Issues and Trends in Satellite Telecommunications

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***Abstract*—In this paper we will discuss a bit about satellite telecommunications. A brief introduction and history of satellite telecommunications will be presented. Then a discussion of certain prevalent satellite orbit types will be given, because this is relevant to understanding how certain satellite applications are employed. Various areas of ongoing research in the field of satellite telecommunications, to include bandwidth allocation, satellite constellation design for remote parts of the world, and power generation, among others will be discussed.**

Keywords—satellite communications; telecommunications; satellite orbit types; bandwidth allocation; constellation design; power generation

I. Introduction

It goes without saying that satellites have broad and far reaching applications in many areas. Most of these applications relate to telecommunications, meteorology, military spying, navigation, scientific measurement and ground mapping. Yung-Wey and Tat-Chee remind us satellites have mainly been used in the past for TV and telephone transmissions, "however in recent years, the satellite's role in telecommunication has expanded to provide backbone links to geographically dispersed Local Area Networks (LANs) and Metropolitan Area Networks (MANs)" [1]. The ability to launch a platform into space to carry out certain tasks was a revolutionary idea when it began about 50 years ago and has, in addition to becoming one of the main functions of the space program at the time, it led to advances in communications, military applications, and meteorology among other things. Yung-Wey et. al indicates that as promising as satellites are, "there are several drawbacks such as technological complexity, high costs, and Line-of-Sight (LOS) requirements for reception and transmission" [1]. Even though satellite technology has advanced much in the last 50 years, it continues to advance and progress as new applications are found, speed and data throughput is increased, and ingenious control methods are developed. This paper will seek to give a brief history of satellites and how they are used, and the issues and trends of current satellite telecommunications research.

The remainder of this paper will be organized as follows: Section 2 will give a brief discussion of the history of satellites and their applications so more insight into what is happening can be gained and what the future holds. The following section will give a brief overview of different types of orbits, since this will factor into later discussion of research ongoing with satellites. And then the main body section will discuss several research areas that are ongoing to show where the technology is currently being taken and what the future might hold. The last section will present a conclusion and summary. Through this layout, the need for more research in the area of satellite telecommunications will become clear. There are many areas, as will be presented, where improvements can be made in satellite telecommunications, and improvements to any of these areas will result in advancements in the field. These advancements will be manifested in the way of reduced operating and construction costs as well as improved speed and throughput.

II. Brief History of Satellites

It is well known that the first artificial satellite was Sputnik, launched by the Soviets in 1957. The United States launched their first satellite only a few short months later. According to Slotten, President Kennedy declared that this new technology would be used to create a global communication system using satellites and this became known as the International Telecommunication Satellite Consortium (IntelSat) [2]. Later on, the potential of satellites for telecommunications was first demonstrated when, according to Slotten, "In July 1962, a New York Times correspondent proclaimed that the first live television broadcast from Europe to the United States using the communications satellite Telstar would "rank as one of the magnificent accomplishments in television history."' [2]. Since this time, the United States and the other countries that were part of IntelSat poured money into further telecommunication satellite development. The United States Government Accountability Office states that in the 1970's, the first geostationary satellite was launched and was used for weather observation and forecasting. Since that time, the United States as used two geostationary satellites for this purpose until the present day [3].

III. Types of Orbits

There are three main types of orbits used for satellite telecommunications. LEO, or Low Earth Orbit, is one type of orbit commonly used on satellites today. According to Boriboon and Pongpadpinit, it is a satellite trajectory in which a satellite platform moves very rapidly in a low orbit. A constellation of these satellites will be used because they are so close to the earth that they cannot provide full disk coverage. This closeness is why they move faster than geostationary satellites. But this has an advantage; frequencies can be reused due to the rapid orbits, and thus the capacity of telecommunication use is higher [4]. Pontani points out other advantages of low earth orbit satellites. They are cheaper to build and operate compared to geostationary satellites. They are also cheaper to launch and have lower operating power requirements. Furthermore, they provide much higher resolution images due to being much closer to the earth's surface. Time delays are obviously smaller as well, which has advantages in telecommunications. For this reason, constellations of LEO satellites are being used more than geostationary satellites these days for telecommunications purposes [5].

Another type of orbit is the geostationary orbit. According to Poole, this is where the satellite orbits at the same angular speed of the earth's rotation, so it stays over the same spot on the equator. This orbital altitude is 35,900 km above the earth's surface. This has advantages of more ground coverage (nearly the entire half of the earth facing the satellite) and continuous dwell time (since the satellite does not move). The drawbacks to this are higher operating costs, lower resolution, and more power needed for transmission due to it being further away.

