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Future Challenges and Opportunities for Satellite Communications in the New Space Age

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Abstract

In recent years, the interest in satellite communications (SatComs) has been rekindled as a result of technology improvements and private investments and enterprises. There are a lot of exciting open research questions in SatComs that need to be addressed in this survey. We then go into great detail into five different parts of the subject: the system itself, air interfaces, media accesses (such as fiber), networking (such as Ethernet), and testbeds and prototyping (such as USB). Finally, a list of potential future problems and their associated open research questions is provided.

As commercial 5G mobile communication systems have begun to appear, the integration of satellite communication with 5G systems has gained attention in the industry. Integration and conversion of communication protocols are the initial considerations when integrating two communication systems. Satellite and 5G communication protocols have yet to be fully integrated. This study proposes a novel protocol stack model from the perspective of protocol system integration and achieves integration at the protocol level by evaluating the differences and features of satellite and 5G communication protocols. Network deployment may be divided into three types based on the features of the various network applications. Finally, the satellite communication and 5G integration use cases are shown.

Index Term's: space-based data collection, 5G integration, non-terrestrial networks, satellite communications, Antenna..

Introduction

Media transmission, backhaul, news gathering, and other uses for satellite communications (SatComs) have all emerged since the technology's beginnings. As Internet-based applications have grown, SatComs have undergone a shift in their architecture to concentrate on data services, such as broadband SatComs. First and foremost, there's the fast acceptance of media streaming rather than linear programming; and second, there is the pressing demand for broadband access in rural and underdeveloped nations, as well as aero/maritime and other underserved regions. It is the goal of this study to summarize these technical advancements in an organized fashion, as well as to emphasize the significant research problems and open questions. Section II focuses on the aforementioned advances and their corresponding needs, which have pushed SatCom innovation in this area. Section III goes on to discuss the many applications and use cases that SatCom researchers are investigating right now. First, we'll look at system elements, then air interfaces, and finally medium access approaches as the newest SatCom additions. 4) networking and the higher levels of abstraction. To ensure that the reader is able to follow the information without having to consult additional sources, some preliminaries are supplied in an instructional way. Some sophisticated SatCom principles have been shown via the development of communication testbeds. This section examines these testbeds. In the last part, we'll showcase some of the most pressing and interesting unsolved research questions.

A new era of global growth has been ushered in via satellite communication. Commercialization of 5G, the next generation of mobile communication, has also begun. 5G satellite integration has recently emerged as a new industry hot subject. In certain circumstances, complete coverage is not possible due to ground network development constraints. Even in emergency situations, marine, aviation, and railway communication may be enhanced because to the satellite's broad area coverage capacity. 5G network's fast transmission rate and reduced time delay further improves satellite communication user experience. Since 5G and satellite communication systems both have advantages, they may be combined to form a global, seamless integrated communication network that can meet the needs of users in every corner of the world. This is an important development in the field of communications. [1]

MOTIVATION

A. New Constellation Types

As a result, SatComs have traditionally relied on Geostationary (GEO) satellites, which have a long range and avoid rapid movement among these terminals and these satellite transceiver. Multiple beam satellite systems are designed to offer effective frequency recycle and high-bandwidth broadband rates throughout their coverage region, much like terrestrial cellular networks. Modern communication technologies as well as lower launch prices are motivating the development of more ambitious constellation designs. The required manufacturing and launch processes, on the other hand, seem to have developed, and a practical implementation and deployment may now be within reach. There have already been several large-scale LEO plans revealed by firms like SpaceX, Amazon, OneWeb, and TeleSAT, some of which include thousands of satellites and some of which have actually launched demonstration satellites. By the end of 2020, SpaceX plans to have over 12000 satellites in their Starlink constellation, which now stands at 242 [2].

B. On-board Capabilities

In the past, innovative SatCom methods were hampered by the computing power available on board the satellite. Because most satellites are used as a relay, the processing on board must be waveform agnostic in order to be effective. Second, the power supply and route loss are directly proportional to the mass and launch cost of the satellite. To round things off, because the asset will be in orbit for an extended period of time, the on-board components and technologies used must be very dependable and resilient. It is also possible to update the onboard waveform processing of software defined radios over the lifespan of a satellite.

C. Non Terrestrial Networks

The major goal of this program is to analyze the peculiarities of architecture and air interface in order to easily incorporate these assets into 5G systems. NTNs' extensive coverage, multicast capabilities, and ability to work in conjunction with existing local terrestrial infrastructure are all highly prized by the appropriate parties.

