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THESIS

WIRELESS TECHNOLOGY VIA SATELLITE COMMUNICATIONS FOR PEACEKEEPING OPERATIONS

by

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September 2001

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How can reliable information be shared amongst international, military, and non governmental organizations in support of peacekeeping operations? This thesis examines a wireless alternative to enhance existing communication infrastructures as a primary means of information exchange. When assessing the need for wireless and making a determination of its use, a study of its markets, trends, future growth, policies, and regulations must be taken into consideration. Wireless technology via satellite communications can offer a great advantage of information exchange for mobility-deployed organizations requiring extensive geographical coverage such as peacekeeping operations. With the emergence of higher transmission rates and technological options (i.e. video conferencing, Wide Area Networking, internet accessibility, voice/fax/data transfer, etc.) for satellite communication, the examination of wireless technology and the options it presents becomes paramount. Peacekeeping efforts involve the coordination and collaboration of civilian/military organizations that depend exclusively on information exchange for rapid response and operational readiness. The use for wireless as a necessary communication requirement will aid in the achievement of these objectives.

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WIRELESS TECHNOLOGY VIA SATELLITE COMMUNICATION FOR PEACE KEEPING OPERATIONS

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Submitted in partial fulfillment of the
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ABSTRACT

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EXECUTIVE SUMMARY

The purpose of this research is to demonstrate the extent to which wireless technology via satellite communication can be utilized for peacekeeping operations in remote regions. The author addresses the issue by providing an overview of peacekeeping operations and discussing the need for reliable and timely communication between civilian and military organizations. This thesis offers and overview of wireless and satellite technology and reviews important concepts, basic structures, components, and systems architecture for a wireless system:

- The need for and limitations of wireless technology
- An examination of markets, trends, policies, regulations, and potential for wireless within the next decade
- A detailed view of several existing satellites and the segments (space, ground, control) associated with their operation
- A discussion of broadband satellites (GEO) and how they can support the communications requirement of peacekeeping efforts in remote regions
- A description of developing satellites and their possible use with peace operations
- Fundamental requirements of wireless for a ground operation and the benefits and concerns associated with each
- An evaluation of the technology in terms of capabilities for peacekeeping operations

The recommendation for a wireless system for peace operations include the use of broadband satellites located in geostationary orbits, their high transfer rate, global coverage area, and reliable system architecture support for newly developed applications and technologies. Although limitations do exist with regards to security, vulnerabilities, latency, and space congestion, the benefits outweigh the disadvantages and demanding conditions for peacekeeping operations.

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I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to provide the reader with an overview of wireless technology and an assessment of how that technology can be utilized for peacekeeping operations. The thesis introduces key aspects of wireless communications such as, market trends, future growth of technologies and markets, and descriptions of various satellite platforms. Secondly, the thesis will provide some recommendations for a wireless system for the unique requirements of peace operations, especially those in remote regions.

B. BACKGROUND

Peace Operations is a new and comprehensive term that comprises three types of activities: support to diplomacy (peacemaking, peace building, and preventative diplomacy), peacekeeping, and peace enforcement. The related activities include traditional peacekeeping as well as peace enforcement, i.e., humanitarian assistance, establishment of order and stability, enforcement of sanctions, guarantee and denial of movement, establishment of protection zones, and forcible separation of belligerents.

Peace operations and peacekeeping operations, in particular, are not new to the U.S. military; what is new about them is the number, pace, scope, and complexity of recent operations. Although the primary mission of the armed forces of the United States is to fight and win the nation's wars, any daily newspaper or evening news program shows that U.S. forces are often called upon to support a variety of operations spanning the conflict spectrum. Examples may include peacekeeping operations in Bosnia, Haiti, and Kosovo (Post bombing campaign) or counter-drug operations in the Caribbean and Latin America. Although there may be tactical similarities, many of these operations include tasks that apparently have little or nothing to do with warfighting. This is the environment that is called Operations Other Than War (OOTW) and one the military is likely to face for some time to come. Over the past few years, OOTW's represent about 90% of the types of operations the military are employed to support. [Ref. 39]

Peacekeeping operations often take place in environments less well defined than in war. The identity of belligerents may be uncertain and the relationship between a specific operation and the campaign plan may be more difficult to define. Forces may not encounter large, professional armies or even organized groups responding to a chain of command. Instead, they may have to deal with loosely organized groups of irregulars, terrorists, or other conflicting segments of a population as predominant forces. These elements will attempt to capitalize on perceptions of disenfranchisement or disaffection within the population. Criminal syndicates may also be involved. The close link desired by such elements and the civilian population at large means that traditional elements of combat power, such as massive firepower, may not apply to peace operations. The nonviolent application of military capabilities such as public affairs, civil affairs, and Psychological Operations (PSYOP) may be more important. [Ref. 39] Hence, the political and cultural dimensions of the battlefield become more critical to the conflict. Settlement, not victory, is the ultimate measure of success, though settlement is rarely achievable through military efforts alone. The military actions must complement diplomatic, economic, civil, informational, and humanitarian efforts in pursuing the overarching political objectives.

Peacekeeping operations are usually conducted in the full glare of worldwide media attention, and therefore the strategic context of a peacekeeping operation must be communicated and understood by all involved in the operation. Soldiers must understand that they can encounter situations where the decisions they make at the tactical level have immediate strategic and political implications. [Ref. 40] In addition to the overall strategic and political context of the operation, soldiers should also be aware of the area's history, economy, culture, and any other significant factors. Failure to fully understand the mission and operational environment can quickly lead to incidents and misunderstandings that will reduce legitimacy and consent and result in actions that are inconsistent with the overall political objective.

This consideration leads directly into the ability to provide timely and accurate information to all units and forces aimed at providing the necessary support to assist in peace operations.

Taking advantage of the power of information and information technology and integrating all aspects of information to achieve the full potential for enhancing military operations is essential. The employment of information technology in peace operations is different than in war. Peace operations need to accommodate a different (and more restrictive) set of constrains than those that apply to wartime operations. There are operational, legal, and political constrains that control, shape, and influence how the military, civil, and political actors behave and employ the tools of information assessment to achieve their (often competing) objectives. The political will of the UN, NATO, the United States, and other nations to win the hearts and minds of potential adversaries is also a critical factor. For example, the will of NATO and the nations it comprises was challenged by the Bosnia crisis. Adapting the go-to-war capabilities of the military to accommodate the needs of a coalition peacekeeping information operation is a challenge as well. These were significant challenges for NATO and the nations that participated in *Operation Joint Endeavor* in the former Yugoslavia (Bosnia-Herzegovina). [Ref. 38]

The Internet became a major player in the Bosnia operation. Internet home pages (e.g., DoD's BOSNIALINK and NATO, SHAPE, AFSOUTH, IFOR, and Task Force Eagle home pages) were used by the Public Affairs organizations to inform and update the general public. The Public Information offices used the Internet for media interactions and translations of foreign news articles. The Information Campaign staff "surfed" the Internet for information on the situation in Bosnia (e.g., news reports, adversary propaganda and disinformation, biographic data on key leaders, maps, historical reports, and cultural and demographic information). The intelligence community used it for open-source assessments; legal and medical personnel used it as a reference tool, and the engineers used it for technical reference activities such as predictions for the height of the Sava River to adjust the pontoon bridges. [Ref. 40]

International and humanitarian organizations had home pages on the Internet (e.g., the UN and RELIEFWEB, respectively) that provided information related to their activities in Bosnia. Deployed U.S. military personnel used it to maintain contact with their home organizations, be they located in Europe, CONUS, or elsewhere. The Internet also had value as part of the MWR support, e.g., educational material, travel information, and e-mails to home from the troops in the field.

The information environment of today is becoming increasingly complex and developments in information technology are revolutionizing how nations and their militaries, organizations, and people interact. The merging of civilian and military information networks, databases, and technologies put vast amounts of information at the user's fingertips. The advanced information systems and capabilities may enable the military to achieve an operational advantage while denying those capabilities to the adversary—referred to by the military as information dominance. Achieving a knowledge advantage requires a highly developed sense of information requirements and an ability to manage the collection, processing, use, and dissemination of that information to the right place, at the right time, for the right purpose. The military information environment consists of both friendly and adversarial military and non-military elements. It also includes organizations that support, enable, or significantly influence a military operation for peacekeeping missions such as Non Governmental Organizations (NGO's), North Atlantic Treaty Organizations, the United Nations, and any other disastrous relief organization designed to provide timely relief and aid to countries in need.

Technology can help to capture as well as disseminate information and experience. It could be utilized to help a wide variety of actors working in a United Nations mission's area of operation to acquire and share data in a systematic and mutually supportive manner. United Nations development and humanitarian relief communities, for example, work in most of the places where the United Nations has deployed peace operations. These United Nations country teams, plus the NGOs that do complementary work at the grass-roots level, will have been in the region long before a complex peace operation arrives and will remain after it has left. Together, they hold a wealth of local knowledge and experience that could be helpful to peace operations planning and implementation. An electronic data warehouse, capable of sharing this data through a three tier website, could assist mission planning and execution and also aid conflict prevention and assessment. Proper melding of this data and data gathered subsequent to deployment by the various components of a peace operation and their use with geographic information systems (GIS) could create powerful tools for tracking needs and problems in the mission area and for tracking the impact of action plans.

International Peace-Keeping operations most often take place in areas where existing communications are inadequate or non-existent. Independent, inter-operable and reliable, satellite communication solutions not only support the huge logistical demands of such operations, ensuring that lines of command are always available, but also contribute to the welfare and morale of personnel. Typical usage scenarios include:

- Support of gatekeeper roles through rapid transmission of still and live video reconnaissance information
- Provision of self-contained, highly mobile and simple to operate communications in the support of disaster relief operations where existing networks have been destroyed or have become overloaded
- Delivery of a rapid deployment video-conferencing capability to any location, maintaining high level contact between headquarter and field staff and nongovernmental organizations.
- Access to hybrid LANs (if applicable) and WAN's to review critical logistics management information
- Availability for welfare purposes of telephone and recreational email services to personnel located far from home

Existing infrastructures may not be able to support any hardwired network configuration that will optimize standard usage of a Local Area Network, Wide Area Network, or server driven platforms for an operation requiring critical information exchange and data transfer. The need for a wireless network that will allow for communication for specified users to access critical information concerning peace keeping operation is paramount when considering a warranted alternative.

C. RESEARCH OBJECTIVE

This research examines an alternative method of information exchange for peacekeeping operations when existing infrastructures cannot support the necessary requirements for timely and reliable communication. Wireless telecommunication is clearly diverse, with dozens of types of operational services being offered and the potential for many more to be introduced and implemented at rapid rate of development. The use of satellites to provide ease of operation and installation is essential for regions that require greater fields of view for line of sight communication. Satellite

communication will be seen as a necessary alternative or augment to hard wired infrastructures in place.

D. THESIS ORGANIZATION

The fundamental concepts of wireless technology and its connection to satellite communication is provided for this thesis. Chapter II serves as a background and overview of wireless technology that includes future growth, trends, policies, and regulation of the technology. This is not a detailed account of the specific aspects of wireless but an overall summary of its basic components. Chapter III focuses on commercial satellite technologies (mainly broadcast), its segments (space, ground, control), projected systems, and the limitations and concerns of its use (vulnerabilities, security, interoperability, latency and quality of service). Chapter IV provides a general recommendation for satellite communication during peace operations and discusses the relevancy and necessity of such a system. Chapter V is a brief conclusion that summarizes the need for wireless technology for peace operations.

E. METHODOLOGY

The information for this thesis came from the general literature on wireless technology, satellite communication, and their markets and trends. Textbooks were a primary source, supported by various articles and technological studies found on the internet. In addition, Major Darius White served as a major source for information on satellite communication due to his experience and expertise as a signal officer for the United States Army.

F. EXPECTED BENEFITS OF THIS THESIS

Satellite communication is seen as a critical vehicle for communication during peacekeeping operations. This study makes a recommendation on the necessary satellite system (s) needed to support wireless network requirements for regional information exchange in remote areas. This information will aid readers evaluating present and future technologies for advanced planning efforts that involve geographical and economic

assessments of a country's communication infrastructure. Ultimately, it demonstrates the technological capability that will enable military and civilian organizations to exchange information from a stationary or mobile platform. Peacekeeping efforts require the coordination and collaboration of civilian/military organizations that depend exclusively on information exchange for rapid response and operational readiness. The use of a wireless system will support that effort.

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II. FUNDAMENTALS OF WIRELESS TECHNOLOGY

A. OVERVIEW

This chapter will further discuss four basic ideas (transmitter, frequency, modulation, and receiver) concerning the basics of a wireless system and then provide information concerning trends, policies and regulations, and the future growth of wireless systems. In addition, a detailed examination of past, present, and future markets are covered in Appendix A and should be reviewed carefully as a significant evaluation for implementing any wireless system.

B. BACKGROUND

The basic concept of a wireless communication system is almost deceptively easy to understand. An electromagnetic signal is created, modulated, amplified, and broadcast to one or more receivers that can be fixed or mobile. The data in that signal is received and demodulated in order to recover the original information that was sent (Figure 1.1). A basic system will normally consist of a transmitter, receiver, and a channel (i.e. radio frequency) that utilizes different carrier frequencies for each baseband (information signal) that is transmitted. The basic issues that one must address in the design of wireless systems is common to all of telecommunications, namely the effective use of the available frequency spectrum and power to provide high-quality communications. Some wireless systems often involve mobile services; this implies a constantly changing environment with rapidly changing interference conditions and dynamically variable multi-path reflections. This condition, plus the potential of conflicting demands for the use of radio frequencies in a free-space medium, means difficult challenges for creating high-quality signals.

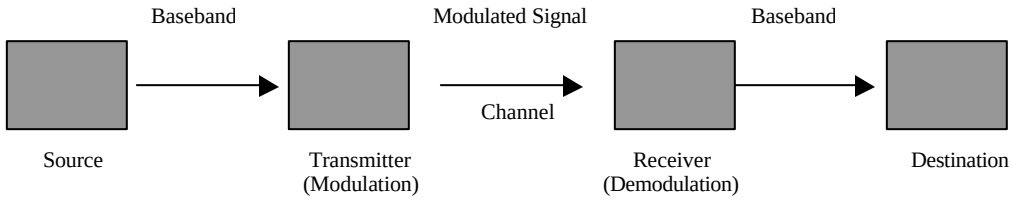

Figure 1.1. Basics of a Wireless System.

C. BASICS OF WIRELESS

Every wireless system must have the basics of a transmitter (modulation), receiver (demodulation) and a channel (frequency) to transmit the signal from a stationary or mobile reference. Modulation is the process of using an information signal (baseband) to vary some aspect of a higher frequency signal for transmission. Demodulation (also called detection) is the inverse of modulation. Its purpose is to restore the original baseband signal. The transmitter and receiver are very important parts of any radio communication link and at most base stations they are separate components or they can be combined into a transceiver which transmits and receives signals simultaneously (i.e. cellular phone). The use and concerns of radio-frequency shall be addressed in this section An overview of these basics are provided in this section.

1. Transmitter

The function of a transmitter is to generate a modulated signal with sufficient power, at the right frequency, and to couple that signal into an antenna feedline. The modulation must be done in such a way that the demodulation process at the receiver can yield a faithful, uncorrupted copy of the original signal. Differences among transmitters result from variations in the required power level, carrier frequency, and modulation type, as well as special requirements such as portability and the ability to be controlled remotely.

2. Receiver

The receiver performs an inverse function of the transmitter. It must separate the desired signal from others present at the antenna, amplify it greatly (often 100 decibels or more) and demodulate it to recover the original baseband signal.

3. Radio-Frequency Spectrum

Radio waves are a form of electromagnetic radiation, as are infrared, visible light, ultraviolet light, and gamma rays. The major difference is in the frequency of the waves. The portion of the frequency spectrum that is useful for radio communication at present extends form roughly 100 kHz to about 50 GHz. Wireless communication mainly occupies the very high frequencies, ultra high frequencies, and super high frequencies portions of the spectrum (Table 1.1). Lower-frequency systems need inconveniently large antennas and involve methods of signal propagation that are undesirable for wireless systems. Extremely high frequencies are still difficult to generate and amplify at reasonable cost though that will change in the future.

a. Concerns for Radio Frequencies

The current uses of radio frequencies for wireless telecommunications include conventional fixed and mobile satellite communications, direct broadcast satellite services, scientific data relay from spacecraft, high frequency to millimeter wave-guide terrestrial radio relay, conventional radio and television broadcasting services, wireless cable television entertainment systems, instructional fixed television services, amateur radio services, specialized mobile radio services, analog and digital cellular radio telecommunications services, paging services, wireless Private Automated Brand Exchange and Local Area Network services, emergency vertical communications, disaster warning and relief systems, and military communications (terrestrial and space communications). Sometimes these services have separate frequency allocations from each other and sometimes they compete with each other or with other public telecommunications, industrial or scientific applications.

The rapid growth of wireless services has thus had the affect of creating rapidly growing demands on a limited resource (frequency allocation). Furthermore, the desire to use frequencies in the Ultra High Frequency Band (UHF) (i.e., below 3 GHz) has served to compound this problem. The physical characteristics of the radio spectra in terms of "effective" wavelengths have concentrated demand for most wireless services between the High Frequency (HF) bands and the Ultra High Frequency (UHF) band. The next two bands in the Super High Frequency (SHF) and Extremely High Frequency bands are presently being used for wireless services. Those radio frequency bands that are most commonly used for wireless communications today are as follows:

• High Frequency (HF)—3-30 MHz	(PRIME BAND)
• Very High Frequency (VHF) 30-300 MHz	(PRIME BAND)
• Ultra High Frequency (UHF) 300-3000 MHz	(PRIME BAND)
• Super High Frequency (SHF) 3-30 GHz (also known as microwave)	(INCREASING USE)
• Extremely High Frequency (EHF) 30-300 GHz (also known as millimeter wave)	(PROSPECTIVE USE)

Table 1.1. Key Frequency Bands for Wireless Communication.

