on cost and performance.
2. Clearing frequency bands for WLL use because the military and electric utility was using most WLL frequency bans
3. Difficulty in obtaining towers from the limited number of manufacturers (only 3) that build the towers for antennas in South Africa
4. Delays obtaining solar panels to provide power for its WLL networks
5. Limited availability of air conditioners to keep the equipment cool
6. Insufficient outlets at customer homes to which the terminal equipment could be kept plugged in at all times
7. Upgrading the existing switch suppliers to support WLL
8. Inaccurate population statistics based on outdated methods that made network planning difficult

This case study illustrates that there are significant obstacles to the deployment of WLL technology. Although some of these issues may be unique to the South African market, most of the remaining problems are experienced by WLL operators in all emerging markets. Almost every major installation of WLL equipment has faced serious setbacks, resulting in delays to network installation. With time, as more experience is being gained, WLL installations have accelerated in South Africa and other countries.

Source: N. Baker, "Telkom South Africa: Case Study in WLL Deployment," *Pyramid Research Report*, www.itu.int/ITU-D/fg7/case_library/ documents/pyr001.doc

9.6.2 Wireless Local Loop in Angola[6]

Mercury Serviços de Telecomunicações SARL is an Angolan-based Telecommunications Company which provides voice and data services to its customers in Angola. Customers include private individuals as well as oil companies such as BP, Shell, and ExxonMobil, among others. Due to its success, the company is expanding from its primary location, the capital city, Luanda, to other regions of northern and southern Angola. Mercury operates solely with wireless equipment due to the high costs of copper and fiber in Angola. The company currently has an SDH (Synchronous Digital Hierarchical) radio link backbone in Luanda and is in the process of extending that backbone to other regions of the country. Mercury's customers connect to the backbone through MMDS technology with data rates of up to 2.5 Mbps.

As part of its expansion plans, Mercury wanted to create terrestrial radio link between Luanda and Lobito to support voice, data, and fax communications. Mercury wanted to use this interconnection to also sell telecommunications services to their customers along the busy national roads. The terrain between Luanda and Lobito is not "friendly" territory. Angola was ravaged by a 25-year civil war that seriously affected the accessibility by roads to most areas of the country. Because of cost and physical safety factors, a wireline system was not an option, thus the entire system had to be based on wireless technology. Mercury chose to create the connection between the two cities by using roughly 10 microwave radio links which were spaced about 50 km from each other. The radio links had to have a direct line of sight between the transmitters and receivers. Thus multiple links between multiple towers ("multi-hop" network) along the main road were provisioned.

Mercury is successfully using the multi-hop WLL to provide data/voice services along the main road. It has also been able to sign a contract with a local cellular phone provider to carry their traffic between the two provinces. The overall cost of the project, including equipment, construction of towers, and training, was USD 10 million. Alcatel was given the contract to actually build the entire project.

Source: Technical Renderer Form, *Luanda Lobito SDH Backbone*, Part IV, Mercury Telecommunication Services, Luanda, Angola, July 2003.

9.6.3 Satellites Help U.S. Troops in Iraq Feel Closer to Home[7]

For the American soldiers deployed in Iraq on long or indefinite tours, any opportunity to call home and speak with family and friends is greatly cherished. However, Iraq has extremely limited telecommunications infrastructure – there are fewer than two fixed telephone line connections per 100 Iraqi citizens and virtually no cellular phone infrastructure. Thus the opportunity to call home was rare – once every two or three weeks for sometimes as little as 5 minutes, and that after waiting in line for several hours.

Although satellite communication has been an important part of military operations throughout the war in Iraq, its use has been limited to important tactical and intelligence information needed for military decisions. However, Master Sgt. Kelly Grafton of the 11th Aviation Regiment, stationed in Baghdad, decided to provide his unit with satellite access for the sole purpose of keeping in touch with loved ones. To do so, he leased bandwidth from a commercial satellite operator and contacted Tachyon, Inc., a Virginia-based provider of

[6] Suggested by Moacir Araujo.