D. New Space

However, New Space does not relate to any single technological innovation but rather to the shift in our attitude regarding space. It was the result of three interrelated factors: 1) the commercialization of space, 2) the downsizing of satellites, and 3) the development of new space-based services. In contrast to the old institutional method, private enterprises like as SpaceX and Rocket Lab are taking the manufacture and, more importantly, the launch of satellites under the auspices of privatization. Multiple cube/micro/nanosatellites might be launched from one rocket thanks to the shrinking of satellite and component parts. To achieve the latter, the first two characteristics have to be combined, allowing for fast and economical space travel. Earth observation, radio frequency (RF) monitoring, asset tracking and sensor data gathering are among the many data collection constellations that have already been launched in this approach. Satellite Internet of Things (SIoT) is a novel way to gather data from sensors on the ground and send it back to the ground via satellites. Dozens of private firms are now working on prototypes in an effort to develop a commercially successful service. In order to effectively downlink the acquired data back to the ground for processing, almost all of these initiatives depend on low earth orbits, which introduces additional communication issues. Traditionally, each of these endeavors would need a large earth station network in order to ensure high availability.

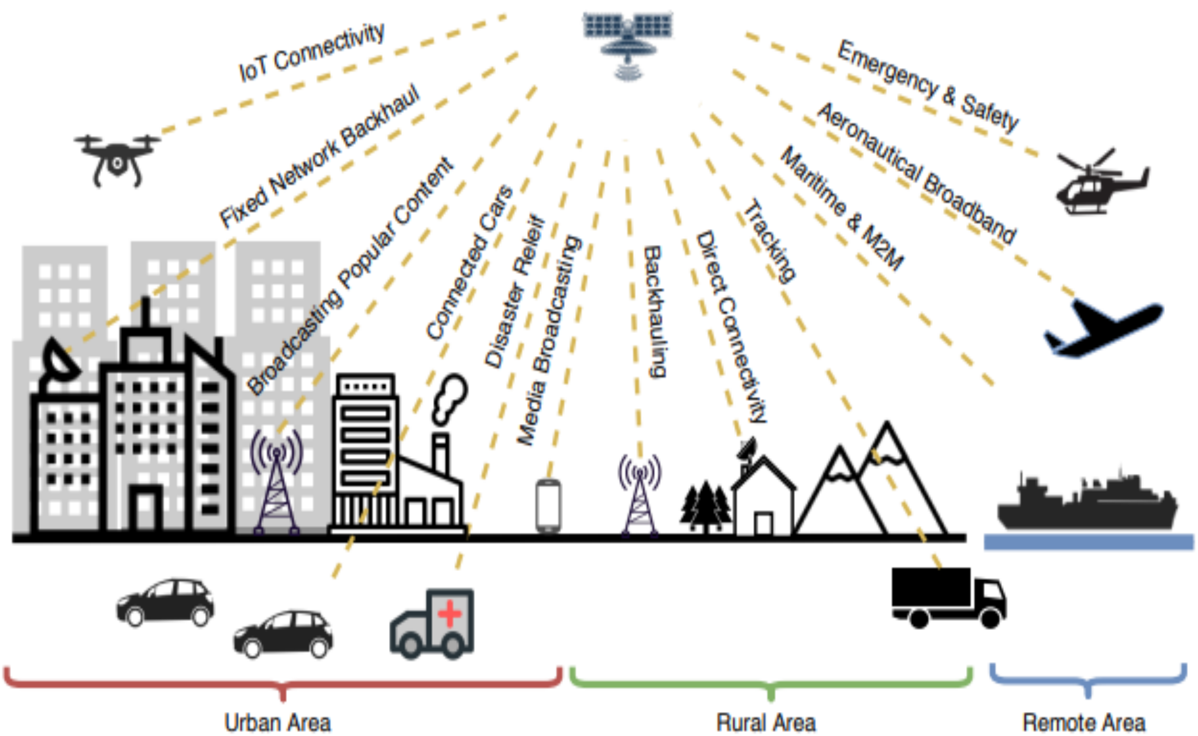

Fig. 1. What is the significance of satellites in the 5G ecosystem?

APPLICATIONS & USE CASES

An important function for SatComs may be played in many applications and use cases, which is why we've included this area.

A. 5G Non Terrestrial Network

To meet the needs of emerging markets like automotive and transportation, media and entertainment, e-health, and Industry 4.0, 5G will be more than simply a continuation of existing standards. Sixth and seventh, respectively. 5G application cases have been categorized into three key groups: improved mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low latency communications [8]. (uRLLC). There is no doubt that satellites will play an important role in the 5G ecosystem. As of March 2017, the 3rd Generation Partnership Project (3GPP) has completed two research issues (SI) on the function of satellites in the 5G network [9, 10]. Since NTN has been authorized as a new 5G feature after a two-year research period, a work item (WI) has been assigned to begin in January