Those frequencies above 3000 MHz are most typically used for satellite communications and terrestrial microwave even though so-called cellular television or Local Multipoint Distribution System (LMDS) in the millimeter wave are now planned for commercial services. Research and development for the utilization of millimeter frequencies for advanced satellite communications and digital cellular broadcasting are actively in place. These higher frequencies are subject to precipitation attenuation effects, atmospheric heat scintillations, and propagation distortions of other types. They are also unforgiving of any interruptions in direct line-of-sight connections in the transmission path. Frequencies below the high frequency (HF) range are, on the other hand, very limited in bandwidth. They thus offer limited utility for many future services, especially broadband services like television or high definition television. Even with highly

innovative frequency reuse concepts and digital compression, it seems unlikely that broad band applications for the VHF band or below would develop in the future simply because of the very limited spectra available. These conditions have combined to create a major problem in obtaining sufficient frequency allocations that are interference free or at acceptable interference levels.

b. Frequency Reuse

The answer to the limited availability of frequency bands has been several fold. Most significantly, methods have been developed to allow intensive reuse of available frequency bands. The most common ways have been creation of geographically defined beams that are isolated from other beams. In satellite communications there are larger regional beams, zonal and very narrow, and very powerful spot beam antennas that allow for increasing degrees of frequency reuse. In terrestrial cellular radio telecommunications each "cell" has a geographically restricted coverage area. In the future with personal communications services there will be micro-cells or possibly even "pico-cells" that create very small coverage areas for extremely high levels of frequency reuse. The patterns of cell coverage for three types of cells are shown in the diagram that follows. The first is that of conventional cellular radio systems. The second is that for relatively low-powered micro-cellular systems. The third is for cellular satellite coverage from a low earth orbiting system demonstrating negative Signal to Noise ratio for a given transmission. These are shown in Figures 1.2, 1.3, and 1.4, [Ref. 1] respectively. In each case it should be noted that these are idealized or theoretical diagrams rather than actually measured system performance.

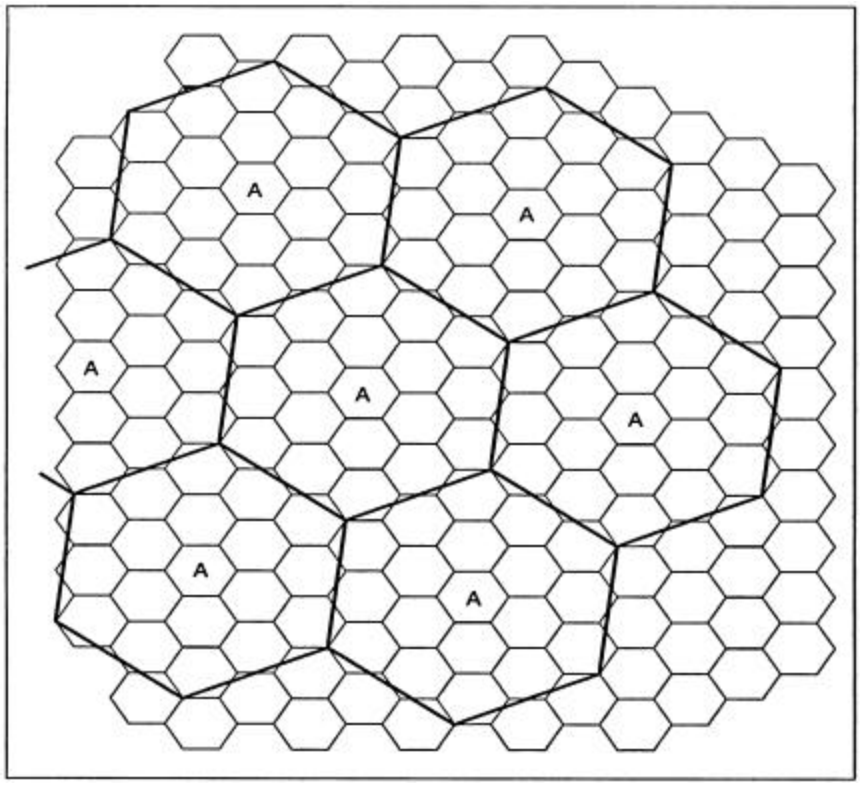

Figure 1.2. Cellular Coverage for Conventional Mobile Radio Service [From Ref. 1].

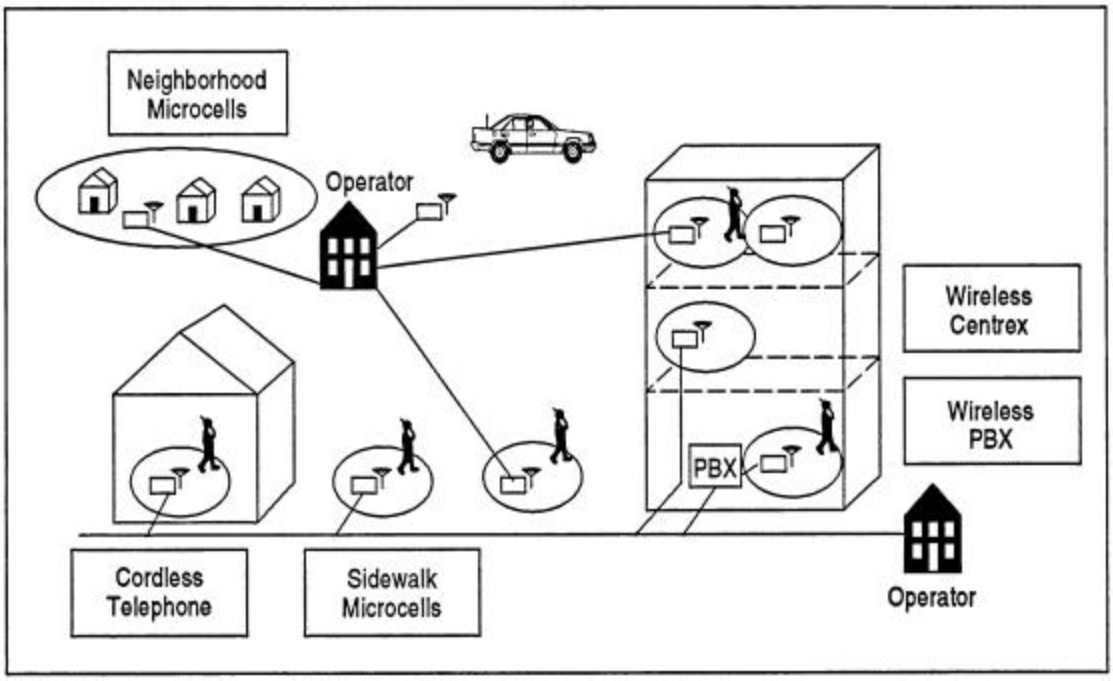

Figure 1.3. PCS Microcells [From Ref. 1].

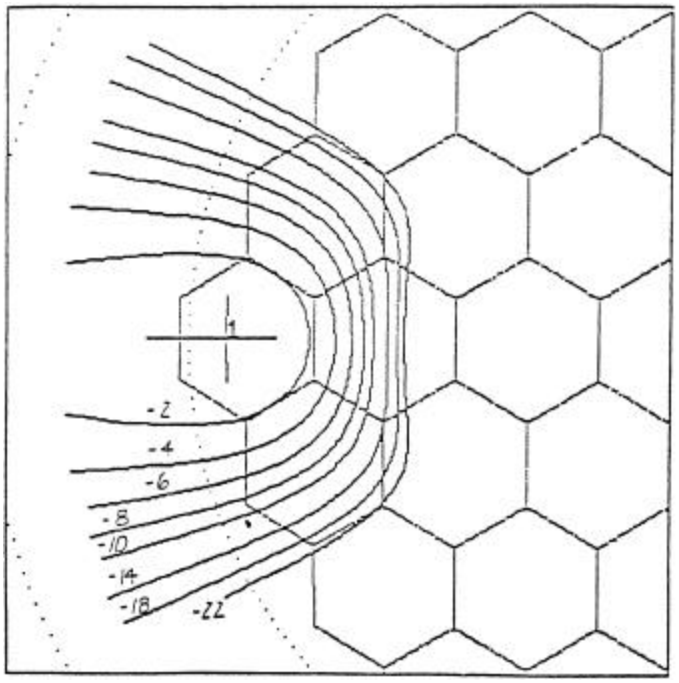

Figure 1.4. Cellular Coverage for LEO Mobile Satellite System [From Ref. 1].

Another important technique used to achieve frequency reuse is that of polarization discrimination. In this case, the wanted frequency transmission is separated from the unwanted transmission by "polarizing" the signal. This concept is essentially the same as that used in polarized sunglasses. The polarization technique most often used is that of linear or orthogonal separation. That is to say the "wanted" and the "unwanted" transmission patterns are sent exactly at right angles to one another. Alternatively, there is circular polarization with one signal being sent with left-hand circularization and the other being sent with right-hand polarization. It is possible with these combined techniques (i.e., spatial or cellular beam separation and polarization discrimination) to achieve dramatically increased reuse and thereby much greater capacities. Today there are plans for tenfold to even forty-fold reuse in some of the low earth orbit satellite systems. With advanced Personal Communication Services (PCS) systems, frequency reuse techniques that achieve one hundredfold/ and ultimately even thousand-fold reuse levels are achievable. This can allow much more extensive, versatile, and broader band wireless applications including all forms of video and imaging services.

c. Technological Interest

There are other technologies that are also important to making more effective use of the limited frequency spectra that can be practically used in a free-space wireless environment. These involve the modulation, encoding, and multiplexing of signals.

At this stage it is important only to note that new modulation, coding, and multiplexing techniques can produce dramatically more reliable and higher-quality wireless transmission systems. The use of digital techniques, in particular, can especially help to create higher capacity systems. First, this is because digital systems such as Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) are more resilient against interference and noise. Second, digital compression techniques also allow more effective use of the available channels or frequency bands. In the area of voice services, digital compression techniques can be utilized to achieve acceptable service at bit rates as low as 4.8 kilobits per second. This is an improvement in efficiency of some ten times over conventional voice services. [Ref. 2]

High-efficiency analog systems will, however, continue to be used during this decade, more particular, Single Side Band (SSB) techniques can yield results that are more efficient than conventional Frequency Division Multiple Access (FDMA) systems. In general, however, digital techniques and especially CDMA or spread spectrum systems will expand as this modulation matures and catches up to the technologically and more mature TDMA systems. In short, both TDMA and CDMA are expanding in general use and broad customer acceptance for terrestrial mobile services are overwhelming in demand. TDMA will continue to be used in satellite systems, although CDMA systems will also be increasingly used here too. This may, however, tend to create problems with regard to interfacing with terrestrial fiber optic systems. This is because optical systems are tending toward Dense Wave Division Multiplexing (WDM) schemes or so-called "color multiplexing" techniques. These two multiplexing concepts are basically not very compatible with one another. [Ref. 2.]

D. TRENDS OF TELECOMMUNICATION

When broadcasting information from a single point of origin to all receivers such as in the case of conventional radio and television stations or a traditional cable television system, the requirement is essentially only for transmission. The functions of signaling and switching are not particularly required. Today, however, almost all telecommunications systems are becoming more interactive. Integrated service networks that combine voice, data, e-mail, fax, radio, video, and imaging are becoming more prevalent. It is possible that in time conventional one-way broadcasting systems with no interactive capability will slowly become obsolete.

In this process of moving toward integrated and interactive systems, there are two extremely important trends. One trend is the movement to create hybrid telecommunications networks that combine fiber optic cable systems with wireless systems. There are at least three major examples of this hybridization. One is the combination of wireless mobile PCS systems with cable television systems or the largely wire-based Public Switched Telecommunications Network (PSTN). Here the wire, cable, or fiber systems act as node connectors. The second key hybrid system would be in combining or interconnecting wireless Private Automated Branch Exchange (PABX) or Local Area Network (LAN) systems in buildings with the traditional wired telephone network. This would typically involve using fiber optic cables as the vertical risers within the building structure but using wireless within the offices. The third case would be the use of wireless LANs to connect to large and geographically extensive enterprise networks, or WANs, which are often "wired", or fiber networks. There will be more examples in the future as new technical developments such as even more advanced low earth orbit satellites and infrared bus systems become available and offer new service capabilities in terms of hybrid interconnections.

The second trend, as noted above, is the move toward interactivity. This is abroad-based trend for all types of telecommunications systems, regardless of their purpose (i.e., data communications, voice, entertainment, imaging, etc.). The objective is to make telecommunications systems more versatile. This means enabling telecommunications systems to be more mobile, more quickly restorable, more flexibly

controlled and utilized, as well as more intelligently managed. This has already proven effective in dealing more efficiently and urgently with short-term or crisis problems. These type of flexible and mobile response systems are indicative of present and future trends with wireless networks. [Ref. 2]

A third and final key trend is in the move to create some form of universal protocol and transmission scheme that is truly open to all forms of telecommunications regardless of the application. This trend being driven by digital transmission systems but without any clear winners. However, there have been progressive moves upward to Transmission Control Protocol/INTERNET Protocol (TCP/IP), frame relay, Switched Multi-Mega-bit Digital Service (SMDS/DQDB), and to cell relay. Cell relay is operationally expressed in the format of Asynchronous Transfer Mode (ATM) networks both on private and public systems. This new high throughput, flexibly routed ATM system can be utilized to provide all forms of data, voice, and video services in terms of broad band ISBN networks.

Only broadband satellites operating in the SHF band can handle gigabit per second traffic. The simpler and lower-speed protocols can and do work on wireless systems, but they are being phased out in favor of the higher-efficiency and higher-speed protocols that have often been optimized for fiber-based systems. The use of millimeter wave-based LMDS wireless services that are being carried out in the United States as well as office-based infrared LANs, PABXs, and multipurpose "buses" are the forerunners of new wireless systems that arc broad band enough to be compatible with ATM systems. In fact, for intra-office and short-range applications, there are already operational, off-the-shelf wireless systems that can operate at very high bit rates.

New digital encoding and modulation techniques that can, among other factors, increase quality, reliability, tolerance to interference, throughput, and cost efficiency. The issue of protocols and transmission standards, especially in the context of B-Integrated Services Digital Network (B-ISDN) services will also be considered in this respect.

- Digital compression, which can increase cost efficiency and "effective throughput" with power-and frequency-limited systems

- Frequency expansion strategies that include new higher band allocations and more intensive frequency reuse techniques
- Infrared frequencies for expanded wireless services
- New types of satellite constellations and orbits for new wireless and mobile applications
- Advanced concepts involving hybrid wire and wireless systems

E. COMPARISON BETWEEN WIRE AND WIRELESS

The difference in the use of spectrum is obvious. Wire technology confines the transmission and its carrier waves within the medium that forms the conduit for communications. This allows the same frequency to be used as often as required, because simple insulation and isolation of the transmission frequencies within the wire can prevent interference even with immediately adjacent conduits. In the wireless environment, however, the frequencies are used. This means they spill out into the environment and create interference for anyone attempting to use the same frequency. Additional techniques such as physical isolation of satellite beams, cellular systems, polarization discrimination, coding, and other techniques allow frequencies to be reused many times or be used much more effectively between and among shared-use systems. There are, however, clear limits. In short, there is a fundamental difference in standards-making, regulation, and resource allocation when it comes to wire and wireless telecommunications systems. Clearly wireless radio services just in terms of spectrum use alone pose a much more difficult problem. [Ref. 2]

1. Radiation

The issue of regulation of radiation of radio signals has several implications. One is simply to minimize interference into other telecommunications systems by simply limiting irradiated power. There is the other concern of radiated power posing a health problem to the user of telecommunications equipment and networks. [Ref. 7] Both the technical and the health related aspects of regulating electromagnetic radiation are considered of great importance today for operational, technical, financial and health-related reasons. Particularly in the microwave and millimeter wave areas, there is

ongoing research that suggests mat more stringent health standards may indeed be required. To date, however, ongoing empirical tests of radiate power and health risks are still inconclusive.

2. System Architecture

Many people would consider the system architectures and design features of wireless systems to be essentially technical or operational issues, rather than an area of policy or regulatory concern. In fact, this is one of many areas where technology and policy intersect. Telecommunications networks that are hierarchically concentrated with fixed or wire-based links and designed to funnel increasingly heavy streams of traffic to and through high-capacity switches have been considered the "normal" form of communications for many decades. This reflects not only telecommunications tradition but also a traffic engineering concept that evolved with so-called national telecommunications monopoly organizations. It has been thought for more than a century that the larger such concentrated hierarchical networks become and the more traffic they service, the more naturally efficient they will be. Today new options are available. Wireless networks can clearly mimic the architecture of the traditional hierarchical or "vertically integrated" network, but they can also create "horizontal" networks that "bypass" the concentrated network through "mesh" or webbed networks that connect remote to remote nodes directly together. [Ref. 7]

The key to note is that up until the 1980's most regulatory authorities and most telecommunications engineers thought in terms of large natural telecommunication monopolies and economies of scales achieved through concentrated telecommunication networks. The neatly sorted out and well-compartmentalized world of telecommunications began to shift and then, in effect, to seriously unravel. Wireless, which received an impulse in terms of long-distance communications with the advent of satellites in the 1960s and 1970s, rather quickly came of age in the world of telecommunications with the cellular radio telephone in the 1980s. [Ref. 4]

Wireless communications grew and expanded everywhere in the 1980s. Beyond the most obvious case of the cellular telephone, there was also Instructional Fixed

Television Service (IFTS), wireless cable. Satellite Master Antenna Television (SMATV), Direct Broadcast Satellite, mobile and fixed satellite, and specialized mobile radio; even private wireless service for LANs and PABX's began to be taken seriously. Ironically it was when fiber optic cable was seemingly exerting its dominance in high-capacity transmission systems that wireless actually made its major surge forward.

This wireless revolution in telecommunications by almost perfectly overlapping with the divestiture of AT&T, the wide spread growth of fiber optics, and a worldwide surge toward privatization, deregulation, competition, and liberalization is sometimes overlooked. Today, however, policy makers are beginning to recognize that wireless is not only important, but it is, in fact, a key "enabling" technology that is allowing many of the regulatory innovations to succeed [Ref. 8]. Wireless services were an easy way to bring new capital and new competitors into the new arena. The ability of wireless to either overlay or expand existing systems or alternatively to compete with established systems without massive new capital investments is actually a key element in new competitive regulatory environments around the world. With wireless telecommunications the basic ground rules of the entire industry are changed.

It is now possible to have multiple carriers, alternative system architectures, and competitive environments without necessarily creating over-investment or placing one's future on a single technology or media. Most significantly, at least in the U.S. competitive context, it is possible to have true competition in the last mile of service at the local loop level.