The last type of orbit to discuss is the highly elliptical orbit. In this setup, according to Poole, the satellite will be at varying distances from the earth and moving at a nonconstant speed. This is because when the satellite travels closer to earth, the speed at which it moves increases due to being pulled by earth's gravity. When it slingshots around and travels away from earth again, it slows down. This highly elliptical orbit enables the satellite to have a long dwell time when it is at apogee (farthest from earth). Thus, by placing numerous satellites in a constellation like this and coordinating their orbits, permanent coverage over a certain area can be achieved without having to use a geostationary or geosynchronous satellite. The following image from Ian Poole at Radio-Electronics.com discusses various types of circular earth orbits and their altitudes.

TABLE. I. TYPES OF SATELLITE ORBITS AND ALTITUTES [6]

SATELLITE ORBIT DEFINITIONS			
ORBIT NAME	ORBIT INITIALS	ORBIT ALTITUDE (KM ABOVE EARTH'S SURFACE)	DETAILS/COMMENTS
Low Earth Orbit	LEO	200-1200	
Medium Earth Orbit	MEO	1200-35790	
Geosynchronous Orbit	GSO	35790	Orbits once a day, but not necessarily in the same direction as the rotation of the Earth – not necessarily stationary
Geostationary Orbit	GEO	35790	Orbits once a day and moves in the same direction as the earth and therefore appears above the same point on the Earth's surface. Can only be above the Equator.
High Earth Orbit	HEO	Above 35790	

IV. ISSUES AND RESEARCH IN SATELLITE TELECOMMUNICATIONS

There is always research going on in the field of satellites, telecommunications, and their applications. One of the areas that has the most research and application is trying to get reliable satellite coverage in remote parts of the world where it is not practical to provide signal via traditional conducted mediums like copper wire or fiber optic cable.

One area of research is in how to get reliable, consistent signal for Internet connectivity into Antarctica. An article by Lee, Wu, and Mortari points out the current problem doing research in Antarctica. That part of the world is a prime area for various kinds of scientific research due to the fact that it is relatively untouched and it is away from population and human activity. Furthermore, the remoteness of Antarctica, coupled with the extremely cold temperatures cause conventional network connectivity to be unavailable. With the important research going on there, it is important to have this connectivity. There are small ad hoc wireless networks that permit connectivity throughout research stations and to the nearby deployed sensors, but not to the outside world. For connectivity to the outside world, people rely on satellites. But the only satellites currently providing coverage there are geostationary satellites and certain iridium low earth orbit (LEO) satellites. The geostationary ones orbit at the equator and thus provide spotty coverage along the coasts of Antarctica, leaving the interior and polar region uncovered. The LEO satellite are optimized for maritime use and not properly positioned to cover most of Antarctica. Thus, the coverage is spotty and not constant due to satellite movement and other conditions. The need for more reliable coverage is clear [7]. Lee, et. al designed a satellite constellation using three satellites that had them arranged such that they were closest to the earth over the northern hemisphere and much farther from the earth over the South Polar region. This resulted in much slower movement over Antarctica and as a result, greater dwell time over that region, which is what they wanted [7]. Lee and his team tested the coverage by evaluating the amount of time that the satellites were over the areas of interest producing acceptable connectivity in the required bandwidth [7]. Using an analysis of 5 selected stations such that one is representing the South Pole and the other four are in the four quadrants, Lee et. al showed that all 5 stations had coverage to at least one of the 3 satellites 100% of the time in a day, and for over 50% of the time each station could communicate with two of the satellites. This was a very promising result with only a limited number of satellites [7].

Another area of research in the area of telecommunications satellites concerns the generation of electricity on them in a cost effective way that does not make the satellites too heavy. The reason weight is a concern is because it costs more money to launch a satellite in a rocket the heavier it is. In a paper about this topic, Geneste discusses a proposed way to generate electricity on a satellite that is an alternative to the traditional photovoltaic cells. These are the cells traditionally known as solar panels, and have been the go-to power source for satellites for decades. According to Geneste, the costs are typically high because space users are rather limited in what they can use to power satellites beyond a standard primary battery. He discusses ongoing research in a thermal acoustic engine. This is a version of a standard Stirling Engine. A Stirling Engine would not be appropriate for a satellite because satellite designers typically do not like to have moving parts on a satellite. A thermal acoustic engine would be a design that has a sound wave play the part of the piston. As he explains it, "the linear alternator on the left generates a primary sound which is thermally amplified and feeds the linear alternator on the right which creates electricity. A portion of the electricity is injected again in the system for further functioning" [8]. Geneste goes on to point out that currently these types of engines are so heavy that any savings in power generation or design are cancelled by the excessive weight, which translates into extra cost to launch the satellite into space. Therefore research is being done into ways to make thermal acoustic engines that weigh less so they could be more cost effective than photovoltaic cells [8]. He states that this would "be a dramatic breakthrough in the upcoming years for electricity generation onboard space crafts in general allowing much greater available powers, more reliable power subsystems and in the end much cheaper devices" [8].