2020 [11]. The 3GPP has specified three primary use cases for NTN 5G systems [12]. By providing service continuity in situations when terrestrial networks alone or a combination of them cannot do it, NTN may considerably improve the 5G network's dependability. Especially in the event of moving platforms and mission-critical communications (e.g. automobiles, trains, planes, etc.). As a second benefit, NTN can ensure that 5G services are available everywhere, including in places where terrestrial networks don't exist or aren't viable or cost-effective to reach (such as the desert, seas, forests, etc.). Last but not least, NTN's satellites are effective at multicasting or broadcasting over a very large region, enabling the scalability of 5G services. In order to relieve the terrestrial network of traffic, popular material might be transmitted to the network's periphery or directly to consumers. Figure 2 shows an example of the satellite use cases for each 5G service group, which may be found below. 1) eMBB's usage in satellite applications: The authors in [13] have compiled a set of eMBB service use cases for satellite-based 5G, which we'll go through here. • Backhauling and tower feed (BATF): In this use case the satellite provides a complementary role by backhauling the traffic load from the edge of the network or broadcasting the popular content to the edge, hence optimizing

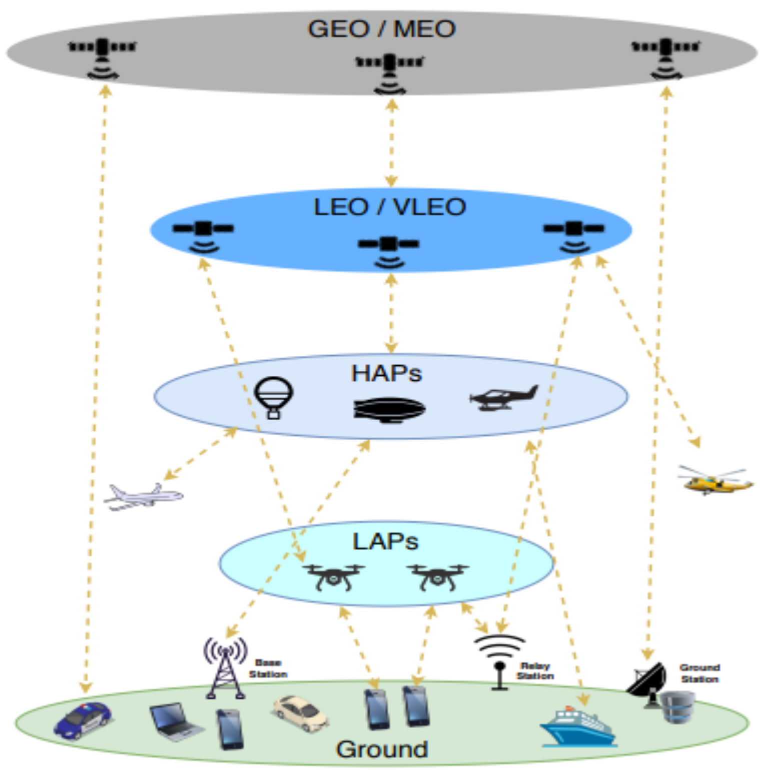

Fig. 2. The design of a multi-layer communications system

B. VLEO and SatCom-assisted

Airborne Networks Thanks to recent technical advancements in aerial and smaller satellite platforms, intermediary communications layers have formed between terrestrial and classic satellite segments in recent years. The operating height of these new platforms may be used to classify them regardless of their intended use. There are three key categories to consider: VLEO satellites, HAPs, and LAPs (low altitude platforms) (LAPs). VLEO has an altitude range of 100 to 450 km, HAPs have a range of 15 to 25 km, and LAPs have a range of 0 to 4 km. [16] These new platforms allow for the creation of a new, multi-layer communications architecture that can handle the most difficult cases. The new multi-layer communication paradigm is shown schematically in Fig. 2. The advantages and drawbacks of LAPs, HAPs, and VLEO satellites are discussed in the following sections. First, VLEO platforms are in a lower orbit than LEO satellites, which is why they are referred to as VLEO. As a result, they may be more compact, less expensive, and easier to use. However, at such low altitudes, the atmosphere is denser, and as a result, aerodynamic forces are greater.

Aeronautical and Maritime

Communication and Tracking In addition to the above listed applications, satellites may play a significant role in tracking systems for aircraft and ships at sea. Device-to-Device (D2D) communications and the Internet of Things (IoT) have a lot in common. Low data rates, infrequent communication, and simplicity of protocols are just a few of the parallels that may be seen. Automated Dependable Broadcast Surveillance Increases in the number of people using air travel have been occurring steadily in recent years, reaching two billion passengers per year in 2018 [29]. Air Traffic Management (ATM) system, on which billions of future passengers' safety depends, may be unable to cope with this exponential growth [30]. Automatic Dependent Surveillance-Broadcast is increasingly being used to assist the next generation of air traffic management systems (ADS-B). Despite the fact that ADSB is not currently required in all parts of the globe, it will be installed in the majority of flying aircraft by the year 2020 at the very latest. For separation and situational awareness, the ADS-B system relies on an aircraft's ability to navigate to its destination using GNSS data and barometric altitude, communicate with an air traffic controller, and engage in cooperative surveillance with the controller. An aircraft's navigation system provides the data needed for ADS-B, therefore there is no need for human interaction. The ATM network receives the ADS-B signals and relays them to the available sensors. Typically, these sensors have been installed near the Air Traffic Control tower (ATC). There is no way for ADS-B receivers at ground level to receive signals from planes flying over places without any ADS-B ground stations, such as