[7] Suggested by Raymond Ciarcia.

equipment that allows for Internet access via a satellite link. Tachyon supplied Grafton with a 1.2 meter dish connected to an outdoor short-range radio transceiver. An indoor radio transceiver, connected via coaxial cable to a box containing an Ethernet port, was supplied to communicate with the outdoor transceiver. The Ethernet port was then connected to a wired LAN consisting of 26 computers. As a result, these 26 computers provide over 350 soldiers high speed access via satellite to the Internet, where they can email, chat, and even video conference with family back home, and Grafton has been credited with setting up Iraq's first "Internet café."

This more frequent communication with family and friends boosted morale and provided the momentum to use satellite communication for Internet access to soldiers in Iraq. A second company, Maryland-based Hughes Network Systems Inc., has started providing U.S. military units with its Directway satellite terminals. These terminals, essentially gateway routers between Ethernet and satellite, are specifically designed to send and receive high-speed, IP-based Internet traffic via satellite links. A single terminal can provide a shared bandwidth of up to 2 Mbps for up to 20 computers. Hughes also provides the satellite link. Data traveling to and from the Hughes terminals are relayed to the Eutelsat W1 satellite, which communicates with a ground station in Griesheim, Germany. Eutelsat W1 provides coverage across Iraq and Afghanistan. Figure 9-1 provides a partial view of the satellite setup.

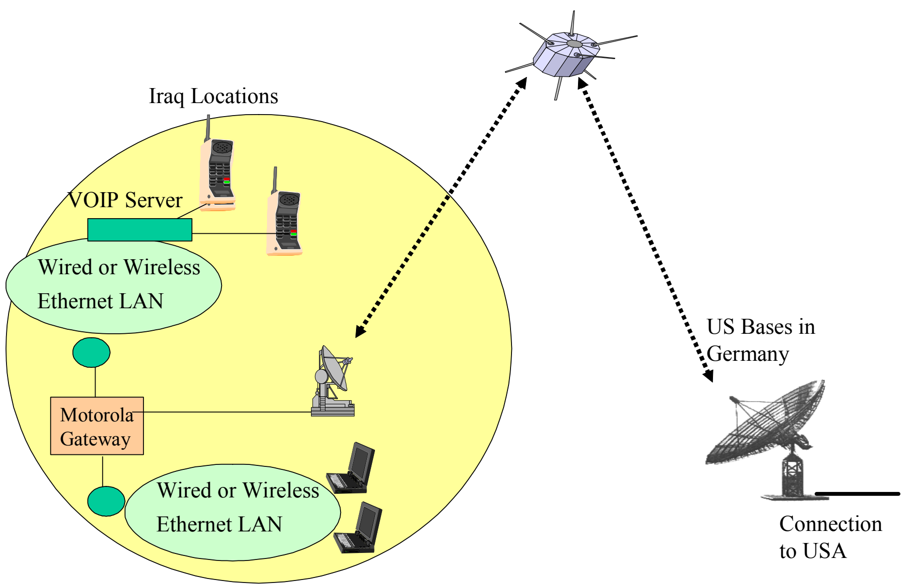

Figure 9-16: Simplified View of Internet Communications in Iraq

Mobility is naturally an important factor when setting up such a communication outpost. California-based Skyframes, another Internet-via-satellite provider, uses satellite technology that requires smaller dishes, and thus has been able to provide the military with devices that are even more portable. Furthermore, laptops with 802.11 wireless Ethernet cards have been replacing wired computers, increasing mobility by negating the need to set up wired LANs in Iraq's newest "Internet cafés." The idea has gained so much popularity among military units in Iraq that Skyframes is establishing Internet capabilities via the satellite Intelsat IS906, which communicates with a base station in Germany using TDMA at a rate of 2.5 Mbps. Skyframes will provide the military units with enough bandwidth to support 200 computers and 30 Voice Over IP connections. Voice Over IP is very popular because it allows phone-like communication over the Internet, along with video conferencing, which is much more intimate than mail, email, or text chats.