3. Reconfigurability and Mobility

The cost and the cost efficiency of fiber optic cable is impressive. The idea that silicon-based fiber is inexpensive is certainly a compelling idea although somewhat misleading claim made in favor of advanced cable systems [Ref. 8]. Free-space transmission, however, is dependent upon no media except the earth's environment or in the case of satellites, the void of space. This is a very cost-effective medium, although the move to auction off exclusive frequency allocations in the United States, New Zealand,

and elsewhere does suggest this "free" access to the electromagnetic environment is and will change the world.

The true advantage of wireless communications is not its ability to use a nearly free medium for transmission, but rather the instant ability to connect virtually any point to any other point whether stationary or moving. Fiber cannot do these things, nor can it be instantly reconfigured to add or subtract points of service. This fundamental difference between wireless and wired service gives rise to much different regulatory concerns.

Fixed wired networks are static and thus easy to monitor. Furthermore, wire networks typically do not irradiate power and frequencies into the earth's environment. Wireless systems in contrast are dynamic, always changing, always prone to create new or unexpected interference into other networks, and are possibly able to create health problems or concerns. The very strategic advantage of wireless communications, i.e., their mobility and re-configurability, also makes their effective oversight and regulation much more difficult.

F. POLICY AND REGULATION IN WIRELESS

The key to understanding policy and regulation in the wireless domain is the clear understanding of how "wireless systems" differ from the so-called "wire" systems. The historical separation of wired and wireless telecommunications regulation and standards-making goes back almost a hundred years to the invention of radio transmission by Guglieimo Marconi at the turn of the twentieth century and even further to the invention of the telegraph some sixty years before that time.

The International Telegraph Board was first established in Bern, Switzerland and then later moved to Geneva, Switzerland to become the International Telecommunication Union (ITU). This organization was established in 1865 in order to regulate the new electronic messaging technology invented by Samuel F. B. Morse in the 1840's. The International Telecommunication Union (ITU) was thus firmly established for some five decades based on wire technology before radio transmission first emerged in the first decade of the twentieth century. The result of this new technology within the ITU structure was to create for the purposes of standards-making two bodies, both known as

International Consultative Committees. One unit of longstanding and proven worth was for telephone and telegraph and the other new and "exotic" or "experimental" unit was for radio technologies. This formal separation of the two technologies at the international level was mirrored at the national level as well. Only in the new structure of the ITU just implemented is this division between wire and wireless technologies merged together for standards-making purposes.

It is only recently that the concept of integrated digital services and seamless international telecommunications networks suggested that a separation might be unwise. Further, the idea that radio is somehow the new or not entirely proven telecommunications technology still remains within the fabric of the international telecommunications community. The radio and satellite people were largely consigned to an observer status. As only one example of this problem as of the late 1980s is the case of high-speed ISDN codecs standards. From 1986 to 1989 INTELSAT and COMSAT spent millions of dollars to develop a broad band satellite system designed to operate at 140 Megabytes per second. Then in 1989, they abruptly found their development was almost complete when the committee experts decided that the broad band standard would be shifted to 155.5 Megabytes per second instead.

At the time the division was first created between wire and wireless almost a century ago it appeared to make a great deal of sense, but in today's world this division has been rightly questioned. The ITU as the entity responsible for international regulation and for standards-making in telecommunications has been reorganized. It will integrate the "wire" and "wireless" standards-making into a single unit, but not quite. It will still have a radio telecommunications unit for frequency registration and coordination. It is still not clear how integrated the wire and wireless standards and policy-making process will really be. As the world of telecommunications migrates toward such basic concepts as Integrated Services Digital Network (ISDN), broadband ISDN, SONET, SDH, and ATM, the logic of integrated, interdisciplinary, and hybrid approaches to standardization and regulation seems to make a great deal of sense. Full applications of these principles are still incomplete even with the new reorganization of the ITU. [Ref. 7]

The problems and issues go well beyond the ITU. There are other international organizations who are working in the telecommunications standards area as well. These include the International Standards Organization (ISO), which has worked with the ITU on the basic concepts of Open Systems Interconnection (OSI). In addition, there are the International Electronic Technical Committee (IEC), the Institute of Electrical and Electronics Engineers (IEEE), and the General Agreement on Trade and Tariffs (GATT). When it comes to standards-making, the more units involved, the more difficult the process becomes.

Today, the development of telecommunications standards, despite the work of the ITU, the ISO, the IEC, the IEEE, and the GATT, has moved toward the national and regional level. This "regionalization and nationalization" of the process serves, in effect, to undercut the power and authority of the international standards-making agencies. In Europe mere is the European Telecommunications Standards Institute (ETSI). In the United States there is the American National Standards Institute with specific units devoted explicitly to developing telecommunications and information technology standards. In Japan there is the Telecommunications Technology Committee, while other regions such as South and Central America have their CITEL Committee, Africa has the Pan American Telecommunication Union (PATU), and the Asia-Pacific Telecommunity considers standards issues as well. Often the pattern of standards evolution today sees several national or regional "protostandards" evolve first. Then within the ITU framework and that of other international standards organizations the process of "standards coordination" replaces that of a single international standards development.

There are thus a number of formalized procedures that are directed toward developing systematic global standards. These activities include protocol conversions, open systems interconnection (i.e., OSI), transmission systems, switching and signaling systems, and a host of other areas as well. Despite these efforts there are now multiple international approaches to network design. Ironically there are now more and more standards with less and less effectiveness and yet they cost more and more to develop. [Ref. 9]

Unfortunately, today this observation is really not just an ironic thought but rather more of a reflection of reality. It is sadly and rather true that even the concept of openness that is intended to make everything compatible with everything else based upon "universal standards" has at least three different names. There is the OSI of the ITU and the ISO, the open network access of the FCC, and the open network provision of the European standards group, ETSI. Despite these many standards-making efforts whose name begins with open, the idea of a truly open and truly universal standard has not made real headway. The TCP/IP standard used for the INTERNET system has in some ways made the most progress. The attempt to create a new version of TCP/IP for implementation may well have even undercut this standard in that the new version is not backward compatible to those using the older version. An extension of protocols such as these can lead to monopolization (Microsoft) for industry giants that possess the resources and capital to limit the users selection and dominate the competition entirely.

G. THE FUTURE OF WIRELESS TELECOMMUNICATIONS

Market demand, new services and applications, new technology, and policy and regulation will continue to create an exciting future for wireless telecommunications. Some services will peak and ebb, but other new services will fuel continued rapid growth. Key aspects of that future will be defined by new standards and by new business practices. Other key factors will be new innovations that allow wireless services to be even more mobile, broader in bandwidth, and of higher quality. Part of this trend will be that wireless services will increasingly add an entertainment- and consumer-convenient component in addition to its current high level of focus on business services. Finally, financial and tariffing matters and new forms of private networks and value-added services will define the other dimensions of this media's growth.

Attempts to project the future in many instances fail because they are heavily technology based. This is logical in the sense that technology often follows a reasonably predictable developmental path that can be projected in a linear or smooth path forward. Policy and regulatory patterns as well as business and economic factors are much more random and unpredictable. Nonlinear events are certainly much more difficult to understand, describe, and certainly to predict. In the majority of cases, however, it is the

non-technical factors that make the biggest impact on patterns of future development. This is not to say that the future cannot be intelligently considered as long as reasonable expectations are maintained about what is "knowable" and what is not. [Ref. 2]

Key factors that can be helpful with regard to the future are cycles of history and regulatory practice. One can also consider the vectors and speed of global change that may occur across the international landscape. Furthermore, parametric modeling can help show the level of impact that various changes in one area might make across the entire field of telecommunications.

Certain aspects of the future seem clear. The most obvious aspect is the likely growth and development of mobile services with wider band applications.

The future developments that are the least clear are the final results associated with the changing patterns of ownership and control of wireless services and products. The current framework of turmoil and transitional effects, frequently called "convergence," impacts every aspect of the field. At a minimum it spreads across the industries that we today know was communications, cable television, content (e.g., entertainment software, etc.), consumer electronics, and computer better known as the 5 C's. [Ref. 11]

These industrial mergers, acquisitions, restructurings, new joint ventures and partnerships will likely have as much impact on the future as governmental reforms and regulations. This is because they will be so pervasive and fundamental. The application of wireless services to key social needs will also be a key factor in the future as well. Education, medical and health services, and public safety will define new tele-service markets, and many of these will require mobile and wireless services. This is not to say that new business applications and changes in governmental regulations and standards at the national and international level will not be important as well. The rich intermix of all these factors will likely create a rapidly growing wireless industry of the twenty-first century that will if anything place even more of a premium on the mobility and flexibility of communications services.

Despite all of the very positive aspects that indicate a very bright future for wireless telecommunications, it is always wise to recognize that in high-growth

industries, change can occur rapidly and that it is advisable to be conservative in times of very high expectation and vice versa. There is also often a tendency to become over-enamored of new technology for its own sake as well as to overlook broad shifts at the societal level that can have unexpected impacts on particular industries. However, the range of technologies that will be developed and deployed in the next decade is long and impressive. The broad level of market support for developments in the wireless field can be expected to promote rapid progress in the following areas:

- Advanced digital modulation and encoding will help accelerate advances with regard to many areas such as spread spectrum (CDMA), advanced codec designs for imaging and video, and improved interface protocols and error control techniques. Software advances will, in general, lead hardware advances for some years to come;
- Advanced digital compression techniques will likewise generate major gains not only in terms of performance and quality, but also in terms of cost reductions;
- Microcellular and picocellular systems within advanced digital mobile networks will create significant increases in frequency reuse and operational capacities. This trend is likely to be slower in coming than was first projected as PCS cell sizes are adjusted to accommodate vehicular traffic.
- Advanced node interconnection systems for PCS networks, particularly within cable television and wideband telephone systems, will create new types of networks capable of providing broadband wireless services.
- Active reclamation and reallocation of frequencies for new, higher-value, and consumer-defined applications will proliferate. (This may be in terms of reallocation and spectrum auctions or it may be accomplished by indirect means, such as the case of enhanced specialized mobile radio services);
- Advanced satellite systems design concepts will include on-board signal regeneration, signaling, switching, plus cellular beam systems with active phased array antennas (smart antennas);
- Advanced inter-satellite links with high-speed throughput and multiple satellite interconnection will be achieved with optical link telescopes and millimeter wave systems;
- Advanced hand-held and compact ground transceivers will begin to use the latest in strip, patch, and phased array antenna systems. MMIC technologies and digital processing techniques will become operational

and the price of these devices should drop dramatically over the next decade.

This chapter focuses on many aspects of wireless to give the reader a fundamental understanding of its technology. It is a segue into the next chapter that will introduce an overview of satellite systems, its segments, limitations, and future growth.

III. SATELLITE COMMUNICATIONS

This Chapter was completed in collaboration with Major Darius White

A. BROADBAND SATELLITE SYSTEMS

Satellite broadband communication networks have had and will continue to have a significant impact on data communications in peace operations. The enormous demand for high-speed networking, recent advances in technology, and new regulations are expediting the implementation of high-speed satellite networks. In well-developed areas such as the U.S. and Europe, satellite systems will compete primarily in the "last mile" where very little high-speed infrastructure exists today. However, in underdeveloped, rural areas, and during disaster relief and post-war operations, broadband satellite systems will provide the total network infrastructure.

The new technology will be valuable during peace operations because it offers wireless bandwidth-on-demand services everywhere on the globe, 24 hours a day, with guaranteed quality and reliability, and at a reasonable price. The capacity allows for transmission of thousands of computer files of 1Mb in size each, in a second. The ability to handle multiple channel rates, protocols and service priorities provides the flexibility to support a wide range of applications including computer WAN/LAN interconnect, Internet and organizational intranets, multimedia communication, and wireless backhaul. offering access speeds thousands times faster than today's standard analog modems.

This section begins with a background discussion of satellite communication technology, services and systems, as they exist today. Next, a detailed look at the current broadband satellite networks is presented. Systems covered will be INTELSAT, EUTELSAT, PANAMSAT, and INTERSTUPNIK. Forthcoming geostationary or geosynchronous earth orbit (GEO), medium earth orbit (MEO), and low earth orbit (LEO) satellite networks are discussed. These include ASTROLINK, CYBERSTAR/SKYNET, SKYBRIDGE, SPACEWAY, and TELEDESIC/ICO. Finally, deployment issues facing broadband satellite service providers (SSPs) are explored. Issues of concern include latency and quality of service, network security, loss of service,

congestion, and interoperability. All of which are essential topics for the use of satellite communications during peace operations.

1. Broadband Satellite Frequency Allocations

The Super High Frequency (SHF) band (3 to 30 GHz) is the most commonly used band of frequencies for broadband applications. Within the SHF spectrum of frequencies there are three main letter designated frequency bands as defined by the Institute of Electrical and Electronics Engineers (IEEE) Standard 521-1984 (1989) as shown in Table 3.1 below:

BAND	UP-LINK (GHz)	DOWN-LINK (GHz)	ISSUES
C	3.7-4.2	5.925-6.425	Interference with ground links.
Ku	11.7-12.2	14.0-14.5	Attenuation due to rain.
Ka	17.7-21.7	27.5-30.5	High equipment cost.

Table 3.1. SHF Satellite Communications Frequencies [From Ref. 29].

The C-band is the most used frequency band. C-band frequencies are also allocated to terrestrial radio relay microwave systems that are used by telephone companies to interlink switching centers. To minimize interference, power flux density limits on satellite transmissions are set and enforced by international agreements. A spot beam antenna, which concentrates energy in a specific location, using C-band frequencies usually covers a large region, (i.e. a hemisphere).

Ku-band frequency spot beams are localized to a smaller region (i.e. a continent or country). The Ku-band spectrum came into use as a result of the lack of enough available C-band frequencies to meet growing customer requirements for higher throughput. Because of its smaller wavelength and greater attenuation due to rain atmospheric conditions in this band become a factor. To overcome this effect extra power margin is design into the link. This not only means that additional power must be available onboard the satellite, but also more sensitive reception systems must be employed to overcome the rain attenuation.

Until recently, Ka-band was used for experimental satellite programs in the U.S., Japan, Italy, and Germany. In the U.S., the NASA Advanced Communications Technology Satellite (ACTS) was used to demonstrate advanced technologies such as onboard processing and scanning spot beams. The growing congestion of the C and Ku bands and the success of the ACTS program increased the interest of satellite system developers in the Ka-band satellite communications network for exponentially growing Internet access applications.

2. Space Segment

There are two parts to the space segment: the satellite platform or bus (the basic frame and structure of the satellite) and the payload. The payload functions and capabilities are the reason a satellite is placed into orbit. The payload provides space-based capabilities to the user and distinguishes one type of satellite from another. For wide area network applications broadband communications satellites are vital.

One of the defining characteristics of the space segment is the orbit in which the satellite operates. There are five main orbits used by communications satellites: Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geosynchronous, Geostationary Orbit (GEO), and molniya. [Ref. 17] There are advantages and disadvantages to each orbital method, as shown in Table 3.2. Most communications satellites systems are placed in GEO. A number of future broadband systems will be designed to operate in LEO and MEO as well as GEO and will be covered in greater detail later in the chapter.

Type	LEO	MEO	GEO
Description	Low Earth Orbit	Medium Earth Orbit	Geostationary Earth Orbit
Height	500-1000 miles	6000-12000 miles	22,282 miles
Time in LOS	15 min	2-4 hrs	24 hrs
Merits	Lower launch costs. Short round trip signal delay. Small path loss.	Moderate launch cost. Small round trip delays.	Covers as much as 42.2% of the earth's surface. Ease of tracking. No problems due to doppler.
Demerits	Shorter life, 5-8 years. Encounters radiation belts.	Larger delays. Greater path loss than LEO's.	Very large round trip delays. Expensive Earth Stations due to weak signals.

Table 3.2. Characteristics of Satellite Orbits [From Ref. 31].

In communications satellites, the equipment which provides the connecting link between the satellite's transmit and receive antennas is referred to as the transponder. The transponder forms one of the main components of the payload. It is the series of interconnected units which form a single communications channel between the receiver and transmit antennas in a communications satellite. Transmission via a satellite transponder is often likened to a "bent pipe" because the satellite simply channels the information back to the ground. Future satellite systems will offer on-board packet processing and switching that will allow configuration of networks upon request and data routing to provide two-way interactive communications and bandwidth on demand.

As an example, the bandwidth allocated for the usual C-band service is 500 MHz, and this is divided into sub-bands, one for each transponder. A typical transponder bandwidth is 36 MHz, and allowing for a 4 MHz guard-band, 12 such transponders can be accommodated in the 500 Mhz bandwidth as seen in Figure 3.1. By making use of polarization isolation, this number can be doubled. This method exploits the fact that carriers may be on the same frequency but with opposite senses of polarization (i.e. horizontal vs. vertical or right-hand vs. left-hand circular), can be isolated from one another by receiving antennas matched to the incoming polarization. Because carriers with opposite senses of polarization may overlap in frequency, this technique is referred to as frequency reuse. Frequency reuse may also be attained through the use of spot

beam antennas, and these when combined with polarization isolation, can provide an effective bandwidth of 2000 MHz from an actual bandwidth of 500 MHz.

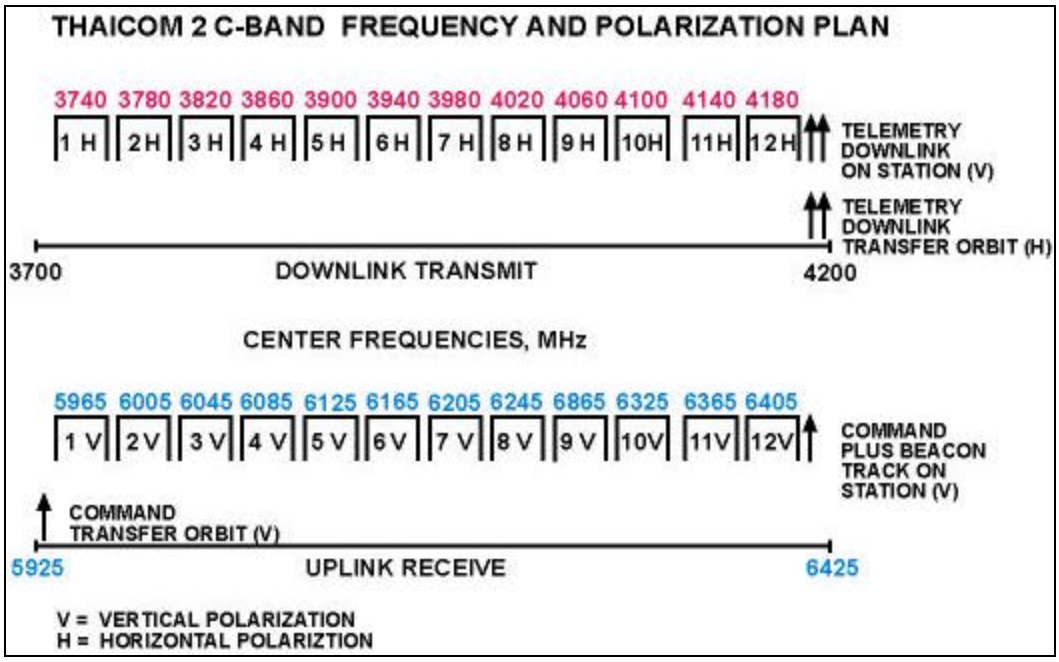

Figure 3.1. C-band Transponder Frequency Plan for Thaicom-2 Satellite [From Ref. 18].

