SATELLITE COMMUNICATIONS

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Summary

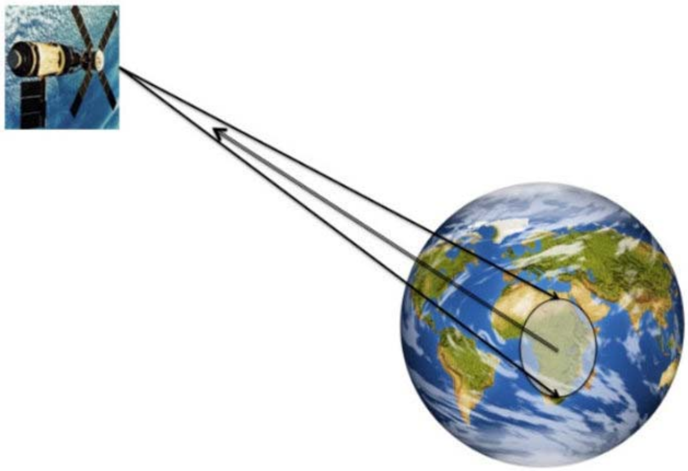
Recent developments in the area of satellite communications are making low cost data transmission and television broadcasting possible to sparsely populated areas spread over a large geographical region. One of the key enablers of this technology is modern digital communication. In this chapter, we present an overview of the digital communication technologies behind the communication link between a satellite orbiting in space and an earth station. The description is introductory and meant for a general

audience.

1. Introduction

The area of space science has for a long time had its original creative ideas drawn from the realms of science fiction. Many accomplishments of space science such as landing a man on the moon definitely sound like fiction coming true. One such accomplishment is communication using satellites in space, commonly called satellite communications. The original idea of using satellites for telecommunications is credited to Arthur C. Clarke's article “Extra Terrestrial Relays” that appeared in the magazine *Wireless World* in October 1945. Clarke had described a scenario where satellites in space are used for beaming television programs into homes. Today, the satellite television broadcast industry is a reality that is probably worth trillions of dollars. With the proliferation of direct-to-home television systems, satellites can communicate to individual homes through small dishes!

The technology behind this reality involves a wide range of areas from space shuttles and launch vehicles to microwave antennas and microelectronics. A complete study of a satellite communication system is a daunting exercise today. Even leaving the “rocket science” out of consideration, the telecommunications aspects of the technology are impressive in their own right. A satellite used for telecommunications typically is about 36,000 kilometers high up above the earth – this is roughly the distance covered if one were to drive in a large circle round the earth's equator. Signals sent from a broadcasting television station on earth are received by the satellite, which retransmits the signal to a section of the earth as shown in the picture below.



Picture 1. Depicting region covered by a satellite.

The fact that the signal after traveling such a long distance can still result in a clear picture on our television screens is nothing short of a wonder of modern telecommunication engineering.

The picture above illustrates another important feature of satellite communication systems that has no equal among terrestrial communication systems. A satellite-based system can communicate simultaneously to a geographically wide area in an efficient and cost-effective manner in spite of the high initial investment involved in building and launching a satellite. In particular, rural communities spread out over a large area stand to benefit greatly from satellite communication systems. The benefits are not limited merely to television broadcast. Today, it is possible to deliver other services such as internet connectivity using satellite communication systems to rural communities. Services such as the Global Positioning System (GPS) use a number of satellites to reach literally every corner of the globe. Remote sensing applications using satellites have resulted in great progress towards digital maps, accurate weather forecasting and developments in agriculture and deep sea fishing.

Another fascinating area involving satellites is the exploration of our universe. Exploration satellites sent towards other planets and generally into space send back detailed pictures of parts of our universe that have proved to be useful to astronomers, physicists and space scientists alike. The search for extra-terrestrial intelligence has inspired many generations to explore space and study space science. The photographs captured by the satellite far away in space need to be transmitted to an earth station. The telecommunications challenge involved in this transmission is staggering to say the least. The distances involved are well and truly astronomical. The clarity and impact of the many pictures released by NASA (www.nasa.gov) periodically illustrate the impressive achievement of the telecommunication systems in exploration satellites.

In this article, we aim to provide an overview of the various telecommunications technologies involved in a point-to-point link between an earth station and a satellite. The emphasis is mainly on the *digital communication* technologies that have played a vital role in making satellite communications feasible today. We begin with a brief overview of contemporary satellite communication systems along with their various components and technical features in Section 2. In the later sections, we present a detailed overview of the various digital communication technologies beginning with *source coding* in Section 3. This is continued in Sections 4 and 5 that look at *modulation* and *error correction*, respectively. The ideas discussed in Sections 3, 4 and 5 are used in Section 6 to determine *link budgets* for satellite links. In Section 7, we comment on the future direction of satellite communication systems and technologies. We conclude with some remarks in Section 8. The writing in this article is meant for a general audience and does not assume an engineering background.