Sources:

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"GlobalNet Launches Mobile Phone Service In Iraq." *Space Daily*, 31 Jan. 2004. Available from: http://www.spacedaily.com/news/vsat-04b.html

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Wakeman, Nick. "Satellite Communications Boost Troops' Morale in Iraq." 24 Nov. 2003. *Washington Technology* 18, no. 17. Accessed 31 Jan 2004 from: http://www.washingtontechnology.com/news/18_17/online-extra/22241-1.html.

9.6.4 Satellite-based Distance Learning Systems

Satellite-based distance learning (DL) programs are prevalent throughout the world at present. Due to technological advancements, satellite systems can combine broadband data rates with small terminals, thereby providing affordable Internet access to homes and small businesses. Today's satellite-based Internet solutions permit pictures, sound, and text to be digitized, combined, and transmitted in a single stream of data for reception on a wide variety of devices.

Many universities around the globe use satellite-based DL systems (see [Collins 2000] for an analysis). In addition, commercial organizations are providing such services. An example is the Public Broadcasting Service (PBS). PBS offers courses for college credit through its Adult Learning Service (ALS), established in 1981. ALS became a national broker for the distribution of telecourses, which typically include textbooks, study guides, faculty manuals, test banks, and video lessons. More than 5 million students have enrolled in courses offered by local colleges and universities using telecourse packages distributed by PBS (http://www.pbs.org/als/about_als/index.html).

A satellite-based DL system relies on one-way audio and video and may use terrestrial-based technologies, such as the telephone, fax, and Internet applications, to allow remote students to communicate with the instructor during class broadcasts. A satellite-based implementation also may provide an interactive audio and video classroom, the most technically advanced form of DL. Many courses broadcast via satellite are commonly complemented and enriched by a Web-based component. However, DL satellite implementations may be used strictly for accessing online courses and resources, especially in remote areas lacking broadband access. Many DL satellite providers also are delivering video courses to desktop computers over terrestrial-based networks. However, this requires high-bandwidth connectivity, and appropriate computer equipment is necessary to take courses via video streaming. DL implementations also require educational institutions to adapt programs and course offerings for online learning environments.

Northern Arizona University (NAU) developed a program for delivering training and continuing education programs to students at homes and hospitality establishments using a combination of satellite and Internet technologies. This project involved the delivery of three different hospitality courses to four different Arizona sites using the Web and Internet for course materials, learning exercises, and asynchronous communications through e-mail and bulletin boards. A satellite dish and receiver were located at the student sites (business establishment and at each home) for receiving delayed broadcasts of live class sessions. The main goal of this project was to evaluate the technical, financial, and administrative aspects of satellite-based DL systems.

The satellite solution implemented in this investigation did not have Internet access capability – the students used a terrestrial ISP for Internet access. The only aspect of the satellite solution that was directly evaluated involved the delivery of video over the UniversityHouse channel – a nationwide satellite delivery channel launched by NAU for coursework and training classes. The satellite channel was leased from EchoStar Communications, Inc., a provider of Direct Broadcast Satellite (DBS) services. Although satellite-based Internet access was not used in this project, developments in satellite-based Internet technologies and services were also evaluated.

Network is the basic technology that unites the DL instructor with the DL students. Network technologies suitable for DL implementations include satellite, cable modem, digital subscriber lines (DSL), and wireless cable. Although DSL and cable modem solutions are becoming increasingly available in metropolitan areas, many areas around the globe do not have such access. A satellite-based solution is a possible alternative that can address residential and business customers equally well in far-flung places. This was the main reason for choosing satellite-based instructions for the NAU project.