Full transponders can usually be leased for 1-year time periods essentially worldwide. Bundled transponders (e.g., 1.544 Mbps T-1 circuits) can be chartered for any term of lease based on other users' bundled requirements. The recurring costs of transponders or circuits vary with requirements for bandwidth and power, frequency, and special features such as spot and hemispherical beams. The non-recurring costs include connection, setup, documentation, and calibration. There are several companies that sell or broker transponder time within CONUS as well as international transponder time. Transponder rates vary by time slots, and transponder usage, for example prime time and non-prime. The average rate for a full transponder in prime time is $940.00 per hour; non-prime time is $840.00 per hour. For half transponder time the cost is $705.00 and $630.00 for prime and non-prime respectively [Ref. 15].

Another defining characteristic of the space segment is the equivalent isotropic radiated power (EIRP). The word isotropic means, rather loosely, equally in all

directions. Thus, an isotropic radiator is one that radiates in all directions. EIRP is the equivalent power that an isotropic antenna would have to radiate to achieve the same power density in the chosen direction at a given point as another antenna [Ref. 31]. Satellites radiate and focus power on the downlink in a directional manner rather than isotropically. Therefore it is used as a figure of comparison and is often expressed in decibels relative to one watt (dBW). When reviewing a diagram of a satellite's antenna footprint pattern the EIRP will be annotated within concentric rings. The higher the EIRP, the more energy is delivered to the receiver. The upshot means either higher achievable data rates or smaller required receive antennas. EIRP can be used for a number of calculations and evaluations (i.e. to determine the transponder usage efficiency). However, for our purposes it will be used merely as a tool to illustrate signal strength within a given coverage area when such illustrations are provided. To avoid interference to other services, international jurisdictional bodies (e.g. the International Telecommunications Union (ITU)) control EIRP levels [Ref. 29]. For commercial broadband communications satellite the upper limit of downlink EIRP is 60 dBW.

3. Ground Segment

This segment is also known as the terminal segment. It comprises the actual equipment on the ground that receives from and transmits signals to the satellite. Ground terminals can vary from hand-held or man-portable terminals, to fixed or mobile shelters containing user equipment. The most common data service for broadband applications is the VSAT (very small aperture terminal). A VSAT is a device (also known as an earth station) that is used to receive satellite transmissions. The "very small" component of the VSAT acronym refers to the size of the VSAT dish antenna, typically 3 to 6 feet in diameter, which is mounted on a roof on a wall, or placed on the ground. This antenna, along with the attached low-noise blocker or LNB (which receives satellite signals) and the transmitter (which sends signals) make up the VSAT outdoor unit — one of the two components of a VSAT earth station.

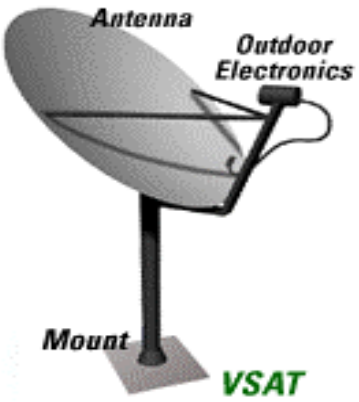

Figure 3.2. VSAT Antenna [From Ref. 27].

The second component of VSAT earth station is the indoor unit. The indoor unit is a small desktop box or PC that contains receiver and transmitter boards and an interface to communicate with the user's existing in-house equipment (i.e. LANs, servers, PCs, TVs, kiosks, etc). The indoor unit is connected to the outdoor unit with a pair of cables.

The advantage of a VSAT earth station, versus a typical terrestrial network connection, is that a VSAT is not tied to a ground infrastructure. This is capability is particularly vital during peace operations due to the lack of pre-existing indigenous communications networks and systems. A VSAT earth station can be placed anywhere, as long as it has an unobstructed view of the satellite. VSATs are capable of sending and receiving all sorts of video, data and audio content at the same high speed regardless of their distance from terrestrial switching offices and infrastructure. VSAT networks are quite simple. Typically, customers install a router that is connected either to a satellite dish on site or to landlines leading to a gateway managed by a satellite service provider. At remote sites the VSAT is connected via coax to a digital interface unit (DIU). The DIU acts like a router and connects to an Ethernet or token ring LAN. The satellite is used to connect subscribers independently of the terrestrial network. Common access methods are essentially the same ones that have existed since VSATs were first made commercially available; these are Code Division Multiple Access (CDMA), Single Channel Per Carrier (SCPC), Time Division Multiple Access (TDMA), and Demand Assigned Multiple Access (DAMA). Configurations can be either star or mesh and

shared hubs. These different topologies and access methods are used to distribute information throughout the network. To satisfy user's need for higher speeds, access methods are combined to optimize bandwidth.

There is an inherent 0.25-second one-way (one uplink and one downlink) delay in VSAT networks due to the distance of GEO communications satellites from the earth. Older applications could not manage these delays, and would time-out or crashed. VSAT software is now much smarter and helps to overcome the effects of the inherent delay of GEO satellite transmission. This software is capably of spoofing applications locally and only transmits the necessary information over the satellite. Future VSATs will be smaller, cheaper, more powerful, and smarter. These VSATs will be designed to be plug-and-play with the communications network of any organization.

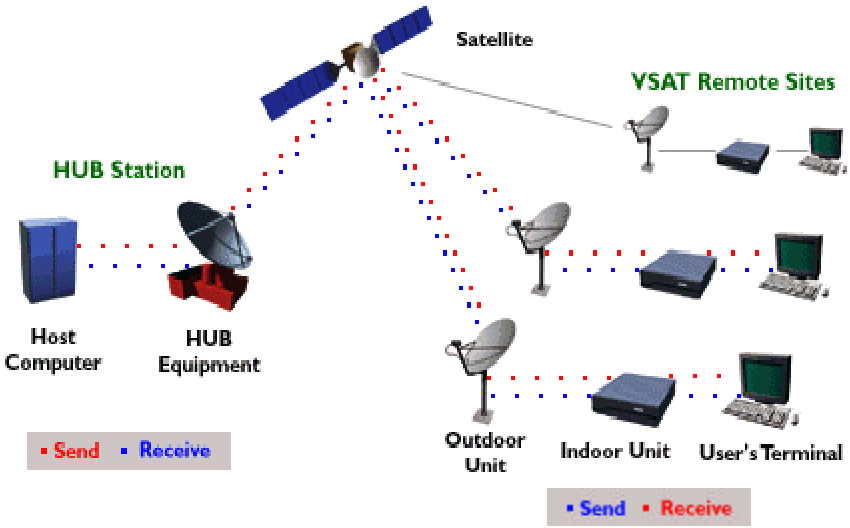

Figure 3.3. VSAT Network (Star Topology) [From Ref. 27].

While historically, the majority of VSATs operate in the Ku-band, C-band VSATs have been allowed through the introduction of spread spectrum signaling that prevents interference (due to the broad beam-width of C-band VSATs) to adjacent satellites. The worldwide number of VSATs is difficult to determine with any precision. It is estimated that for 1997 there were about 300,000 units worldwide. Considering the needs in Asia, Africa and S. America, the number should easily double within ten years. [Ref. 12]

Users wishing to gain access to a satellite network must use VSATs that meet the minimum operational technical requirements for earth stations transmitting on leased capacity as outline in the satellite provider's technical documentation. This usually means obtaining a "Type Approval" TA certificate. A TA certificate guarantees that the mandatory parameters of all earth stations of a given standard lay within specified limits. This is to ensure an adequate level of protection to other services carried by the space segment, as well as other services handled by adjacent satellites.

Current VSAT throughput is typically 2.4 Kbps to 8 Mbps. A number of future Ka-band systems are planning to provide wider throughput (10 kbps to 100 kbps) and "ultra high throughput" (1.5 Mbps to 155 Mbps) services to small VSATs (45 cm to 60 cm diameter antennas) know as Ultra Small Aperture Terminals (USAT). These systems are aimed at providing video conferencing, private "intranet" services, telemedicine, distant learning, two-way Internet access and multimedia communications in the future.

4. Control Segment

The control segment is responsible for the operation of the overall system which includes platform control, payload control, and network control. The control segment consists of ground satellite control facilities, systems onboard the satellite, and communications networks linking the control facilities. A Network Control Station (NCS) performs various control and management functions, e.g., configuration management, resource allocation, performance management, and traffic management. The number and location of these NCSs depend on the size of the network, coverage, and other international standards and regulatory issues. Teleports are also a major part of the Control Segment. They provide additional monitoring and management of the network. Furthermore, teleports allow connectivity between satellite terminal users in different beams, as well as providing access to the terrestrial communications infrastructure. This type of connectivity can provide a reach back capability for peace operations units from their location to sustaining bases and headquarters outside the immediate area of operation. Where information is available some components of the Control Segment will be covered in the Ground Segment portion.

B. DESCRIPTION OF EXISTING COMMERCIAL SYSTEM

1. INTELSAT

The INTELSAT system started life out as an international satellite consortium consisting of member and non-member countries. INTELSAT was founded in 1964 as the world's first commercial satellite operator. The U.S. Government created a quasi-government organization, the Communications Satellite Corporation (COMSAT), with the mission to develop satellite technology for the Western World. COMSAT, the predecessor of INTELSAT, launched the Western World's first manmade commercial satellite in 1963 called Early Bird. The Early Bird Satellite had a channel capacity of 24 voice grade telephone channels and provided connectivity with 3 stations in Europe, the UK, France and Germany. In 1974 INTELSAT activated the direct "hot line" link between the White House and the Kremlin.

Today, INTELSAT owns and operates a global communications satellite system that provides capacity for voice, video, corporate/private networks and Internet in more than 200 countries and territories. More than 36 countries rely on INTELSAT satellites for their domestic systems. As an example, the Norwegian domestic satellite system (NORSAT) connects the Spitsbergen Islands to the national network with all facilities, including the Integrated Service Digital Network (ISDN). The system also provides communications to the oil installations in the North Sea, which are located beyond line-of-sight of the mainland.

Today INTELSAT has 143 member countries and Signatories. In November 2000, INTELSAT changed its status from a treaty based, international cooperative to a private organization. The four largest shareholders are Lockheed Martin Global Telecommunication, Videsh Sanchar Nigam Limited of India, France Telecom, and Telenor Satellite Services AS of Norway.

a. INTELSAT Space Segment

INTELSAT satellites are among the most complex satellite systems today offering worldwide coverage. INTELSAT satellites operate in the C-Band and Ku-Band

frequency spectrums. The C-Band spectrum is typically Circular Polarization. The Ku-Band spectrum is Linear Polarization.

INTELSAT has a fleet of 21 spacecraft in geostationary orbit. The satellites come in four different versions: the INTELSAT V/V-A, INTELSAT VI, INTELSAT VII/VII-A and the VIII/VIII-A. The newest generation of INTELSAT spacecraft, the INTELSAT IX series, is currently in production. With this constellation INTELSAT has global coverage. INTELSAT has 10 satellites in the Atlantic Ocean region serving the Americas, the Caribbean, Europe, the Middle East and Africa with orbital locations ranging from 304.5^{o} E to 359° E. There are 4 satellites are in the Indian Ocean region and 3 in the Asia Pacific region serving Europe, Africa, Asia, the Middle East, and Australia with orbital location ranging from 60° E to 110.5^{o} E. 3 satellites serve Asia, Australia, the Pacific, and Western North America from orbital locations ranging from 174° E to 180° E over the Pacific Ocean region.

INTELSAT 902, was launched on 30 August 2001, and will provide high-power, Ku-band spot beam coverage for Europe and the Middle East and more C-band capacity to the Indian Ocean region.

The coverage map (Figure 3.4) shows a typical footprint for a Ku-band spot beam. The decibel watt (dbW) curves (i.e. 51.0 dbW, 49 dbW, etc.) represent positive gains in reference to Signal to Noise ratio for a given transmission. For this particular satellite (INTELSAT 707) there are 4 spot beams, 3 Ku-band and 1 C-band. There are also 70 transponders, 42 C-band and 28 Ku-band. The requirement for the receiver depends on where in the footprint it is located, the higher the EIRP, the better. Together with the received power, the signal data rate will determine the size and receiver sensitivity.

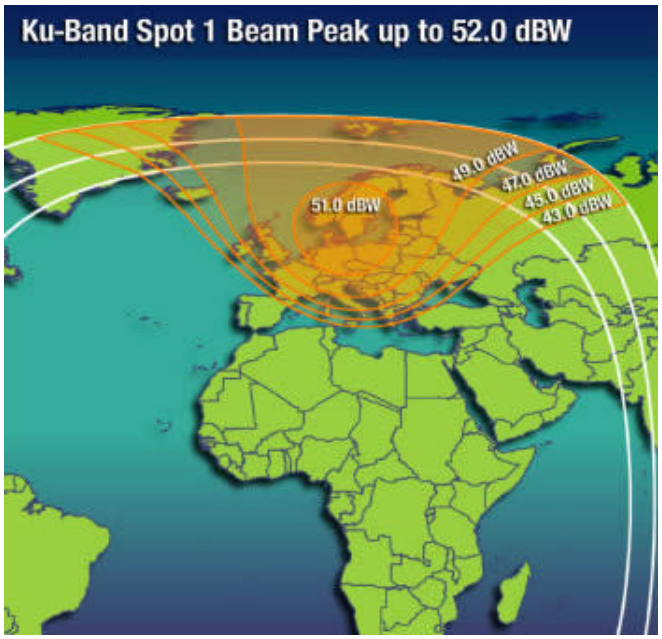

Figure 3.4. Ku-band Spot Beam Antenna Coverage [From Ref. 21].

The most up-to-date satellite in the current inventory is the INTELSAT VIII series (Figure 3.5), manufactured by Lockheed Martin. It has a capacity of 22,500 two-way telephone circuits, three TV channels and up to 112,500 two-way telephone circuits with the use of digital circuit multiplication equipment. It has a 14 to 17 year life cycle, 15 years being nominal.

Figure 3.5. Intelsat VIII Series [From Ref. 21].

b. INTELSAT Ground Segment

INTELSAT supports VSATs for use in wide area private networks. The user must be authorized to use INTELSAT satellite services from an earth station. There

are two means of accessing the system. Either through earth stations that have been type-approved by TA certificate, or through earth stations verification testing.

c. INTELSAT Services

The satellites can be used to transmit images, sound and data in analog or digital format, from anywhere in the world. Bandwidth options range from 100 kHz to 150 MHz, with data throughputs ranging from 64 kbps to 4 Mbps. Customers can choose to lease transponder capacity from only 10 minutes up to 15 years.

2. EUTELSAT

EUTELSAT is a European satellite consortium consisting of 47 European member countries and Signatories, the three biggest being British Telecommunications p.I.c., Telecom Italia S.p.A, and France Telecom. [Ref. 21] It was established in 1977 and is Europe's largest satellite operator. It operates satellites for fixed and mobile communications services. The EUTELSAT system is a regional network covering Europe, Africa, the Baltic States and eastward into Moscow, Russia. The EUTELSAT system is a popular regional network that has satellites operating in the Ku-Band spectrum using linear polarization, with the exception of those transponders transmitting to the Russian coverage on the W4 satellite, which uses circular polarization.

a. EUTELSAT Space Segment

EUTELSAT operates over 300 transponders on 14 GEO satellites. The satellites provide full coverage of Europe and also cover parts of Africa and Asia, including the entire Middle East. Two of the satellites are equipped with a steerable spot beams that can be oriented anywhere visible from 13 degrees East, in either northern or southern hemisphere. Over half of EUTELSAT bandwidth is devote to TV broadcast. 6 of the 19 satellites in the EUTELSAT constellation offer VSAT network support these are: EUTELSAT II-F2, TELECOM 2A, W1, W2, W3, W4. The W4 satellite downlink coverage is shown below.

In mid-2002 the HOT BIRD 6 satellite will introduce Ka-band services for the first time to complement the extensive range of Ku-band services already provided from 13 degrees East. The satellite will provide four transponders operating in the Ka-band in conjunction with a Western European coverage. [Ref. 21]

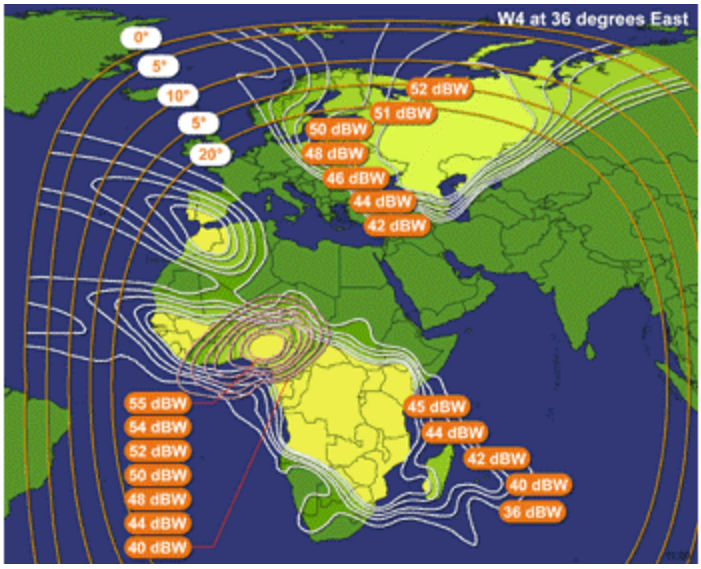

Figure 3.6. EUTELSAT W4 Satellite Antenna Footprint [From Ref. 21].

b. EUTELSAT Ground Segment

EUTELSAT offers VSATs through partnerships with national companies. The capacity used is operated in Single Channel Per Carrier/Frequency Division Multiple Access mode (SCPC/FDMA) at information bit rates of 2.4 Kbps to 2 Mbps, and up to 8 Mbps on the newer W series satellites.

c. EUTELSAT Services

Almost 20 transponders are used for one and two-way VSAT networks for applications such as video-teleconferencing, stock control, telemedicine, distance learning, and newswire distribution to name a few. Transponder capacity can be leased from 10 minutes to 12 months. EUTELSAT is also setting up a bandwidth-on-demand network for corporate and institutional communications that will be operated on a pay-as-you-use-basis. Called EWDS (EUTELSAT Wideband DAMA Services), it will be able

to support applications such as LAN-to-LAN interconnections, high-speed file transfer and support various standard network protocols such as Frame Relay and ISDN.