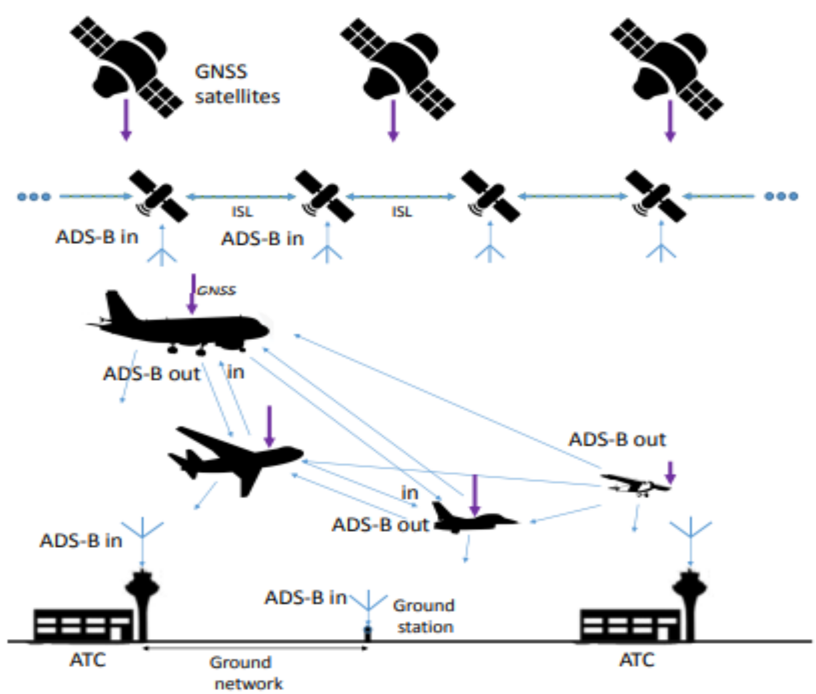

Fig. 3. ADS-B hierarchy with low-orbit satellites conducting ADS-B reception

Oceans or the Arctic regions, for example. Thus, ground stations become crowded by the amount of work they have to do, leaving a substantial portion of airspace unmonitored [30, 31]. As a result, in recent years, it has been suggested to use a LEO constellation of tiny satellites to build space-based ADSB receivers that can be integrated into the whole ATM relay network. Low latency and worldwide ADSB coverage may be achieved in this method [31, 32]. Satellite-based ADSB systems are shown in Fig. 3. Enhanced airplane safety and efficiency are made possible thanks to frequent and dependable ADS-B communications from space. This may be explained by the fact that the aircraft's ascent trajectory is tailored to meet certain safety requirements, resulting in fuel savings of millions of dollars annually [33]. Nevertheless, this raises the issue of having to deal with a greater volume of data that must be sent to control centers. Satellite-based ADS-B reception and networking are provided by a few specialist firms. SPIRE [34] and Aireon [35] are two examples. Both firms use a space-based ADS-B network and cloud computing to deliver a worldwide air traffic monitoring system. Second, the International Maritime Organization (IMO) regulates the use of the Automatic Identification System (AIS) on ships as a short-range tracking system. In order to minimize ship collisions, it delivers real-time identification and location information to vessels and shore stations. A decade after it was first proposed, satellite-based receivers, which give worldwide coverage and faster reaction times as well as greater dependability, have just recently made it more popular [37]. It has been possible for satellites equipped with AIS receivers to detect signals broadcast by transceivers equipped with an AIS transponder since 2008. For hazardous goods, space-based AIS receptions offer up the potential of unmanned transoceanic flights, allowing the elongation of non-time-critical missions, as well as the optimization of fuel use or the direct use of electrical or solar power. For boats and coastal authorities in busy port regions, these satellites provide additional data sources that can't be accessed by ordinary radio-frequency identification (RFID) receivers. In virtually real-time, satellite-based AIS can gather AIS data globally. Companies including SpaceQuest, ExactEarth, Marine Traffic, ORBCOMM, and SPIRE have been commercially exploiting space AIS during the last decade [34].