Through satellites, video is delivered directly to a student at the scheduled broadcast time, or tape-recorded for viewing at a later time. However, success of such delivery depends on whether a user can afford the monthly fees and installation and equipment costs, on the strength of the signal at the receiving site, and on the ease of installing and operating the equipment. In case of NAU, a separate ISP was needed for Internet access. For Internet access through the DBS platform, data requests were uploaded via the terrestrial link, then downloaded from the Internet to a receive-only dish over a high-speed DBS link. Such a hybrid satellite-based Internet system is an interim solution until the more reliable and convenient two-way satellite-based Internet systems are widely implemented. Two-way satellite-based Internet systems are based on Very Small Aperture Terminal (VSAT) technology and provide both data transmission and reception without depending on a terrestrial network. For a seamless interoperability between satellite and terrestrial networks, the long-latency and error-prone characteristics of satellite links need to be taken into account.

Based on the results of the investigation, the NAU project successfully provided remote hospitality employees with accessible, flexible, affordable, and appropriate educational opportunities. In general, the students, whether at home or work, were satisfied with both the technology and the quality of the learning.

A personal note may be appropriate here. I taught a DL program through a large university in the winter of 2001. The university had 5 centers in different parts of New Jersey and the New York area. Instead of delivering the content directly to home, the content was delivered to these centers. I was in one center, the other four were getting satellite feeds. Overall, the offering was a success. The students liked the idea of going to a close-by center instead of driving long distances in the winter weather. However, there were several technical glitches (the satellite links disappeared in the middle of the lecture; I could hear the students but they couldn't hear me, and vice versa). Basically, technicians had to be standing by – a difficult thing to do for evening courses.

Main Source: G. Collins, "Case-study: A Satellite-based Internet Learning System for the Hospitality Industry," *Online Journal of Distance Learning Administration*, Volume V, Number IV, Winter 2002. Web link: www.westga.edu/~distance/ojdla/winter54/collins54.htm

This paper provides a comprehensive analysis of satellite-based distance learning (DL) systems, examines various DL systems, and points to many sources of additional information on this topic.

Additional Sources:

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9.6.5 Communication Capabilities on Mission for Mars[8]

In January 2004, two rovers landed on Mars to explore the planet's surface. A critical part of this system is the communication system that allows the rovers to receive commands from ground-based operators and to send their images and scientific data home.

Each Mars rover is equipped with two modes of communication. The first is a UHF transmitter which is used to send data to one of two satellites orbiting Mars – Odyssey and Surveyor. Before the spacecraft carrying the rovers reached the Martian surface, the Mars satellite (Surveyor) emitted a radio beacon for which the landing craft was tuned to listen. When the beacon was heard by the lander, it responded with telemetry information regarding its status. This communication was sufficient to inform mission commanders on earth that the rovers were approaching a landing according to plan. Once on the surface, the lander transmitted its success to Survey before it lost line of sight with Surveyor (Surveyor is orbiting around Mars and is visible to the landing site for a limited time).

Once on Mars, the rovers started using a standard X-band transceiver through which direct communication with earth is possible. The rovers use two means of communications. The X band is used for data, particularly equipment status and operator commands, that is time-critical. Other data, such as the stunning images of the Martian surfaces, are first sent to Odyssey or Surveyor by the rovers. They are then transmitted to earth by these satellites (see Figure 9-17). This is how it works. The orbiting satellites store the information in their 2-megabit memories and later forward the information to earth via X band when line of sight with earth has been established. Data is usually stored on Odyssey for an hour or two or on Surveyor for 24 to 38 hours before being transmitted to earth. The difference in holding time is due to differences in orbits and the fact that, unlike Odyssey, Surveyor also has its own data to transmit as it continues to photograph the surface of Mars. Once the information reaches

[8] Suggested by Raymond Ciarcia and Greg Kuperman.

the earth, it is captured in the master servers that store all DSN (Deep Space Network) traffic. The software running on DSN servers extracts the rover data and then transfers it to the local servers at the Jet Propulsion Laboratory Mission Control Center.