3. PANAMSAT

PANMASAT is a privately owned corporation that provides satellite-based communications services. It operates one the largest global network of GEO satellites and technical ground facilities. In May 1997 PANAMSAT and Hughes Galaxy Satellite Services merged giving PANAMSAT Corp control of the Galaxy satellite constellation that provides service to North America, Latin America and the Caribbean.

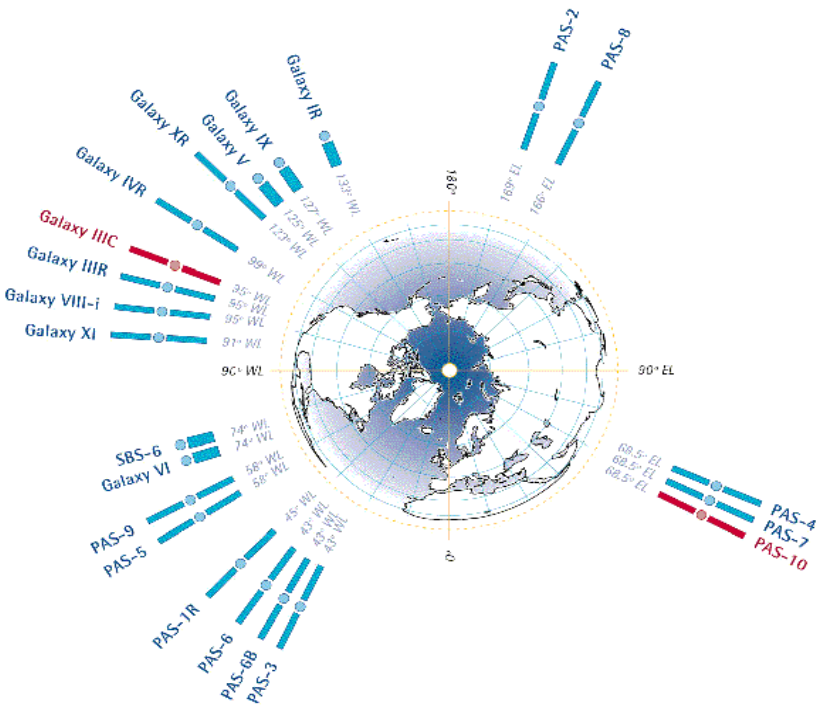

Figure 3.7. PANAMSAT Constellation [From Ref. 19].

a. PANAMSAT Space Segment

The PANAMSAT constellation (Figure 3.7) consist of 21 GEO satellites, 9 of which cover the Americas, 7 are over the Atlantic Ocean region, 2 are over the Pacific Ocean, and 3 operate over the Indian Ocean area. There are over 810 transponders in the total network with at least 380 being C-band and 430 being Ku-band.

b. PANAMSAT Ground Segment

VSAT networks employing PANAMSAT satellites are operated in the United States, Latin America, Africa and Asia. PANAMSAT has 2 Operations Centers, one in Atlanta, GA that monitors satellites over the Atlantic, Indian and Pacific Oceans. The other Operations Center is in Long Beach, CA. It monitors the majority of the Pacific Region satellites. 5 Teleport facilities provide network support and monitoring as well as access to the terrestrial communications infrastructure. The teleport in Silver Creek, NY supports the Hughes Network Systems (HNS), which provides a shared VSAT hub supporting customers operating private networks.

c. PANAMSAT Services

Telecommunications service providers in the U.S., Latin America, Africa, Europe, and Asia use PANAMSAT as their pipelines for communications traffic. PANAMSAT also provides access to the U.S. Internet backbone for ISPs in over 50 countries. Satellite capacity and terrestrial facilities are available to offer everything from 10-minute transmissions to 24-hour leases. Users can access the PANAMSAT system directly or through the HNS. HNS is the largest single user of PANAMSAT capacity for telecommunications services. HNS's corporate customers typically use PANAMSAT-based VSAT networks to link multiple locations together in private communications networks. Wal-Mart, for example, uses a PANAMSAT-based VSAT system to connect more than 3,000 of its stores, Sam's Clubs and distribution centers across the United States [Ref. 19]. This type of network scheme can be easily translated into a peace operations mission.

4. INERSPUTNIK

The INTERSPUTNIK International Organization of Space Communications, one of the first satellite operators in the world history, was established in November 1971 when nine countries signed an agreement on the establishment of a global satellite communications system. Since its creation, INTERSPUTNIK’s membership has grown to 24 countries. INTERSPUTNIK is an open intergovernmental organization that can be

joined by the government of any state. Lockheed Martin is partnered with INTERSPUTNIK. This joint venture covers the whole technological cycle of satellite service ranging from satellite manufacture and launching to long-term in-orbit satellite operation.

a. INTERSPUTNIK Space Segment

INTERSPUTNIK's space segment consists of 5 satellites. The fleet has three series of Russian-made satellites: Gorizont, Express and Express-A and the new-generation LMI-1 satellite manufactured by Lockheed Martin. Gorizont and Express communications satellites operate in the C-band and Ku-band; have global, zone and spot-beam transmit antennas; provide an EIRP value towards footprint edges of 25.5 to 43.0 dBW in the C-band and 36.0 dBW in the Ku-band.

The Express spacecraft are a follow-on generation of the Russian Gorizont-series communications satellites. Each Gorizont has six C-band transponders and one Ku-band transponder. Each Express has ten C-band transponders and two Ku-band transponders. As compared with Gorizont, each Express satellite has more transponders; better power characteristics; improved station-keeping accuracy making it possible to use small-aperture earth stations without tracking systems; longer life; steerability of spot-beam antennas and one zone antenna throughout the whole service life of the satellite. Another satellite in the INTERSPUTNIK system is the Gals satellite. The Gals direct broadcast satellites provide Ku-band service and are designed for direct-to-home TV. Each Gals has three transponders, on-board spot-beam steerable antennas and provides the EIRP towards the edge of the service area within 52.0 to 54.0 dBW.

b. INERSPUTNIK Ground Segment

Intersputnik satellites serve corporate customers who use satellites to establish dedicated VSAT networks for high-speed voice, data and image exchange. INTERSPUTNIK also offers Internet connectivity via teleport services in Europe (Germany and Russia) and on the U.S. East Coast. These teleports are connected via high-bit-rate links to Carrier 1, Cable & Wireless, Mannesman ARCOR, MCI, UUNET

and other major networks. For example, INTERSPUTNIK's teleport partners in Berlin, Germany and Moscow, Russia offer a developed communication infrastructure with access to the European Internet backbone for local providers in Asia, the Middle East, Africa and the CIS using Express-6A (80° East). [Ref. 22] The signal is then delivered via submarine cable to the main information centers in the U.S. The same route delivers information from America to areas served by INTERSPUTNIK satellites operating in the Indian Ocean region.

c. INERSPUTNIK Services

INTERSPUTNIK satellites serve corporate and organizational customers who use satellites to establish dedicated VSAT networks for high-speed voice, data and image exchange. They also offer Internet access to providers and corporate customers via digital satellite links through the new-generation Express-A satellites using their partners' teleports in Europe (Germany and Russia) and on the U.S. East Coast. INTERSPUTNIK provides broadcasters with 24-hour access to space segment for occasional-use television services, including satellite news gathering, and coverage of special events. [Ref. 22]

C. DESCRIPTION OF FUTURE SYSTEMS

Future satellite networks will incorporate newer technology to increase bandwidth and throughput. The less congested Ka-band will be used to afford higher frequency reuse bandwidth efficiency. The use of on-board processing and switching is the biggest step in the insertion of new technologies onto satellites. These satellites will be switchboards in the sky, supported by millions of lines of real-time software onboard the satellite and on the ground, a new phenomenon for satellites. The high data rate satellites face the challenge of being part of a large global system that is dominated by terrestrial technology. At these high data rates, latency sensitive protocols must be modified, or new ones developed, to obtain seamless interoperability with the terrestrial network. Slated to be released into space in the 2002 to 2004 time frame, Ka-band satellites hold great promise as so-called IP routers in the sky with the onboard switching and antenna payload needed for high-bandwidth Internet traffic. They're high-capacity, open platform,

and adaptable. And with speeds promised at 100 Mbps on the downlink and 2 Mbps on the uplink, these new satellites may deliver richer multimedia applications to the corporate enterprise, desktop, or wireless device. Most important is that Ka-band has about twice the allocation and bandwidth of Ku-band, with nearly 6 Gbps throughput per beam.

Carriers allocated orbital slots on the Ka-band by the Federal Communications Commission and International Telecommunication Union are designing spacecraft with spot-beam antennas and intelligent switching to yield better efficiency and more bandwidth. A few have already launched Ka-band spacecraft for regional areas, and global Ka-band systems are expected to follow in the next two years. Table 3 outlines the characteristics of several future wide-band satellite systems. Ka-band was once considered experimental space-band because of problems associated with its higher-frequency allocation, but with technology outpacing most of those problems, it could very well break new ground in satellite affordability. This chapter will outline a few of these future systems. These are: ASTROLINK, CYBERSTAR/SKYNET, SKYBRIDGE, SPACEWAYS, and TELEDESIC/ICO.

1. ASTROLINK

Astrolink is a $4 billion initiative that is jointly owned by Lockheed Martin and international network operators. Astrolink will be an ATM-based, Ka-band, GEO satellite system. Nine satellites are planned, but only a total of five are needed for global connectivity. The service will offer broadband data services from 128 Kbps to 155 Mbps starting in 2002. [Ref. 33]

The Astrolink system will include advances such as on-board processing and spot beam technology. System security will be assured through public key and smart card technology. Optional session encryption will be available depending on local regulation. Up to 100 gateways will connect Astrolink to terrestrial networks worldwide. Inter-satellite links with data rates of 440 Mbps will also be employed.

2. CYBERSTAR/SKYNET

In October 1998, when Loral Space & Communications acquired Orion Satellite Corporation, Loral Space & Communications' CyberStar satellite network announced the commercial availability of its broadband satellite service [Ref. 33]. The $1.6 billion system is a GEO constellation based on the former AT&T Skynet and Orion satellite systems. It is an open protocol, digital system that offers a variety of low-cost, high-speed, data and telecommunication services from Ku-band satellite transponders. CyberStar services currently support high bandwidth IP-multicast solutions for intranets, extranets, and virtual private networks via the Loral Skynet Telstar and Orion satellite constellations. CyberStar is the only provider with plans to concentrate exclusively on direct sales to large and small businesses as well as consumers [Ref. 18]. Cyberstar also plans to offer customers low-latency services through an integrated marketing agreement and $30 million cross-investment with Alcatel's SkyBridge [Ref. 18].

In late 2002, service will migrated to a dedicated constellation of Ka-band GEO satellites. CyberStar's Ka-band satellites will each have 72 independent spot beams. This is more than any other communications satellite, including NASA's ACTS. Unlike other satellite systems, CyberStar satellites will not communicate with one another. They will communicate only with users and gateways on Earth.

CyberStar is also promoting the use of its system to distribute motion pictures with direct digital distribution via IP multicasting. The company was the first to distribute a full-length movie directly to theaters in five U.S. cities over its Digital Distribution Service in October 1998.

3. SKYBRIDGE

SkyBridge is the Alcatel Espace SA-led $4.2 billion satellite venture that is expected to be operational by 2001. Partners include Loral Space & Communications, Toshiba, Mitsubishi, Sharp, Spar Aerospace, and Aerospatiale. SkyBridge will offer Internet access, videoconferencing, LAN and WAN connections, and interactive entertainment services with data transfer rates as fast as 20 Mbps downstream and 2

Mbps on the uplink. System capacity of 200 Gbps is expected to meet the needs of 400 million users anticipated by 2005 [Ref. 37].

SkyBridge recently expanded the system from 64 to 80 LEO satellites. The network now consists of two constellations of 40 satellites orbiting at an altitude of 913 miles. Each satellite illuminates an area of 1,864 miles in radius. There is at least one satellite visible within the coverage area of each terrestrial gateway. However, most of the time at least two and up to four are visible and available to receive traffic.

Unlike other broadband LEO systems, SkyBridge selected the Ku-band instead of the Ka-band. At the lower frequency, SkyBridge is able to use less powerful (and less expensive) transmitters. However, the Ku-band is also very crowded, and many GEOs already use the spectrum. SkyBridge satellites will be susceptible to increased interference from these GEOs when they are over the equator. SkyBridge will solve this problem by shutting off transmission when a satellite is plus or minus 10 degrees from this zone. Ground terminals will then switch to another satellite.

SkyBridge will also bring down costs by using a combination of transmission methods (i.e. satellite links for local access and existing terrestrial broadband networks for long-distance connections). The use of satellite links only when absolutely necessary reduces the overall end-to-end costs.

4. SPACEWAY

The Hughes Communications', Inc. (HCI) Spaceway global broadband communications system is a combination of 8 GEO satellites and 20 MEO satellites [Ref. 36]. Both systems will operate in the Ka-band frequency range. As proposed the Spaceway system will provide 100 percent coverage in four regions: North America, Asia Pacific, Latin America, Europe, Africa, and the Middle East. Service in the first region will begin in 2002. The other three regions will be online by 2004.

Spaceway's "bandwidth-on-demand" capability will provide consumers and businesses with fast access to terrestrial networks (e.g. the Internet, Intranets, and LANs). The system's Ultra Small Aperture Terminal (USAT) receivers will be 26 inches in diameter and provide uplink speeds up to 6 Mbps. Downlink speed will be 108 Mbps. In

addition, the system is fully compatible with a wide range of terrestrial transmission standards such as ATM, ISDN, Frame Relay, and X.25.

The Spaceway GEO constellation will focus on high data rate transport market and will operate from four orbital locations. In contrast, the Spaceway MEO constellation will provide interactive broadband multimedia communications services in high traffic markets globally. Spaceway's MEO constellation will consist of four planes with five satellites in each plane. Orbits will be circular at 6,433 miles. Spaceway satellites will use multiple-beam antennas, and like Astrolink, inter-satellite links. A signal received by one satellite could be relayed directly back to the same beam, switched to another beam, or relayed by inter-satellite links to other satellites.

5. TELEDESIC/IOC

Teledesic LLC is a privately held satellite service provider that was spun off from McCaw Cellular in 1994 in order to creating a high-speed, wireless, switched global network designed to handle two-way voice, video, and data traffic. Teledesic's web site best sums up its corporate vision with the following broad and rather amazing statement:

> Teledesic is building a global, broadband "Internet-in-the-Sky." Using a constellation of low-earth-orbit satellites, Teledesic and its partners will create the world's first network to provide affordable, worldwide, "fiber-like" access to telecommunications services such as broadband Internet access, videoconferencing, high-quality voice and other digital data needs. On Day One of service, Teledesic will enable telecommunications access for businesses, schools, and individuals everywhere on the planet. [Ref. 35]

The Teledesic network is configured with a constellation of 288 LEO satellites. These satellites will blanket the earth and transmit in the 18 GHz and 28 GHz range and provide the equivalent of 20,000 T1 lines to 100% of the Earth's population and 95 percent of the landmass. Qualities of Service levels are expected to equal fiber-based terrestrial networks. Data will be switched from one satellite to another at rates of 1 Gbps inter-satellite links, creating an Internet in the sky. Corporations and consumers in third-world countries will have the same accessibility as those in developed countries.

The service is expected to be operational in 2003 at a cost of $9 billion. It will be the single largest and most ambitious communications project ever undertaken.

Teledesic's major investors include Craig McCaw, Bill Gates, AT&T Wireless Services, Boeing, and Motorola. Motorola's plans to compete with Teledesic were changed when the two companies announced that Motorola's Celestri project would be folded into Teledesic. As part of the merger agreement, Motorola received a 26 percent stake in Teledesic. Motorola was to be responsible for the design and engineering of the 288-satellite system, as well as the ground stations and the network. However, on 6 October 2000, Teledesic and Motorola agreed to end this arrangement in the wake of Teledesic's plans to merge with ICO-Teledesic Global Limited [Ref. 42]. This allows Teledesic the freedom to design their network without having to integrate components from the Celestri system. ICO Global Communications is a London-based company, which provides mobile voice services and medium-speed wireless Internet and other packet-data services on a global basis. However, even in light of these events, Motorola remains an investor in Teledesic.

Teledesic terminals will interface with the standard network protocols (i.e. IP, ISDN, and ATM). The network will be optimized for fixed-site terminals but will work with mobile applications (e.g. aviation and maritime). Standard terminals will have two-way connection rates of up to 64 Mbps on the downlink and up to 2 Mbps on the uplink. High-speed broadband applications will have bi-directional 64 Mbps connections.

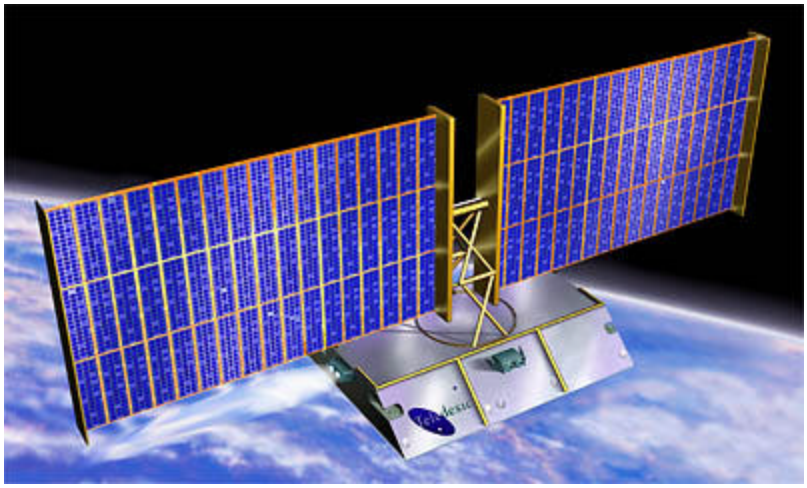

Figure 3.8. The Teledesic Satellite [From Ref. 42].