There is another area of concern that is receiving a considerable amount of attention regarding research in the realm of hybrid satellite communications (hybrid communications just means that Internet data is being sent by a combination of both terrestrial backbone networks and satellite links serving as a backbone too). This area of concern deals with the packet headers. Yung-Wey and Tat-Chee remind us "to ensure that data are sent to their destination over the hybrid satellite-wireless networks, several layers of encapsulations are applied to the packet" [1]. With all the different types of layers the packet goes through, several layers of encapsulation are applied, inducing UDP, TCP/IP, RTP headers, and others, sometimes the headers are far bigger than the payload itself. This is especially true with Voice over IP packets, which have small payloads that can be 25% of the total packet size including headers. Yung-Wey, et. al, propose that to save space and limited satellite transmission resources, they should use some kind of compression that makes use of the fact that many of the header fields that are repeated at each layer are constant, such as the source and destination information, etc. Two existing compression technologies that accomplish this are called Robust Header Compression and Payload Header Suppression [1]. He explains that in Robust Header Compression, the redundant information is not needed to traverse the satellite links. The information in the header is assigned a code so that lets the receiving device can reconstruct the original header information to complete the frame again [1]. The following table, as posted from Yung-Wey, et. al., shows the reduction in byte size of the header information in the tested packets.

TABLE. II. REDUCTION IN BYTE SIZES OF THE HEADER INFORMATION IN THE TESTED PACKETS [1]

	Eth+uncompressed IP/UDP/RTP	Eth-HC+compressed IP/UDP/RTP
SS-BS	60	24
BS-RCST	81	24
RCST-satGW	95	21
satGW-AR	81	24
AR-CN	60	-

IP/UDP/RTP – Internet protocol/User datagram protocol/Real-time transport protocol; Eth-HC – Ethernet header compression; SS – Subscriber station;
BS – Base stations; RCST – Return channel satellite terminal;
AR – Access router

So it was shown in Yung-Wey, et. al that hybrid header compression did indeed contribute to a higher quality of service in Voice over IP connections through hybrid and WiMAX networks. Furthermore, small payload packets benefit a lot with the much smaller header overhead and this had the effect of reducing mouth to ear delay and jitter in the transmissions. This paper indicated that these tests were primarily done over WiMAX networks but can be expanded to other hybrid wireless terrestrial technologies as well [1].

Other research is ongoing in the areas related to satellite telecommunications. Security of the transmissions is one common problem with satellite communications. According to Chang and Cheng, the transmissions passing through the air from the ground to the satellite or from the satellite to the ground are at risk from a variety of attacks such as man in the middle or sniffing. These signals can be intercepted or impersonated. It is possible for a hacker to gain access to information they should not have [9]. The authors point out that a well-designed satellite communication system will have some kind of authentication scheme so that the satellite and ground station will be able to authenticate each other before a session key is negotiated. Research is ongoing on this area to increase the security and reduce the ability for these keys to become compromised in various types of sniffing or man in the middle attacks [9].

It goes without saying that data transmitted between satellites and the ground stations are wireless. Research by Zhang, et. al shows that "the low frequency bands crowding and the increase of broadband services diffusion has created the premise for the development of communications in the millimeter-wave (mm-wave) bands (Q-V bands 35-75 GHz, W-band 75-110 GHz). Due to wider bandwidths and higher frequencies, wireless deliver is expected to provide multigigabit data transmission" [10]. Therefore, they point out that the transmissions on the ground to and from the ground station can only be carried by optical lines as only that can handle the high speed data transmission rates. This introduces complexity in the ground station because expensive and complex equipment is needed to fully integrate the fiber optic signals and the high speed wireless signals to and from the satellites. A whole new set of demodulation equipment is needed for each satellite downlink, which also means more fiber optic lines to the central office from the ground station. Zhang, et. al proposes using optical polarization multiplexing to simplify and lower the cost of the systems operating in the ground station. This is a principle in which the light waves can be broken up by polarization multiplexing into the different satellite signals. Then all the satellite downlinks can be multiplexed onto one fiber optic line to the central office, reducing cost in both fiber optic lines and demodulation equipment, which may be redundant. That way, at the central office the combined signal can be deconstructed again using a polarization beam splitter [10].

V. CONCLUSION

It is clear to see that satellites have a whole host of applications, many of which are in the telecommunications field. It is not as simple as launching a platform containing antennas into space and sending transmissions through it. The huge amount of data and voice transmitted today demands that constant improvements be made in security and data throughput. Furthermore, it is essential that cheaper operating and construction costs are realized because these satellites are going to wear out from the huge demands placed on them. Any efficiency that can be gained in data throughput, power generation, and launch cost will have positive implications for the future. One can never rest in this field; research must be constantly striving to improve cost of ownership, security, and data transmission rates, as well as developing newer and better protocols for how bandwidth is managed. Huge strides have already been made just since the Internet became mainstream.

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