C. Earth Observation Data Collection

For decades, governments and international organizations have relied on Earth Observation (EO) to track and report on weather patterns, keep tabs on ocean currents, spot changes in flora, and assess the toll natural catastrophes like earthquakes and hurricanes have taken. Objective data on what truly takes place, revealing patterns and changes in a manner that could never be viewed from the ground, is provided by this system. There has been a recent shift in investment in agile space activities, rather than typical large-scale government programs, in the space business. Developing nations, institutions, and corporations might all benefit from agile space since it allows for a larger spectrum of participants to participate in the space program. Upstream and downstream make up the bulk of the agile space industry. There are two distinct types of space activities: upstream space and downstream space data activities. Space data collecting and space data analysis firms, such as SPIRE [34], are developing new services by integrating satellite technology to gather information with current data analysis methods. [34] (e.g. machine learning). Machine learning data analysis may be really useful when it comes to the logistics industry. Consider, for example, the problem of keeping track of how many containers are being transported during the day at a seaport. A fleet of tiny LEO satellites can efficiently capture images of the port container storage zone in order to meet this goal. In order to effectively count the number of containers that have been transferred between the various satellite routes, these images are then relayed back to Earth and analysed using some machine learning approach Allows you to acquire a daily tally of container movement [43]. In spite of the benefits that LEO orbits provide for EO applications, they nevertheless offer certain obstacles from a telecommunications standpoint. Satellites in low Earth orbit (LEO) can only guarantee coverage for a few minutes every few hours due to the fact that they travel at a high rate of speed. As a result, a high number of satellites is required to provide continuous coverage. A Gateway (GW) can only communicate with a satellite for a certain length of time for the same reason. Either a huge number of GWs must be installed throughout the world or inter-satellite link (ISL) capabilities must be developed in the satellites to provide continuous communication between the ground and the satellite fleet. Find out more about this topic in Section IV-B.

D. Space Communications

Space exploration relies heavily on the use of telecommunications systems. Apollo 11's lunar landing, New Horizon's images of Pluto, Rosetta's information about 67-p/Churyumov-Gerasimenko comet, and Voyager 1's instruction to turn its camera and capture a shot of Earth from a record-breaking 6 billion kilometers away are just a few of the highlights of my life. We couldn't have accomplished these and many other wonderful things if we didn't have incredibly effective communication systems with our space travelers. Space Exploration started with the launch of the Sputnik in 1957 and has been mostly carried out by robots or extremely brief human flights outside of Earth orbit, like the Apollo Program. With the emergence of the concept of "Space 4.0," many space organizations are working to establish permanent human settlements on other planets and moons in our solar system. This is where ESA's Moon Village idea [44] comes in. It aims to put this paradigm shift into action and establish a location where international collaboration and commercialization of space may coexist peacefully in harmony with one another. Without dependable and high capacity communication between Earth and these human outposts throughout the solar system, such an ambitious ambition would not be possible. There have only been National or Transnational Space Agencies involved in space exploration up until now, but this will soon change with the private sector being involved in space research. Young start-ups, in particular, are eager to take use of the abundant resources on asteroids and the Moon. Many minerals are found on asteroids, including precious metals like gold and platinum as well as rare-earth metals like uranium and thorium. Metals extracted from the Earth's crust for millennia have been crucial to economic advancement and technical innovation. Many asteroids and comets are also assumed to be made up of water and other volatiles (ammonia, methane, etc.). An increasing need for freshwater on Earth may be met by harvesting the water ice that accumulates in glaciers and glaciers. Chemical propellants like hydrazine may be derived from volatile elements, allowing for further exploration and mining. Water ice is estimated to be in the Solar System in the range of 2 trillion metric tons (2.2 trillion US tons) in [45]. V-E3 goes into great length on the problems with Deep Space Communication and the remedies that are now accessible.

Results & discussion

Satellite communication and 5G mobile communication may be integrated in this paper's development proposal. It all begins with the integration of the agreement system. The integration is accomplished at the software protocol level by revising the specification of the communication protocol stack and developing a new protocol stack model. It is logical to separate the protocol stack into two pieces based on the peculiarities of DVB and 5G protocols. There are two layers of protocols: one at the bottom is referred to as physical, and one at the top is known as a "high-layer." The "bottom layer DVB + top layer 5G" concept may be used to construct the integrated protocol stack. There are two layers in the original protocol stack (the physical and data connection layers) (network layer and application layer). Packet encapsulation is done using the original GSE/RLE format, which is still supported by the underlying layer. DVB-S2 is able to take use of current baseband and RF equipment, while retaining the minimal channel overhead of DVB-S1.