Within Teledesic's satellite constellation, each satellite is a node in the fast-packet-switch network. Satellite nodes also have inter-satellite communication links with other satellites in the same and adjacent orbital planes. Interconnection in this manner provides a robust non-hierarchical mesh, or "geodesic," network that is fault tolerant. The Teledesic network combines the advantages of a packet switched network with those of a circuit switched one.

Company	**System**	**Orbit**	**Coverage**	**No. of Satellites**	**Satellite Capacity (Gbps)**	**Capital Investment ($ billion)**
Lockheed Martin	Astrolink	GEO	Global	9	7.7	4
Loral	Cyberstar	GEO	Limited Global	3	4.9	1.6
Alcatel Espace	Skybridge	LEO/GEO	Limited Global	80	2.5	4.2
Hughes	Galaxy/ Spaceway	GEO/MEO	Global	28	4.4	5.1
Teledesic	Teledesic	LEO	Global	288	13.3	9

Table 3.3. Emerging Wideband Satellite Systems [From Ref. 43].

D. ISSUES AND CONCERNS

1. Interoperability

Interoperability and interconnectivity to the external private or public networks is possible with the support of the standard protocol. Government and industry teams in Japan and the U.S. are conducting experiments to develop and demonstrate the role of

satellites in the global telecommunications infrastructure [Ref. 17]. The experiments will help develop satellite transmission techniques, standards, and protocols to determine the best method of integrating satellite links with fiber-optic cables to form high-performance global networks. These trans-Pacific experiments will carry high-speed computer data, high-resolution images, and video for applications such as astronomy, telemedicine, distant-learning, digital libraries, and electronic commerce. In addition, engineers conducting the experiments have incorporated them into an international project known as Global Interoperability for Broadband Networks, sponsored by the G-7 leading economic nations.

However, while the systems may be compatible and inoperable with the indigenous infrastructure, the use of commercial satellite communications systems in foreign countries can involve additional approvals. For example, a common practice for a host nation is the approval of "landing rights" for the operation of any foreign-owned satellite terminals within the host nation's borders. These costs can include, but not limited to, leasing or acquiring ground, the purchasing or leasing VSATs, and fees for the use of the space segment. A primary concern of many host nations is the loss of revenue. Potential revenue could be lost if foreign-owned satellite terminals were used without payment in the form of a tariff. Since transmission systems of the host nation's ministry of Post, Telegraph, and Telephone (PTT) are bypassed whenever a satellite terminal is used, a license/approval fee to use satellite terminals is usually paid to the host nation's PTT ministry. During peace operations these approvals and fees generate delays and barriers during the initial entry phase when establishing the early communications network is vital.

2. Vulnerability

Commercial satellites are built to withstand the rigors of space but not to the degree of military satellites. Although some jam resistance is obtained through the use of spread spectrum techniques, commercial satellite systems lack the beam nulling and signal processing capabilities that give military systems such high jam resistance. If international communications were disrupted, the nation or organization conducting the jamming operation would risk the anger and ire of every nation effected. Additionally

there would be the possibility that the nation or individuals conducting the jamming would wipe out their own ability to communicate.

While satellite service providers typically guarantee 99.5 to 99.9 percent availability, solar interference, heavy storms, and equipment failures do affect operational availability. For example, during heavy rains, satellite signals degrade and cause service interruptions that typically last five or ten minutes. Equipment failures, though uncommon, can have a major impact on communication system subscribers. The vulnerability of commercial satellites was made evident by the failure of the PANAMSAT Galaxy IV satellite on 19 May 1998. The satellite lost proper attitude when both on-board computer systems inexplicably failed. The outage caused a huge wave of communications problems for many economic sectors in the U.S. including over 90 percent of U.S. pager customers. The loss of Galaxy IV literally affected millions of people. In 1994, energetic electrons were blamed for serious anomalies in three GEO commercial communications satellites: INTELSAT K, ANIK E-1, and ANIK E-2. All three suffered a loss of attitude control caused by electronic failures with computer circuitry. Although none suffered permanent damage, television, radio, and telephone services throughout Canada were affected for days.

3. Security

Currently most organizations, including NGO's, with sensitive data secure their transmissions end-to-end. However there is a push to have satellite service providers employ strong link encryption to prevent a satellite takeover and to protect critical network information. Winning approval from the U.S. government to use the strong encryption required has not be easy. One possible outcome is that U.S.-based constellations would launch with strong encryption used only within U.S. boundaries.

Under this scheme, broadband satellite providers would encrypt uplinks to satellites over the U.S., but downlinks to other nations would not be encrypted. In the past Motorola was able to gain permission to encrypt its Iridium wireless telephone traffic in China because it hired a well-known former National Security Council member to work for the company. This accomplishment demonstrates how the vagueness of

current encryption laws allows their implementation to become a matter of bureaucratic discretion. [Ref. 26]

GEO satellite system security will be further complicated due to the incompatibility of end-to-end security schemes like standards-base IPSec (IP Security) and the TCP spoofing required to bring GEO transmissions up to speed. Security experts indicate that IP spoofing and IPSec are incompatible because once a transmission is encrypted, it is impossible for an outside entity such as a satellite service provider to see into the packets to perform spoofing. This is also true when TCP is encapsulated in ATM.

Another security issue for broadband satellite providers lies in their widespread use of ATM. Link encryption is possible on ATM, however a standard for end-to-end cell-based encryption is still evolving.

4. Congestion

As satellite service providers begin the process of launching the hundreds of GEO, MEO, and LEO satellites required to make their networks functional, the potential for congestion (both for orbital slots and for bandwidth) is emanate. Each of the satellite networks will have duplicate gateway stations on earth. Each provider will also have to negotiate interfaces between its gateways and the public. The result will be enormous redundancy and the possibility of extensive interference among the various satellite and land-based systems.

5. Latency and Quality of Service

GEO satellites orbit 22,282 miles above the equator. At that height, GEO satellites travel at the same speed as the earth's rotation, thus appearing stationary. GEOs are excellent for multicasting, but produce unacceptable half-second delays in interactive voice and data communications. This latency is the source of the delay experienced in many intercontinental telephone calls. Since users are not willing to accept this annoyance, many of these systems are being phased out. Latency is noticeable in voice communications when the round-trip delay is greater than 100 to 200 msec.

In fact, the greater this delay becomes the lower the bandwidth the system is able to support. The severity of the delay is also dependent on the size of the buffers used to store transmitted data. Buffer sizes are typically determined by the transmission protocol. MEO satellites orbit between 6,000 and 12,000 miles above the earth. Signal delay times are significantly reduced as a result of their lower orbits in comparison to that of GEO. However, they do not remain stationary over the same spot, have a narrower field of view and are in view for only a couple of hours.

Originally, engineers thought that buffers would severely limit the bandwidth that would be possible in satellite ATM and TCP/IP networks. However, NASA demonstrated in 1997 that TCP/IP over satellite is capable of data rates of 622 Mbps. The team of engineers, working at NASA Lewis Research Center, has proposed TCP over satellite (TCPSAT) to fix the inherent flaws in the TCP protocol.

For GEO systems, solving the problems caused by long-delay transmission paths from their satellites, along with the performance of the TCP standard in that environment will be the priority. TCP uses an algorithm called "slow start" to make sure a new TCP transmission does not overload a path. This doubles the bandwidth used after each round trip through the network. The vast distances covered by GEO satellite links cause longer transmission delays because it takes more time for TCP to get up to speed.

When the round-trip is 500 msec or more, as in GEO systems, the communication session often times-out before the connection ever reaches the full bandwidth of the link. GEO satellite providers are attempting to solve this problem with a technique called "spoofing." Spoofing involves sending fake responses in order to keep the TCP session active and prevent timeouts. However, spoofing is not effective with interactive real-time applications.

For example, a typical client/server transaction such as updating a customer record from an SQL server across the country may take 20 round-trip transactions. This transaction over a fiber or LEO connection typically takes .75 to 1.5 seconds. Over a GEO network, the same transaction would take at least 10 seconds. Although both LEO and GEO networks may offer the same nominal bandwidth, the GEO communication

takes much longer because of the inefficiency many small transactions required by the high-delay GEO network.

On the other hand, LEO systems do not have a problem with transmission latency, but have to address the issue of matching the bit-error performance of currently deployed terrestrial network facilities. Matching land-based system quality is important since these performance expectations are an integral part of the design of common protocols such as TCP and ATM. LEO systems use small, low-powered satellites that transmit to remote computers that have little power themselves. This low transmitter power, combined with high data rates, increases the probability that data will be lost in transit.

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IV. IMPLICATIONS OF WIRELESS FOR PEACEKEEPING OPERATIONS

A. OVERVIEW

Having reviewed Chapters II and III concerning the basics of wireless and satellite communication, this chapter addresses some basic components that are be needed for a field scenario (ground), and the numerous capabilities this network requires. It also addresses the benefits and concerns for broadband satellites communication. Details of the components discussed in this chapter are provided in Chapter III as well.

B. COMPONENTS OF SYSTEM

1. Fundamental Concept

A satellite uses a radio frequency repeater, providing a relay station between a sender and receiver. Communications satellite systems are made up of; the earth segment, consisting of the equipment at the Hub and at the remote locations, and the space segment, the link to and from the satellite. To communicate via satellite, the sender first converts a signal (radio, TV, data, voice, video) into electronic form. This is transmitted or "up-linked" to the satellite using high powered amplifiers and antennas designed to direct the signal towards the satellite.

After traveling 36,000 km to the satellite, the transmitted signal is weak and needs to be amplified by a "transponder" located on the satellite. A transponder is a combination of a receiver, frequency converter and transmitter package. Once the signal has been amplified, and the frequency changed from the up-link frequency (to minimize interference with the up-link), the down-link is sent back to earth. Once the signal reaches the ground it is received by another antenna and amplified before being de-modulated and sent on to it's many destinations.

2. Use of VSAT (Very Small Aperture Terminals)

The most common data service used for broadband communication is VSAT (Chapter III pp. 34-37). Through the use of VSAT, satellite companies such as Hughes have released products such as 'Direct PC' allowing internet download to a single PC to occur at speeds starting at 400Kbps. This is achieved by sending search request (outgoing) packets over the conventional public switched network (dial-up modem, ISDN link, etc) and receiving all incoming data through the personal VSAT antenna. The VSAT antenna that is installed on the roof, is directly connected to the PC via an ISA card inserted into the mother board of the machine allowing download speeds of 400kbps to the machine. This method has the following advantages [Ref. 36]:

- Demonstrable increases in staff efficiency and company cost savings
- High speed transmission for greater use of pictures and video
- Reception of large files with unmatched speed and efficiency
- Direct reception from Internet and other major information databases
- No dedicated facilities such as T1 or ISDN are required to receive Internet information quickly and cost-effectively (assuming use of a dial up connection for sending packet requests)
- Use of the latest in High speed satellite technology
- Limited capital investment allowing individuals and small businesses access to satellite technology
- Windows based applications software provides efficient interface with TCP/IP packages and networks.
- The ISA adapter card can provide: 12Mbps Direct PC signal reception, Secure ASIC based DES decryption to prevent unauthorized access. 128k memory buffer and power to the antenna via coax cable. (Features of Direct PC)
- The antenna dish may vary in diameter and can be mounted in a variety of different positions and is grounded for lightning protection. The installation process is quick taking less then an hour. (AAP Communication Services brochure)

VSAT DAMA (Demand Assigned Multiple Access) networks provide on-demand toll-quality voice, Group III fax and voice-band data together with synchronous and asynchronous data services to remote locations via satellite. This technology maximizes the use of available space segment and ground-based resources, providing bandwidth on

demand. However, other access methods are available such as TDMA, SCPC, and CDMA which also use a star, mesh, and shared hug configuration. These topologies and access methods are used to distribute information throughout the network. An example of the transmission scheme can be viewed in Figure 4.1.

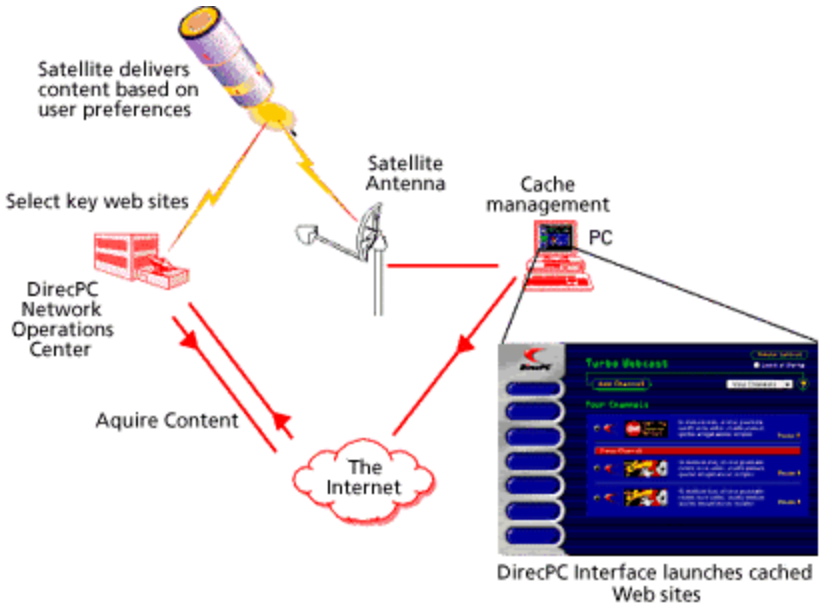

Figure 4.1. VSAT 'Direct PC' Diagram [From Ref. 44].

3. PES (Personal Earth Station) Send and Receive Capability

The PES Network consists of an outdoor component and an indoor component. The Outdoor Unit (ODU) is a small antenna with an antenna mounted radio frequency unit enabling transmission of signals from the remote site, and receiving of transmissions from the satellite (originating from a remote Earth Station). The function of the outdoor unit includes signal reception and down-conversion to intermediate frequencies and signal transmission and up-conversion to radio frequencies. The size of the antenna depends on the data rates required and the availability of satellite coverage. The second component of the PES network is the Digital Indoor Unit (DIU) which converts signals to and from base-band frequencies and provides interfaces to user equipment. Multiple protocols are supported enabling interfaces to a variety of data processing and computer equipment. Video is transported independently of data and voice. An example of this can be demonstrated in Figure 4.2 PSET Network.

The Personal Earth Station dishes allow for a limited ability to send data via the satellite dish also. However the rate at which these dishes can send information is limited depending on the dish size. A two meter dish can only send at 9600 bps, a good backup but inadequate for primary outgoing access if the site has a large amount of frequently hit content on its web server (such as that at SLQ). The dish size may vary according to the data transfer rate required and needed for an operation. The PES effectively supports data intensive applications and provides excellent response times for interactive applications. Capacity is allocated to sites on demand ensuring optimum response times. PES based satellite solutions suit a broad range of applications and requirements including:

- Wide Area Networking
- LAN Internetworking
- File/Batch Transfer
- Financial Transactions.
- Client/Server applications
- Internet/Intranet Access
- Video Conferencing
- Point-to-Point Trunks
- Telemetry Tracking and Control (TT&C)
- Domestic and International Connectivity
- Inventory Control and order management
- ATM operations
- Interactive applications
- Voice, Fax and Data networks
- Telemedicine
- Broadcast Video

Features:

- Advanced satellite access techniques that allocate capacity on demand optimally per session.
- Typical antenna sizes 1.0, 1.2, 1.8 meters.
- Allows for easy expansion of satellite network by adding remote sites or ports per site

- Multiple protocol options support a wide array of user terminal types concurrently
- Integrated LAN capability allowing efficient transmission over wide areas
- Durable equipment ensures continuous reliable operations

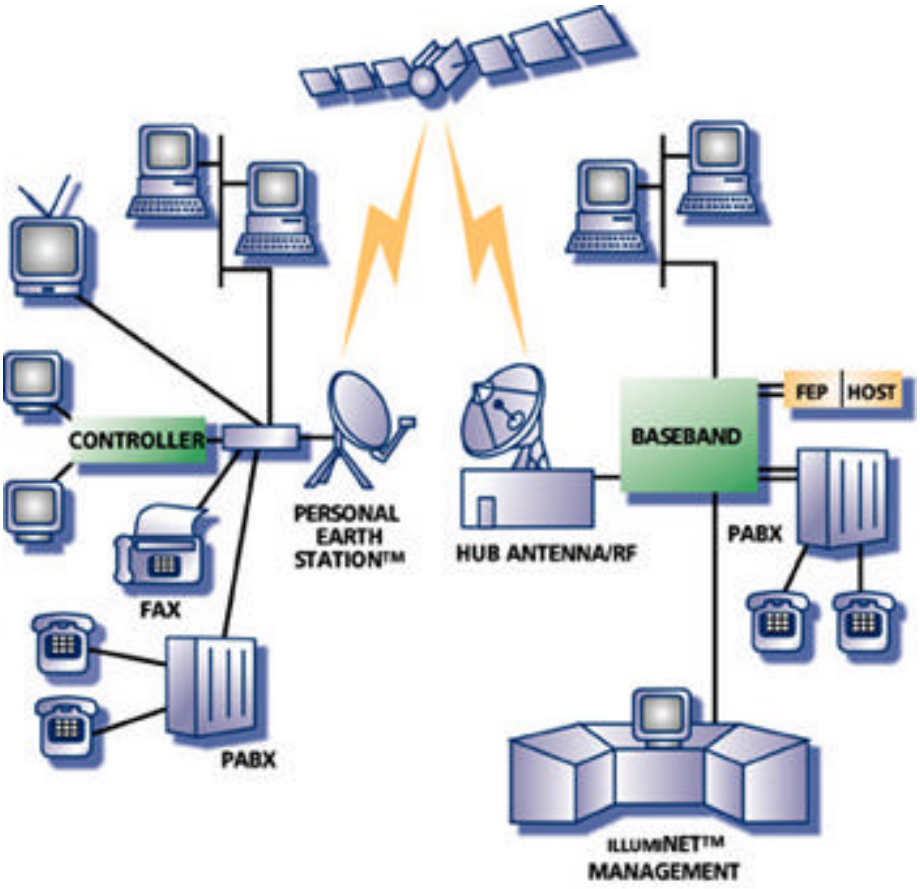

Figure 4.2. PSET Network [From Ref. 44].