2. Overview of Satellite Communication Systems

The era of satellite communications began with the launch of the Sputniks in the late 50s by the erstwhile USSR. This was followed by the launch of satellites such as TELSTAR, RELAY and SYNCOM by the USA. In 1965, the American Communications Satellite Corporation (COMSAT) launched the first 24-hour geo-synchronous satellite called EARLY BIRD marking the arrival of global satellite communications. The International Telecommunications Satellite Organization (ITSO) (previously known as INTELSAT) is an intergovernmental umbrella organization with close to 150 member countries that oversees the operation of today's global satellite communication system (www.itso.int). Through Intelsat Ltd. (www.intelsat.com), ITSO oversees the maintenance and operation of its system comprising of more than 50 satellites today.

As stated in the introduction, this article's focus will be the communication link between an earth station and a satellite in space. We will attempt to understand the issues and challenges faced by the designer of such a communication link. The link from the earth station to the satellite is called uplink, and the link in the reverse direction is called downlink. To understand the link, we need to briefly review some important technical features of the satellite. The first feature is the orbit of the satellite.

2.1. Satellite Orbits

Orbits are the circular paths around the earth taken by the satellites in space. The height of the satellite above the earth determines the nature of the orbit. From a link designer's perspective, the height of the orbit is significant as it determines the power required for transmission from the earth station and from the satellite. There are three main types of orbits.

- Low Earth Orbit (LEO) at a height of about 800 kilometers.
- Medium Earth Orbit (MEO) at a height of about 10,000 kilometers
- Geostationary Earth Orbit (GEO) at a height of about 36,000 kilometers

Two other types of orbits are the intermediate circular orbit (ICO) and the highly inclined elliptical orbit (HEO).

The type of orbit determines the type of service and coverage provided by the satellite. The orbit of the satellite determines the delay involved in the communication process. The signal travels from the transmitting earth station to the satellite, and gets retransmitted back to a receiving earth station. Though the signals travel at the speed of light, the time taken is significant because of the large altitudes. The larger the altitude of the satellite, the larger is the delay in reception. In practice, telephone users notice a large and uncomfortable delay in calls routed through GEO satellites, while a LEO satellite causes an acceptably small delay. Hence, GEO satellites are ideal for applications such as television broadcast.

Another factor affected by the orbit is ground coverage. The coverage is maximum for GEO satellites at the highest altitude. For LEO and MEO satellites, coverage is limited. Hence, many satellites are needed for covering large geographical areas resulting in high costs. Moreover, the LEO and MEO satellites constantly move relative to a point on the earth's surface. However, an advantage of LEO satellites is that smaller and mobile handsets can be used at the earth station for communicating with the satellites since they are relatively closer to earth. One example of a large LEO satellite system is the *Iridium* network. A network of 66 satellites at an altitude of 785 kilometers that cover the entire globe. The Iridium satellite network provides satellite phone services for the US military worldwide. Mobile services for maritime communications, mining and exploratory requirements, aviation, transportation and construction industries, and personal communications are currently being provided by various satellite systems such as Inmarsat, Japan's NSTAR, United States' AMSC, Canada's MSAT and Australia's MobiSat.

A GEO satellite, at a height of about 36,000 kilometers directly above the equator, appears stationary with respect to a point on the earth. The stationarity of GEO satellites is a result of a careful application of Kepler's laws of planetary motion and Newton's laws of gravitational force. Because of their stationarity, GEO satellites are ideal for television broadcast as they do not require continuous tracking of the satellite. In addition, more than one-third of the earth can be covered by one GEO satellite at an altitude of about 36,000 kilometers. This results in excellent coverage of a large geographical area. Three GEO satellites can reach almost all of inhabited earth. However, the earth stations for transmission and reception are larger and need to be more powerful. The number of GEO satellites has been estimated to be between 300 to 600, resulting in a crowding of the GEO orbit. The crowding could result in interference (crosstalk) between the transmissions of different GEO satellites. To reduce interference, the satellites typically use different frequency bands of operation.

2.2. Frequency Bands

The next feature of satellite communications is the frequency band in which the satellite operates. Satellites use the band of radio frequencies in the range 1 GHz to 50 GHz. This is split into the following bands for various types of services.