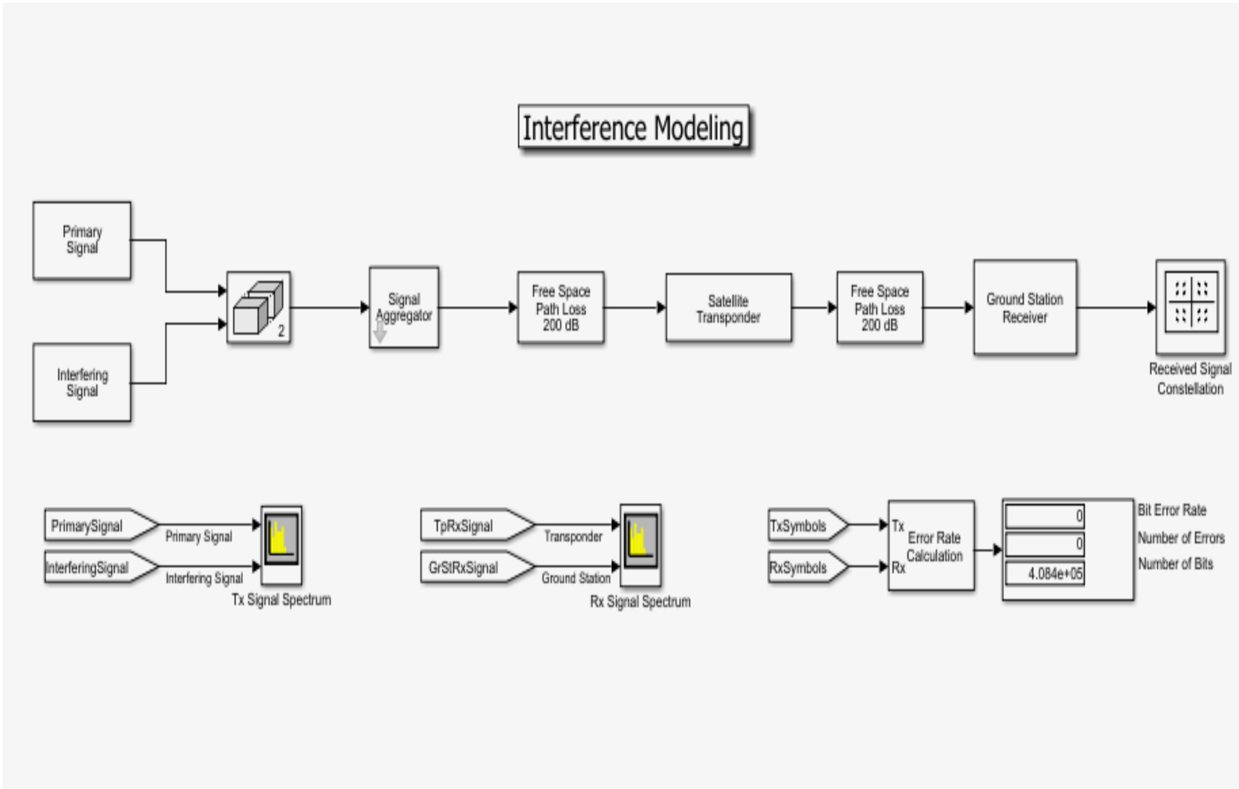

Fig.4 Interference Model of satellite communication in MATLAB/SIMULINK

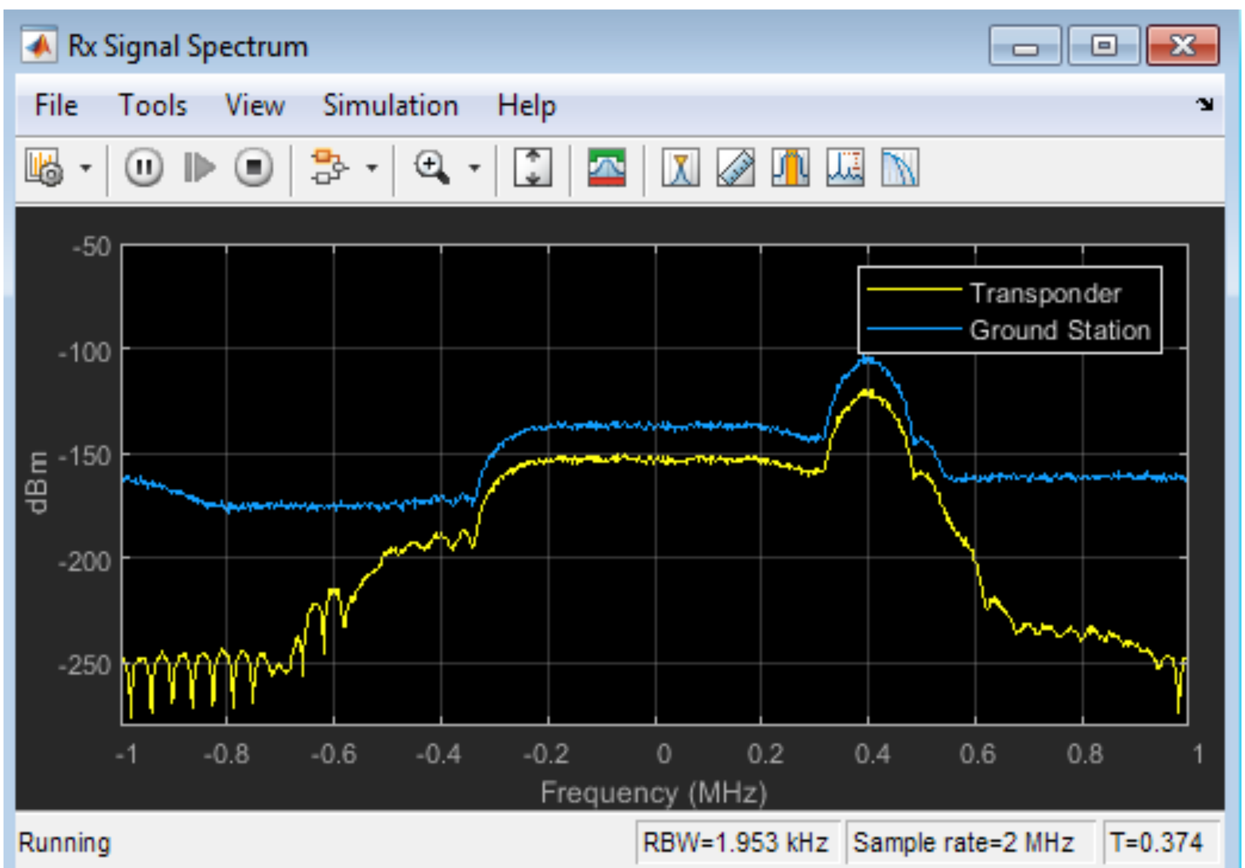

Fig. 5 Receiver Signal spectrum of Satellite Communication

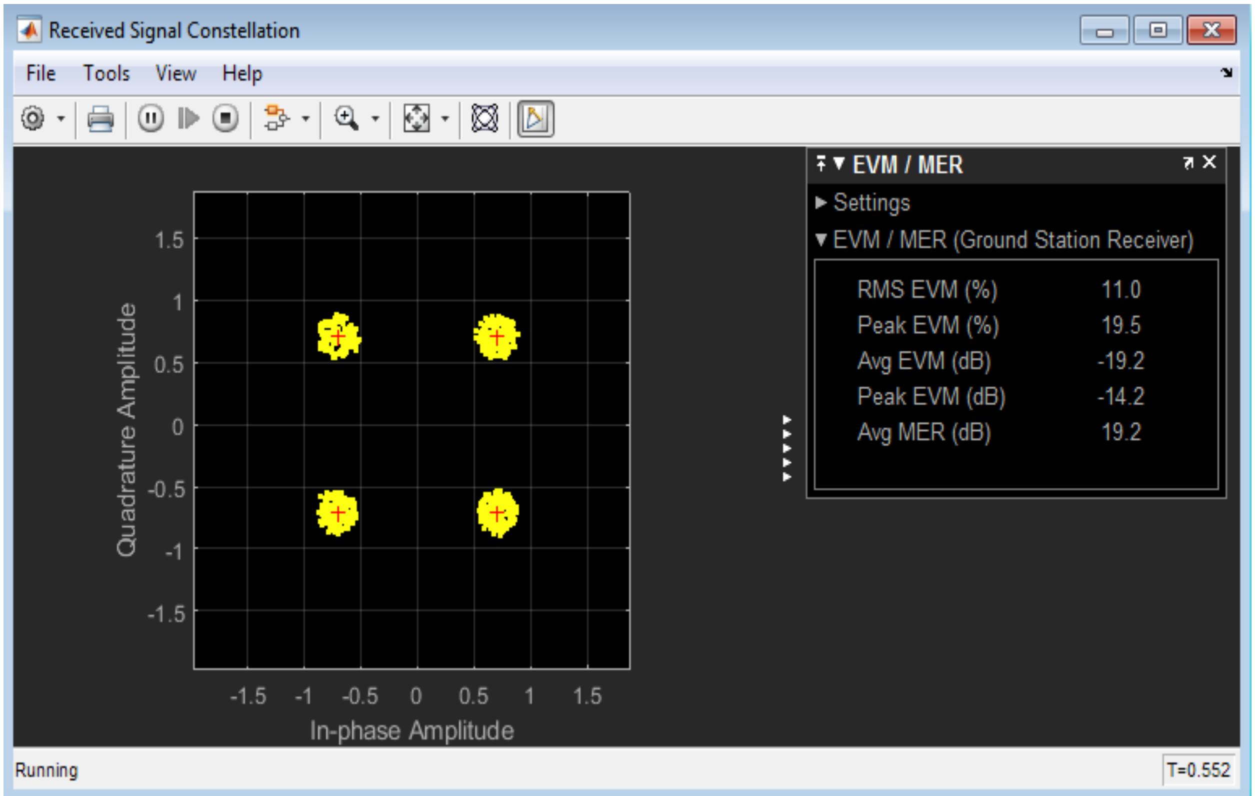

Fig 6. Received signal Constellation

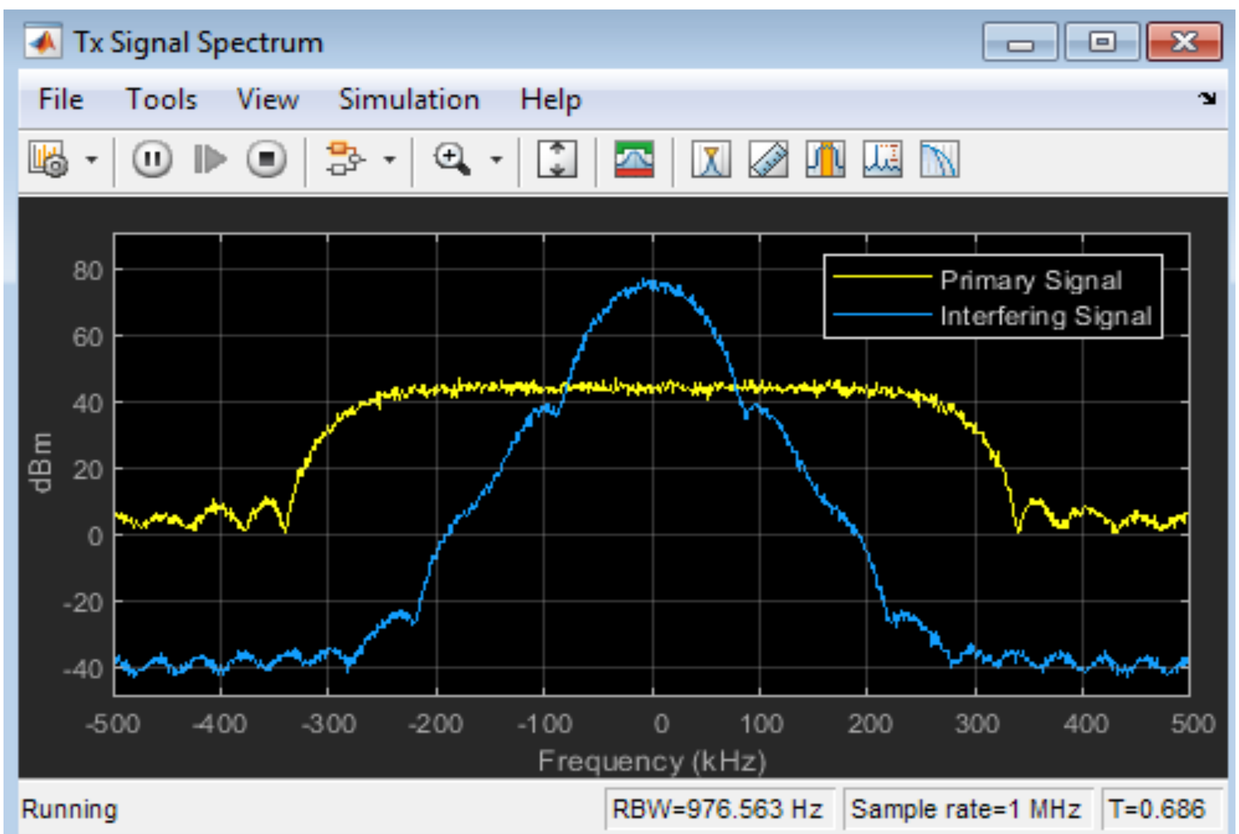

Fig 7:- Transmitter Signal Spectrum

CONCLUSION

Many Internet-based applications and services have grown rapidly, and this has resulted in an ever-increasing need for broadband high-speed, diverse, very reliable, and low latency communications through satellite. With their distinctive characteristics and technological advancements, satellites may play a key role in meeting this need, either alone or as part of an integrated network of satellites and ground-based systems. As a whole, this study has summarized the most recent achievements in satellite communications research from the fields of science, industry, and standardization. In particular, SatCom research has focused on the most critical applications and use cases. In addition, a comprehensive literature assessment of the most recent SatCom contributions in terms of system elements, air interface, medium access control, and networking has been presented. The communication testbeds built to showcase some of the advanced SatCom ideas are displayed. In the end, we've spoken about a few big future problems and the outstanding research questions that will be needed to solve them.

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