Network management and monitoring operations are performed at the VSAT Control Center (VCC), which has primary responsibility for network tracking, statistics monitoring network configuration and overall control. All critical components are fully redundant and staffed 24 hours day. The guaranteed minimum network availability is around 99.5% and the MTBF of remote PES sites is around 40,000 hours. Satellite service providers offer use of their fully manned Shared Hub control centers for network management which provides a cost effective method of using this technology. At the shared hubs are very large earth station the incoming information from the public switched networks and permanent direct connections, are multiplexed and converted into

radio frequency and sent up to the satellites. [Ref. 44] A graphical representation of the entire network with VSAT can be seen in Figure 3.3 of Chapter III.

However it is important to note that a mix of both commercial and defense specific capabilities is advantageous because it remains responsive to DoD's continuing peacetime communications requirements while allowing for a surge in capacity to meet wartime needs. The results of the Commercial Satellite Communications Initiative studies demonstrate that DoD can benefit from an increased role for commercial SATCOM in support of a wide range Command, Control and Communication (C3) and intelligence missions. As a result, the Department has initiated an aggressive program to implement a commercial SATCOM program based on industry's recommendations and congressional direction. There are a number of new pilot projects (i.e. Intermediate Circular Orbit (ICO) narrow band, Teledesic wideband, and Global Broadcast System GBS; ITG model architecture) that will be implemented within the next two decades to effectively provide new commercial services for the Department. DoD has also issued a policy for the use of commercial SATCOM services which will guide the future.

C. BENEFITS AND CONCERNS OF BROADBAND SATELLITES

1. Benefits

One of the advantages besides providing global communications for satellites in GEO is the inexpensive cost associated with its development, implementation, and service. In comparison, Hughes can build a global system for a cost of $4 billion and deploy nearly 30 satellites while Teledesic cost will approximate to $9 billion for a constellation of nearly 300 satellites.

Another advantage of GEO technology is that the ground stations can be relatively simple because they must only target a fixed point in space. (However, tracking GEO satellites are relatively easy and could lead to a jamming or hacking attack by which an unauthorized adversary may pretend to be an authorized user and gain access to the network ultimately performing system sabotage.)

Mobility is also a key advantage and the main reasons why wireless came into existence. Signals are radiated into a free space environment and anyone can receive the signal in the broadcast area whether they are at a fixed location or in a mobile unit allowing users to receive information while performing mobile operations.

2. Concerns

There are several factors that must be considered concerning the usage of Geostationary Satellites with respect to peace keeping operations for the military and supporting agencies: interoperability, vulnerabilities, security, congestion, and latency. These factors are identified in Chapter III and their implications can prove disastrous to a mission due to the almost complete necessity for information for coordination and planning efforts. To serve as an example when PANAMSAT GALAXY 4 satellite spun out of control, it disrupted pager, TV, radio, and information connectivity dependent services for millions. The paging industry in particular was dependent on this single satellite for connectivity and it took days before users could obtain service. Eighty to Ninety percent of U.S. pagers were affected by this disruption and although the company PageNet had a back-up satellite, the transfer of service took time and adjustments to the paging network were done on a city-by-city basis. It must be noted that remote areas took the longest time to regain full service.

As a whole, the national security posture of the United States has become increasingly dependent on its information infrastructure and these infrastructures are vulnerable to tampering, exploitation, and catastrophic failures. The termination of satellite communications for a peace keeping mission can prove disastrous if the primary form of communication is dependent of a single satellite system. Back ups must always be in place and ready to transfer service within a timely manner. A key note to the GALAXY 4 satellite is that remote areas were the last to regain full service. This is critical when developing contingency plans for loss or termination of communication through Satellite technology.

3. Market Trends

Appendix A serves as a detailed view on the market trends, demands, and constraints on wireless technology that should be assessed when making an informed IT decision concerning satellites communications. In addition, the appendix focuses on limitations or restraints that may slow the acceleration of wireless and its rapid/innovative developments.

V. CONCLUSION

A. OVERVIEW

1. Research Question

The purpose of this research is to examine the extent to which wireless technology via satellite communications can be utilized for peacekeeping operations. The author addresses this question by providing background information on peacekeeping operations and the requirements for a stable, reliable, and robust mobile communications system. Chapters II, III, and IV provide review of the fundamentals of wireless and satellite communication:

- A fundamental overview of the concepts, key components, and system architecture associated with wireless and satellites
- The need for and limitations of wireless technology
- An examination of markets, trends, policies, regulations, and potential of wireless within the next decade
- A detailed view of several existing satellites and the segments (space, ground, control) associated with their operation.
- A discussion of broadband satellites (GEO) and how they can support the communications requirement of peacekeeping efforts in remote regions
- A description of developing satellites and their possible use with peace operations
- Fundamental requirements of wireless for a ground operation and the benefits and concerns associated with each
- An evaluation of the technology in terms of capabilities for peacekeeping operations

B. PROJECTION OF WIRELESS IN PEACE OPERATIONS

1. Evaluation of Technology

Existing wireless and satellite telecommunication systems are capable of providing the necessary forms of communication needed for any peacekeeping operation deployed in remote regions. Satellites provide the medium for information exchange that supports the use of developed technologies (i.e. cellular, wide area networks, internet, video teleconferencing, etc.) that are utilized extensively as a significant source of

communication for sharing information. Peacekeeping operations rely heavily on relaying information to the diverse composition of supporting agencies. The need to receive and send up to date and reliable data throughout this complex network is paramount. Wireless via satellite provides a solution.

It must be noted, however, that wireless technology via Satellite communication should always, when possible, be used in conjunction with wired infrastructures. The sole dependence on wireless or wired frameworks alone can be a limitation and is not recommended unless there is no other option. Although future communication paradigms such as "ITG" (ICO, Teledesic, GBS [Ref. 13]) propose the usage of three separate satellite technologies, it is essential that any information technology strategy investigate contingencies for communication failure and have an integrated plan that involves existing ground infrastructures as well. As history has demonstrated (Galaxy IV), reliance on one platform or avenue of communication can prove detrimental if qualified alternatives are not identified and implemented.

2. Market Trends

Appendix A is a study of the markets of wireless and their trends. The appendix is a review of wireless services and how they impact the wireless industry. It is to be used as a helpful tool when considering the selection and implementation of any wireless technology.

C. LIMITATIONS OF THESIS

This thesis provides overview of wireless and satellite technology. Although many fundamental concepts have been explained, the specifics concerning the technical aspects of those concepts were not reviewed in great detail. The thesis was written to provide information to an audience with limited background knowledge of wireless technology. It was not written as a technical study for wireless experts.

It is also important to note that the rapid innovations and dynamic changes in the wireless, satellite, and telecommunications industry may render topics in this research obsolete in following years to come. The speed of change in this field, especially

concerning policy and standards, and rapid interactions among all the elements in a wireless system, are complex and constantly evolving. Thus, developing any wireless system in the future should consider these constraints very carefully.

D. FOLLOW ON RESEARCH

Research in the wireless technology/telecommunication industry continues at a rapid pace when considering this alternative for peacekeeping operations. Areas that were not addressed in this research provide topics of future study:

- Wireless Access System. Common network elements should be able to provide virtually any desired future service combination between wired or wireless access links. The move from a wide range of market specific products towards common standardized flexible "platforms", which meet the basic needs of most major public, private, fixed and mobile markets around the world, should allow a much longer product life cycle for these "core" network and transmission components, and offer increased flexibility and cost effectiveness to network operators, service providers and manufacturers.
- International Mobile Telecommunication–2000 (IMT-2000). A Global "telephone system" evolved under the guidance of ITU Recommendations (voluntary standards) to provide the essential backbone for worldwide communications. The "globalization" trends in all forms of communications, business and even entertainment, requires global standards which have sufficient flexibility to meet local needs and to allow regional/national systems to evolve smoothly towards future global and integrated wired/wireless telecommunications. IMT-2000 system will provide access, by means of one or more radio links, to a wide range of telecommunication services supported by the fixed telecommunication networks (e.g. PSTN/ISDN), and to other services which are specific to mobile users.
- Intelligent Vehicle Transport System (IVTS). Two main wireless schemes in IVHS system have emerged: one is vehicle-to-vehicle link also known as IVC (inter-vehicle communication) and other roadside-vehicle-roadside link. Both these links serve complementary roles. Whereas vehicle-to-vehicle link is necessary to safety reasons towards accidents whereas roadside-to-vehicle link is necessary for broadcasting information useful to the drivers of the vehicle. This may be useful in when communicating with vehicles in nearby areas.
- Deployment of high power satellites with steerable narrow beams. The high power satellite with steerable narrow beams will facilitate usage of low power solid state receive amplifiers with small earth station antennas.

This will provide wide coverage of earth surface. The coverage of earth surface can be selected by beam steering arrangement while high power satellite facilitates usage of smaller antennas. The steerable multi-beam configuration reduces interference with other networks. However it results in small ground coverage areas, more powerful satellite launch vehicles and complicated on-board controls.

- Higher Frequency bands. With full exploitation of conventional C and extended C bands to meet increasing demands for fixed satellite service as also for line of sight radio systems, interference co-ordination has become very difficult. Use of higher frequency bands is inevitable to mitigate these problems

- Global Mobile Personal Communications by Satellite (GMPCS). Mobile cellular communications are growing worldwide at an exponential rate. However sparsely populated, remote and less developed areas may not be covered by cellular services for a long time. ITU has defined Global Mobile Personal Communication by Satellite (GMPCS) system as any satellite system (i.e. fixed or mobile, broadband or narrowband, global or regional, geostationary or non-geostationary, existing or planned) providing telecommunication services directly to end users from a constellation of satellites on a transnational, regional, or global basis. GMPCS user can make or receive calls using hand held, fixed and application specific terminals from anywhere, and at any time.

- High altitude platform station {Stratospheric system}. The payload of the stratospheric relay station consists of separate transmit and receive beam-forming phased-array antennas, separate transmit and receive dish antennas for feeder links with ground switching stations, and a very large bank of regenerative processors that handle receiving, frequency conversion, demodulation, decoding, data multiplexing, switching, encoding, modulating and transmitting functions. This may be ideal of peacekeeping operations of small geographical coverage due to the limited communication scope (60-75 square miles) of this technology.

APPENDIX A. MARKETS

In order to make an informed decision on any wireless IT strategy for peacekeeping operations, this appendix deals with a review and understanding of the markets and their trends. An approach that seems to make a great deal of common sense in terms of obtaining general background information and in establishing key market trends is called a demand assessment of the wireless telecommunications market. A demand assessment is the first step in trying to carry out an evaluation of strengths, weaknesses, opportunities, and threats. This chapter therefore presents an assessment for all major wireless services and applications in terms of the past, present, and future.

A. DEMAND

The continued growth and expansion of wireless services seems likely to continue across a wide spectrum. There are growing wireless markets for education and training activities, for health and medical services; for business, financial, and information activities; and for energy and transportation applications. Current trends also suggest ongoing growth associated with police work, criminal justice, human services, education, health care, and economic and social development. Less clear, however, is what might be the patterns related to military and peace-keeping operations. These areas may well exhibit more modest growth through the 21ST century. It seems significant that those sectors of both the United States and the global economy that are major users of information and telecommunications and that are oriented toward world trade and toward productivity gains are also the areas where perhaps the greatest growth can be anticipated regardless of whether wire or wireless services are concerned. In the past several decades the countries of the Organization of Economic Cooperation and Development (OECD) have moved toward service economies that have served to fuel all forms of telecommunications growth, including wireless. Meanwhile telecommunications growth within the "so-called" developing or industrializing countries of the world, supported in part by development grants and loans, has been even more rapid. Overall these gains in absolute terms have still closed the gap in a significant way for only the most advanced of the industrializing countries such as Singapore, Taiwan, Hong Kong, and South Korea.

Furthermore, these gains by developing countries have typically been in wire and cable systems as opposed to wireless. [Ref. 1]

In the past decade, overall telecommunications development grew about 6 percent per year in North America, 7 percent in Europe and Japan, and about 9 percent in the rest of the world. This statistic is misleading in that some of the industrializing countries grew at rates of 15 to 20 percent per annum while other developing countries with less resources were growing much more slowly. As of the end of 1994 all telecommunications services represent about $550 billion in annual revenues, and this level will likely rise to $1 trillion by the end of year 2001. This can be seen in Figure A.1.

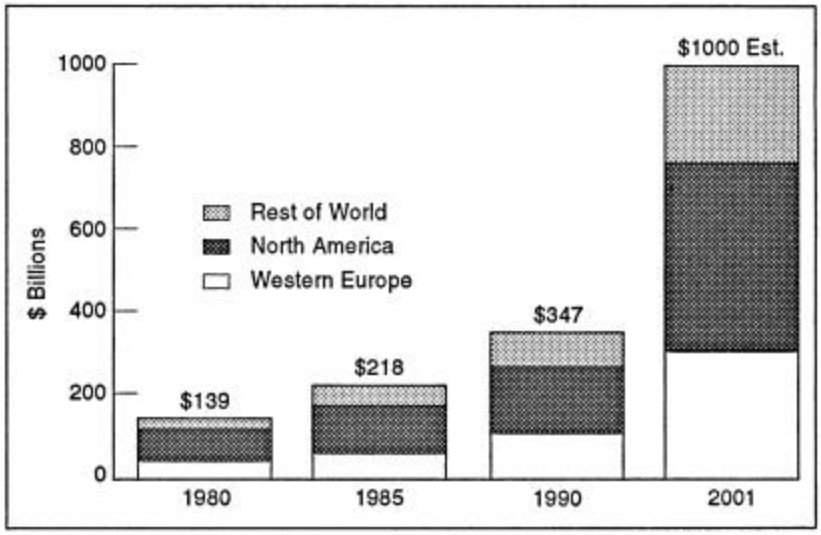

Figure A.1. Worldwide Revenues of Telecommunications (Estimated) [From Ref. 1].

Whether wire or wireless technology will drive the future of telecommunications has been the subject of a great deal of analysis and comment. In particular, at least two major viewpoints on what may happen over the next 20 to 30 years are provided in Figures A.2 and A.3

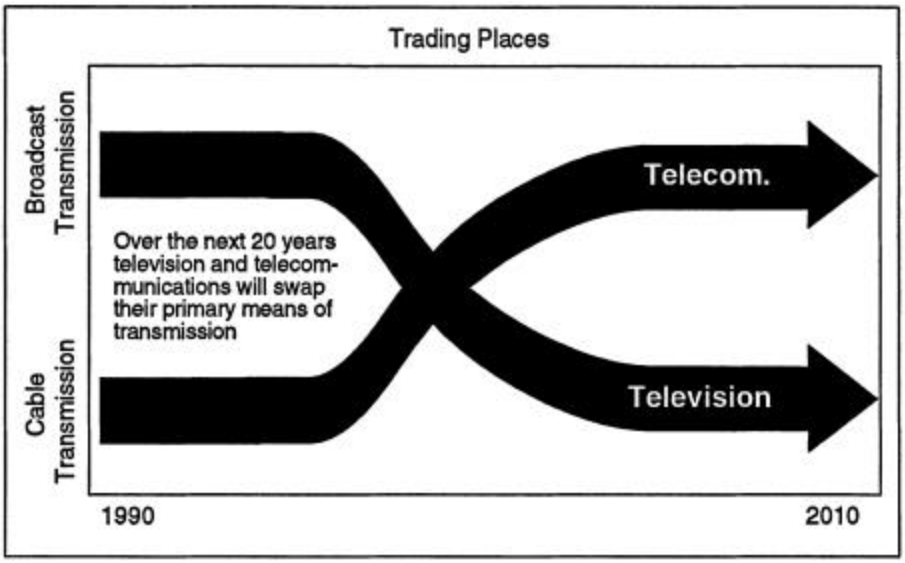

Figure A.2. The “Negroponte Flip” [From Ref. 10].

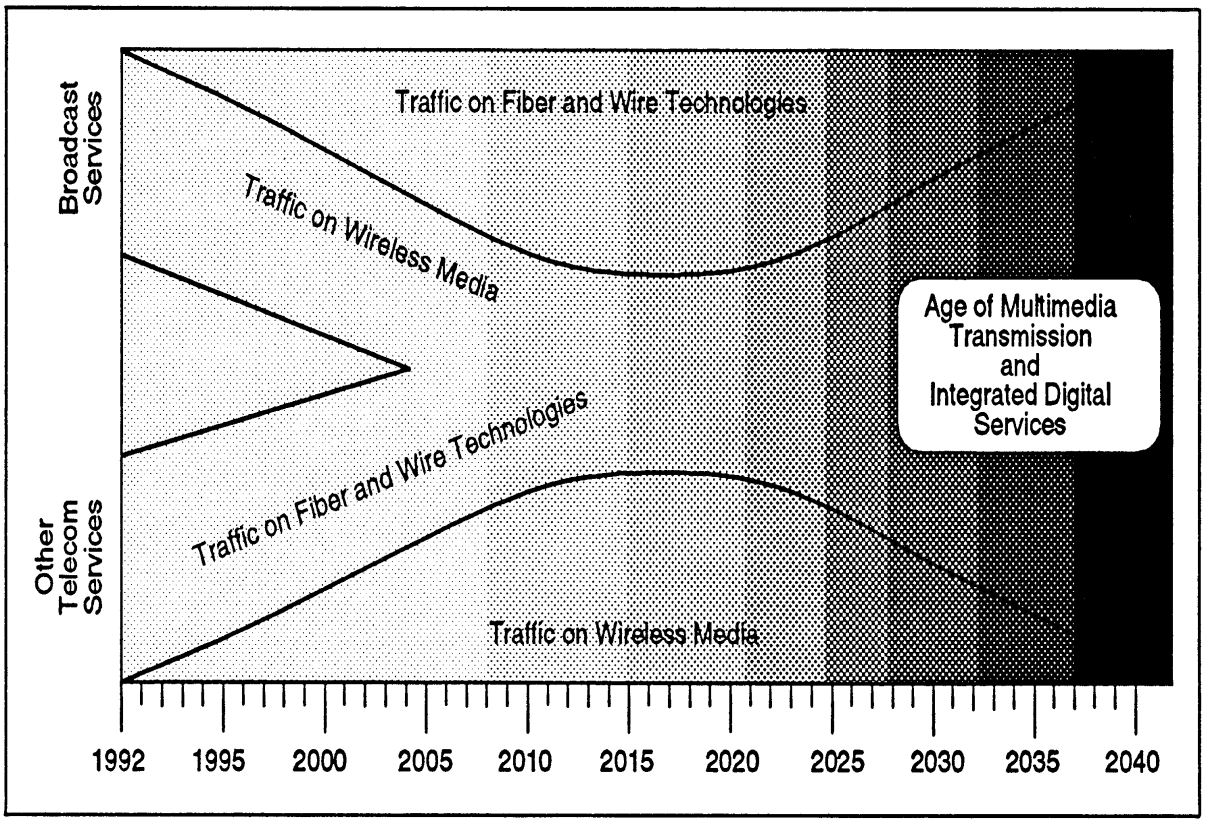

Figure A.3. The “Pelton Merge” [From Ref. 7].