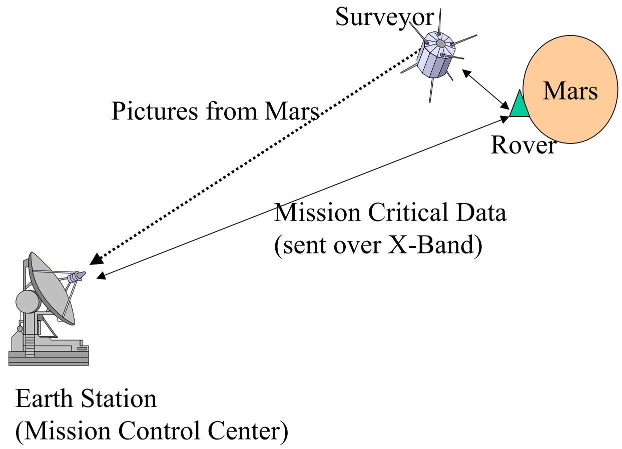

Figure 9-17: Conceptual View of Mars Communications

A few words about the Mars Global Surveyor – it was launched in November 1996 and reached Mars orbit in September of the following year. It was intended to photograph the surface of Mars as it orbited the planet, and to later serve as a relay station for future Russian and French missions. The communication systems aboard Surveyor were designed specifically for the needs of the Russian and French missions, none of which were ultimately successful. However, the US rovers on Mars gave the Surveyor a new life as a communication hub. The Mars Global Surveyor has 16 possible modes by which it can receive data from vehicles on Mars via its UHF receiver. At frequency of 401 MHz, for example, data can be transmitted at 8 Kbps or 128 Kbps. Surveyor's beacon, operating at a frequency of 437 MHz, is the only means by which the orbiter can send a message to devices on Mars. The beacon simply indicates the orbiter's presence to the rovers, and can be modified to indicate that the orbiter is ready to receive data or telemetry information uploads.

Sources:

- Voyager mission: http://voyager.jpl.nasa.gov/news/profiles_dsn.html
- New exploration goals: http://www.whitehouse.gov/space/renewed_spirit.html

9.7 Concluding Commnents

Fiber-optic networks exist worldwide, and are proliferating at a phenomenal rate. The problem is, however, to provide these capacities to actual subscribers, who in general do not have direct fiber access to the network. Currently, the most that is available to most consumers is wire access to the network, since fiber comes to the telephone companies' switching stations in urban or suburban areas, but the consumer has to make the connection to this station. DSL and cable modems can provide access to the fiber backbone but themselves cannot go beyond 1 Mbps.

Wireless services such as Wireless Local Loops, Free Space Optics (FSS) and satellite communications provide an attractive solution to the last-mile problem, especially in densely populated urban areas. It is even more interesting as a means of bringing high-speed digital access to information networks to the third world, and in this sense bridges the so-called "digital divide." These wireless services can be provided on a demand basis without the extensive prior construction of an expensive infrastructure, and can reach remote areas. Transceivers costing at most a few hundred dollars can be installed in the windows or on the rooftops of buildings, and communicate with a local communication node, which provides independent feeds to each subscriber. In this way only paying subscribers receive the service.

9.8 Review Questions and Exercises

1) What are the main strengths and weaknesses of the wireless local loops?

2) What are tradeoffs between MMDS and LMDS?

3) Compare and contrast 802.16 with 802.11.

4) Free Space Optics (FSO) is a competitor to WLL because it can provide high data rates over a few kilometers.

5) FSO systems can support data rates between 1.25 and 150 Gbps (theoretically) with link lengths that can vary from more than 600 feet up to about a mile.

6) In practice, FSO networks support around 2.5 Gbps of data, voice and video communications between 1000 to 2000 feet.

7) Suppose you have moved into a new office and need to decide between MMDS, LMDS, and FSO. Develop a decision table that will help you to make a good decision.

8) What are the key strengths and weaknesses of satellites?

9) What are the limitations of GEOs and how do GEOs compare and contrast with LEOs and MEOs?

10) What is deep space communications and why should anyone care? Are there some possible applications of this for communications on the earth?

11) What is the Interplanetary Internet and how do the Delay Tolerant Newtorks fit into this picture?

12) How are wireless local loops, FSO and satellites competing with fiber in the last mile? Under what conditions is fiber a good choice and under what conditions it is not?

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