- L BAND 1-2 GHz (Mobile Services)
- S BAND 2.5-4 GHz (Mobile Services)
- C BAND 3.7-8 GHz (Fixed Services)
- X BAND 7.25-12 GHz (Military)
- Ku BAND 12-18 GHz (Fixed Services)
- Ka BAND 18-30.4 GHz (Fixed Services)
- V BAND 37.5-50.2 GHz (Fixed Services)

Depending on the band, the characteristics of the *antennas* in the satellites and the earth stations will be different. Though this affects the communication link directly, we will not discuss the details of antenna characteristics. The band of operation also determines the level of sensitivity of the link to interference such as rain. The allotment of bands to different types of services is not very strict as various services are typically offered in every band today.

2.3. Multiple Access

Another aspect of the satellite communication system that affects the design of a link is the type of *multiple access* used by various earth stations communicating simultaneously through the satellite. Three popular methods are time-division multiple access (TDMA), frequency-division multiple access (FDMA) and code-division multiple access (CDMA). Some composite and hybrid techniques that employ more than one of the above methods are also used in some satellite systems. We will not go into the details of this important concept of satellite communications in this article.

The type of multiple access determines the amount of interference or crosstalk seen in a communication link between an earth station and the satellite. The crosstalk is from neighboring earth stations that could be communicating using the same or adjacent frequency bands at the same time. The design of the communication link should be robust against interference because of multiple access.

2.4. Bent-pipe versus Regenerative Satellites

A satellite link connects an earth station at one end to a system called a *payload* on board the satellite. Traditionally, satellites have acted like bent-pipe repeaters – the payload simply turned the signal around, amplified and retransmitted the signal towards the earth. In modern *regenerative* satellites, the signal is first decoded at the satellite using *onboard processing*; then, the signal is re-encoded and transmitted back towards the recipient earth station. Bent-pipe satellites are less complex than regenerative satellites. However, regenerative satellites are preferred as they can be made to use bandwidth resources more optimally by the addition of routing and switching operations.

Clearly, the design of the communication link will have to be different for bent-pipe and regenerative satellites.

2.5. Other Subsystems

In addition, a satellite contains other subsystems such as altitude and orbit control subsystems, power subsystems and tracking and command subsystems besides the communication payload. The effect of the other subsystems on the design of the communication subsystem will not be dealt with in detail in this article.

3. Source Codes – Coding Messages into Bits

Beginning with this section, we will discuss the main building blocks of a modern digital communication link. Claude Shannon, considered by many to be the father of modern digital communication, defines communication as follows:

> "*The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point.*"

In the earliest times, the messages to be communicated were very simple – either a war was won or lost, a king had died or survived. One recalls the earliest system of towers built by the Romans and Greeks to convey such messages over long distances. In such contexts, Shannon's general definition of communication appears to be obviously true. However, are all messages so simple? Can all communication be reduced to a matter of reproducing a selected message?

At first glance, the simplest means of communication such as letter-writing in one's language appears to contradict Shannon. Is one really selecting one of many possible messages when writing a letter? Of course, Shannon is correct, and the key to understanding his definition is to disassociate the *meaning* of the communication from the means. To quote Shannon again,

> "*Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one selected from a set of possible messages.*"

To settle the letter-writing issue, let us try to form a set of all possible letters that can ever be written. Once we make such a set, letter writing does become selecting a message from a set. How does one form such a set? The trick is to see letters as a sequence of characters from the alphabet of a language. Since each character comes from a finite alphabet set (for instance the 26 element alphabet set plus the punctuations and blank space in the English language), the letters themselves come from a set of all possible sequences of characters. Of course, such a set of all sequences of alphabets will include completely *meaningless* letters, but that is irrelevant to the communication problem!

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Biographical sketch

Andrew Thangaraj obtained a B.Tech. in Electrical Engineering from the Indian Institute of Technology, Madras in 1998 and a Ph.D. from Georgia Institute of Technology (USA) in 2003. His doctoral work was in the areas of error control coding and information theory including specific topics such as quantum error-correcting codes, coding for magnetic recording, LDPC codes and iterative decoding methods. He was then a post-doctoral research associate at Georgia Tech Lorraine in Metz (France) for 1 year. His post-doctoral research was concerned with coding for the wire tap channel with applications to Quantum Key Distribution. Since June 2004, he has been an Assistant Professor with the Department of Electrical Engineering at the Indian Institute of Technology, Madras (IITM). He is part of the Telecommunications and Networking (TeNet) group at IITM and currently advises 2 Doctoral students, 2 Masters students and several undergraduate students.