These alternative views have been called the Negroponte Flip and the Pelton/Merge respectively. The viewpoint provided in the "so-called" Flip is that of a

sudden and rather radical shift of usage patterns with most current wire line services for voice and data links to the home and office being replaced by cellular and PCS connections within the next 15 years. It also predicts that most broadcasting services will switch during this same time frame from over-the-air broadcast to cable television or at least its twenty-first century equivalent. In many ways it suggests a major win for fiber optical loss of statements and major loss of satellite and over-the-air broadcast, and major gains for the new Enhanced Specialized Mobile Radio (ESMR), PCS, and digital cellular services. The Pelton Merge suggests, on the other hand, a less dramatic shift in the technology. This in turn suggests a more gradual change in customer-service profiles, in actual consumer and business applications, or in frequency reallocations. Thus, this conservative scenario predicts that there will be wins and losses for both wire and wireless technology, but that the real winner may well be "hybrid" wire and wireless systems that are integrated together. While some shifts can and will occur, the Pelton Merge suggests that "hybridization" will be a more likely result than a complete and tumultuous 15-year flip flop. The full-scale Negroponte Flip is not predicted to occur for the following reasons. [Refs. 1, 10, 41]

1. Economics

The radical flip-flop would require hundreds of billions if not trillions of dollars to be invested. Neither business nor regulators can reasonably agree to such rapid and massive level of investments. Further studies by advertising firms and consumer buying trends have not identified products or services with sufficient new value added to explain massive levels of new investment.

2. Sunk Investment and the Comfortable Status Quo

A tremendous amount of good and serviceable equipment, facilities, as well as key frequency allocations and licenses would need to be prematurely abandoned, transferred, or substantially modified.

3. Obsolete Technology Has a Way of Coming Back

Experimental systems have shown ways to send up to 100 megabits per second over copper wire via a method known as Asymmetrical Digital Subscriber Line (ADSL). The obsolete telephone wire to the home may still prove capable of providing multiple television channels and video on demand. The new low earth orbit satellites, for instance, may create a new high-performance low latency telecommunications service that proves to be highly attractive. (To the extent telephone companies seriously enter the cable television market, this becomes particularly relevant.) DBS service such as DirecTV gives great promise of success.

In any event, the future of telecommunications seems likely to be driven by the merger, overlap, and restructuring of the five C's [Ref. 11], industries as represented by communications, cable television, computers, content, and consumer electronics. In doing so we may, in particular, anticipate that telephone companies, cable television industries, and broadcasters beginning to merge. We shall investigate an old projection that was taken in 1994 to examine the predictability of certain markets and to assess reason for current trends that are existing today. A breakdown of key services in the wireless telecommunications field is provided in Tables A.1 and A.2.

Service Description	Net New Households Change		% Annual Growth	
	Low	High	Low	High
1. DBS Service	7 M	20M	12%	25%
2. PCS/Cellular (Subscribers)	17M	32M	18%	30%
3. Wire-Based Telephone	-4M	3M	-2%	2%
4. Cable Television/Wireless Cable	5M	7M	3%	5%
5. Integrated Cable TV/Telephone Service	4M	5M	7%	10%
6. UHF/VHF TV Over-the-Air	-15M	-25M	-12%	-20%
7. Mobile Cellular Satellite Service (1997=20000 only)	2M	3M	10%	13%
8. Wireless LAN's/Wireless PABX's	2M (Offices)	3M (Offices)	8%	12%
Note: Figures are based on user numbers rather than revenues and dollars to reduce the impact of different tariffing concepts and inflation.				

Table A.1. High and Low Forecast-Basic Shifts in the U.S. Telecommunications Service Mix. (Net Estimate Gains or Losses by Household 1994 -2000) [From Ref. 1].

Service Description	Net New Households Change		% Annual Growth	
	Low	High	Low	High
1. DBS Service	15M	25M	10%	15%
2. PCS/Cellular (Subscribers)	35M	45M	15%	21%
3. Wire-Based Telephone	8M	12M	2%	3%
4. Cable Television/Wireless Cable	11M	16M	4%	7%
5. Integrated Cable TV/Telephone Service	9M	15M	10%	15%
6. UHF/VHF TV Over-the-Air	-20M	-32M	-10%	-12%
7. Mobile Cellular Satellite Service (1997=20000 only)	4M	6M	10%	13%
8. Wireless LAN's/Wireless PABX's	3M (Offices)	4M (Offices)	7%	10%
Note: The countries of the OECD include the United States, Canada, Japan, Australia, New Zealand, and all Western Europe.				

Table A.2. High and Low Forecast – Basic Shift in OECD, Telecommunications Service Mix (Net Estimated Gains or Losses by Household Through 2000) [From Ref. 1].

This chart combines the estimates of some 20 experts for both the United States and the OECD countries. It does not cover the developing countries since the trend lines, particularly for wireless services, are not necessarily parallel. In the developing world today there is, in fact, rapid growth in telecommunications, but this does not yet translate into rapid growth of wireless systems. In the developing societies during the 1980s and early 1990s, there was limited investment in terrestrial wireless service. Radio based services in these countries were largely focused on domestic, regional, and international satellite and some radio and television broadcasting systems. [Ref. 11]

Global trends for overall telecommunications and information technology development are well established and documented by a wide range of statistical data. The likely increase of all forms of telecommunications and information technology is really not in doubt. In general, telecommunications has expanded more than twice as fast as the overall global economy, while wireless services have expanded more than three times as fast, especially within OECD countries. The more difficult issue is whether wire or wireless technology will win out over the other. Will one of the basic types of technology or some important new applications become predominant in the telecommunications field? Alternatively, will some form of dynamic balance be achieved

so that rapid parallel growth somehow is achieved? Finally there are questions as to whether certain specific services and applications will become predominantly wire or wireless in the future.

The overall field of telecommunications and especially mobile telecommunications is thus beset by many forces of change both from within and without. Today the primary forces of change can be thought of as being driven by at least six key factors. These are:

- Convergence
- Globalization
- Technological advances
- New forms of competition
- Changing demand patterns and markets
- Deregulation and liberalization

As this process of convergence occurs, then the "Pelton Merge" of "wire" and "wireless" technology into hybrid systems could well be expected to accelerate [Ref. 7]. What is perhaps most significant is that these major and perhaps optimistic changes still do not reflect the idea of a sudden and dramatic "flip-flop" in terms of the overall structure and revenue profile of the telecommunications industry. This observation applies to both the United States results as well as the projections for the countries of the OECD as well.

An additional key observation is that the largest increase, namely in the area of PCS must also be considered the most uncertain. This is because it is in this area where the most unknowns also now exist. This includes a lack of clarity with regard to standards nature of the service, market demand, technical solutions, and charging structure.

These projections indicate rapid growth of most segments of the wireless market. This suggests there is little in the hybridization trends to slow the spread of wire cable, or free-space communications. In fact this may result in mutual stimuli as they facilitate the needs and demands of a diverse customer base.

This examples of the U.S. and the OECD telecommunications market as reflected in Tables A.1 and A.2 contains an implicit assumption that there will indeed be major

shifts in services. These projections were apparently correct because we have witnessed the shift today. Even so, the tables were is very much within the context of current growth trends for wire and wireless technology. It also assumes wire telephone services will begin transferring to cable television connections to the home as we see today with AT&T. But the accuracy of it to some degree is quite amazing. Based on the above projections in 1994, it is still difficult to project within the various constraints noted that there might be more than a 25 percent shift from today's mix of services within the next decade as opposed to a complete or nearly total flip-flop. Studies conducted by the Center for Telecommunications Management (CTM) and the International Engineering Consortium (IEC) of telecommunications market trends have generally shown similar results in terms of growth rates and swings in wire-and wireless-related service demands. [Ref. 8]

To seek to analyze the implications of this macro level scenario in greater depth, the projections shown in Tables 5 and 6 were developed on an application by application basis. After these figures were developed, high and low estimates for the overall marketplace were also derived by setting the high and low standard deviation from the median response over two rounds of surveys among U.S. and international experts.

Thus, the forecast figures in Tables A.1 and A.2 were developed in the first half of 1994 by compiling the survey results provided by 20 telecommunications experts drawn from carriers, vendors, and users. There is no particular "magic" in these predictions nor is there any reason to believe that actual growth or decline in the market will even be within the high or low limits that this survey produced. The more interesting result is that regardless of whether one accepts the high or low forecasts, the market shifts are in no way like the radical transformations that the Negroponte Flip might predict. These survey results thus seem to reflect what might be called a "reality filter" that factors in market, economic, regulatory, and societal conditions. [Ref. 1]

B. MARKET FACTORS THAT WILL SERVE AS A BRAKE ON RAPID SHIFTS IN THE FIELD OF TELECOMMUNICATIONS

There are at least seven real world factors that would seem to inhibit or delay the longer term trend toward "wire to wireless" transformation and vice versa. These key factors as identified in the survey process are as follows. [Ref. 8]

1. Need for New Frequency Allocations for Digital Cellular and PCS

There are currently new frequencies being assigned to enhanced mobile communications. Likewise, improved frequency reuse techniques are being developed and better digital compression systems are being rapidly implemented. Nevertheless, currently available frequencies could at best support a fraction of the demand if digital cellular was to become the primary telecommunications means for all users in the United States or in the OECD countries. This is essentially true if PCS is implemented with larger cell sizes than the originally conceived micro-cells. This seems by far the most likely assumption.

2. Vested Frequency Allocations for Radio, Television, Military Systems

No one with sunk investment, an established customer base, and wide spread user equipment in an established market readily surrenders it. The military establishment and over the-air broadcasters who now control much of the most interesting spectrum will not give up their assigned frequencies without a fight and some reasonable compensation. There may well be longer-term strategies for migration from lower to higher frequencies or from wireless to wired technology, but this would likely involve ten to twenty year transitions, and not three to five. As in the case of the 28-GHz services or higher, there is strong opposition to the frequency reallocations from satellite users and others.

3. Consumer Acceptance Rates

With most new products and services, there is usually a period of experimentation with the adventurous testing the new offerings. This is often followed by the first of the mainstream consumers, and eventually a bridge is found between the innovators and the mass market. After a base of perhaps ten percent is reached, the true mass marketing

profile comes into play. In the area of new telecommunications products and services, precursor markets are important. Nevertheless consumers are cautious and "overnight" acceptance of new products and services simply does not happen. In telecommunications services as in most market patterns a bell curve effect is usually seen.

4. System Availability and Security

There are several key factors to bear in mind with regard to such issues. They are as follows:

- Wireless communication, because it relies on free space rather than a physical conduit has an increased opportunity to survive a disaster. This is especially true of floods, fires, earthquakes, volcanoes, tornadoes, and hurricanes.
- Security is a much more complicated matter. Digitally encrypted systems are probably well secured regardless of the transmission media. (Some feel that fiber is much more secure than free-space radio transmission, but the fact is fiber can also be intercepted in at least six different ways. Radio obviously can be most easily intercepted but then there is no false sense of security engendered, unlike in the case of fiber.) Meanwhile, public concerns about protection of their privacy is at an all time high. Surveys conducted as of mid year 1993 show that 83 percent of those surveyed were concerned about their personal privacy and 53 percent were very concerned. Comparable figures for 1978, some 15 years earlier, showed those with concerns at 64 percent and those who were very concerned at 31 percent.
- The tandem use of fiber and wireless technology is among the best ways now available to ensure redundancy and back up of telecommunications facilities, and as such wire and -wireless" redundancy or "hybridization" could be helpful in ensuring high system availability levels.
- National policy and regulatory guidelines to ensure effective backup and restorability of telecommunications services for both public and military purposes have been developed by the U.S. Department of Defense, the National Telecommunications and Information Administration, and a high-level U.S. industrial panel. These, however, need to be strengthened and kept constantly up to date. In the age of the information highway this will become even more critical.

C. WORLDWIDE MARKET ASSESSMENT OF WIRELESS TELECOMMUNICATIONS

The wireless telecommunications market is really in no way monolithic and, in fact, it is divided into many discrete sub-markets. Despite this segmentation, there are certain key macro-issues that characterize the global trends with regard to wireless communications.

The world of telecommunications is becoming increasingly more international and interconnected. In spite of this very definite globalization process, however, there is no uniformity of practices in this field around the world. Today there are major inconsistencies in the allocation and use of frequencies for wireless communications and significant differences with regard to the standards that are in use. Frequencies used for television and mobile communications are still used for long-distance HF and VHP communications in the so-called developing world. On a worldwide basis Global System for Mobile (GSM) has won broad acceptance as a digital cellular service. This GSM standard uses Time Division Multiple Access to provide service throughout Europe and many parts of Asia. It is now established as an efficient and reliable service that can serve both vehicular and pedestrian modes of traffic.

In North America, however, there are a number of options that include Specialized Mobile Radio, analog mobile phone service (AMPS) which is becoming rapidly obsolete, and digitally based systems. Some several years ago, the Joint Technical Committee adopted multiple PCS standards that include both TDMA and CDMA systems. As has occurred many times in the past, there is a clear prospect that the world wireless market will be divided by different standards. These standards primarily differ on the basis of frequency allocations, modulation, encoding and multiplexing methods, and operating systems. In the past, such divisions might have implied that local or regional manufacturers of equipment had promoted the difference in standards in the hope of becoming or remaining market dominant in their area. [Ref. 4]

World-class manufacturers with global trading patterns are adept at manufacturing, marketing, distributing, and servicing equipment and products engineered to local or regional standards. Many now manufacture devices that at the click of a switch

can convert from one regional standard to another. In short, telecommunications standards, although they vary in different regions of the world, are today much less of a trade obstacle. For decades the non-tariff barrier was almost as large a barrier as tariffs and duties, but because of the increased technical agility and flexibility of manufacturers and changing regulatory contexts, this is now much less true.

Further, with the new General Agreements on Tariffs and Trades (GATT) agreements that entered into effect in 1995 along with the creation of the new World Trade Organization, this trend toward reduced restrictions on global trade is likely to continue and perhaps even improve. One of the areas that has been almost totally opened to competitive international trade is that of information technology and telecommunications. Although some restrictions on defense-related technologies remain in effect, these too are being reduced. The total global level of trade in telecommunications services is as of the end of 1994 approximately $550 billion and is expected to grow to $1 trillion by the end of year 2001. Of these amounts almost one-third represents global trade. Further, the trade balances between and among Europe/Japan, and North America in the telecommunications equipment and service sectors are close to being equal certainly much more so than in most other critical trade categories. Thus the telecommunications field represents a very large market well suited for active competition and not beset by protectionist concerns.

Nevertheless, this field does represent some complex trade issues, in particular, Japanese restrictions in allowing free and open access to their markets for cellular telecommunications devices have been the explicit cause of a trading crisis. Formal complaints filed by the Motorola Corporation to this effect stimulated one of the most protracted disputes of the 1990s between the United States and Japan.

D. KEY MARKET TRENDS

In coming years, wireless technology and applications will likely continue to develop vigorously. In this process there will likely be a pattern of overlap/merger, and hybridization, so that the strengths and weaknesses of wire and wireless transmission systems can and indeed probably will complement each other. In projecting future market

trends, it is important to start with some well-documented guidelines. First of all, there is a historically documented pattern of telecommunications development wherein revenues for telecommunications services in general, and for wireless technology, in particular, they tend to range from 40 to 65 percent of invested capital. Most typically, revenues for wireless services can be expected to remain closer to the 65 percent end of range for gross invested capital. This pattern generally seems to hold true even in what might be called periods of technological discontinuities or major transitions.

Even the start of cellular radiotelephone and the beginning of personal communications service do not greatly distort the 40 percent rule, probably for two reasons. New technologies and applications at the outset represent a small percentage of the total revenues or investment. Further, there is significant "smoothing" of investment by using longer-term financing arrangements to eliminate heavy spikes of investment. Other key rules of thumb for the telecommunications industry, within the United States at least, is that sales per employee often range between $150,000 and $230,000 per year, while profits per employee per year would often fall between $10,000 and $18,000. [Ref. 1]

Pay as you go financing is thus often used in well-established telecommunications services because of the strong revenue stream. In new services or technologies, however, even if there is a large revenue stream there is still typically a need for much more intensive capital financing. This relationship between capital financing, service growth, and rates of innovation are crucial to understanding today's telecommunications world. In the past, telecommunications operated under an environment of rate base regulation. Investments accepted into the rate base were men used to establish how much profit could be earned. These capital investments were often financed over 15 to 20 years, and the process, in effect, ensured the long-term profitability of the telecommunications operators. But in today's fast-paced world of digital technology, with rapid innovation and short half-lives for equipment and software, the period of amortization is much more reasonably three to seven years in length. New enterprises coming out of a background of me computer industry are often much better able to adapt to this environment than those mat have evolved from the monopoly telecommunications background.

Another key market trend is that related to the latest management techniques and modem management information systems. It is sometimes assumed that market success and especially market dominance is based on superior technology. In today's global markets with large corporations funding sophisticated R&D programs, complex standards-making operations, and a myriad of start-up venture capital firms often developing new leading edge technology, it is increasingly difficult to dominate telecommunications markets. This can today seldom be done through technology alone. The key is, more often than not, innovative management and marketing rather than simply having the best technology. The most successful telecommunications corporations are usually those mat are best at identifying the market, the customer, and especially the customer's wants and needs.

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