A Survey on Satellite Components and Services

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Abstract—A satellite, in a wide sense, is an object orbiting around a planet or a star. Here we only tackle satellites as man-
made satellites orbiting around the Earth and aiming at providing various services. The story of satellites begins at the end of 1960s.
At that time, satellites are very small with dimensions of less than 1 m and weights not larger than few tens of kg. Hence,
signals sent to stations on Earth are very weak and the latter need to have very large antennas and thus very large overall
dimensions. From 1960s up to now, satellites size has continued to increase and so Earth stations receive antennas to be of order
of few centimetres. Nowadays, satellites are omnipresent above our heads, they are bigger, reaching weights of few tons and
satellite systems are getting smarter and more powerful thanks to research and development on advanced components. This
paper aspires to give a survey on recent satellite components and services. We give an overview of the components (communication
system, power and thermal system, and propulsion system) and services which are used today, show recent developments and
open research questions.

Index Terms—satellites, transponders, satellite antennas, satellite communication, satellite navigation systems, telecommunica-
tion services

I. INTRODUCTION

When the first man-made earth satellite Sputnik 1 was successfully launched by the Soviet Union in 1957 the concept of geosynchronous satellites had already been around for 12 years. In October 1945 Wireless World published an article by Arthur C. Clarke which was titled “Extra terrestrial relays – Can Rocket Stations Give World-wide Radio Coverage?” [1] in which he proposed the usage of three relay stations at an orbit of 42,000 km above earths equator to ensure complete coverage of the globe. After analysing the requirements to launch such relay stations, including the rocket design, he came up with the theory that it would only be a few years until his concept would become a reality.

Nowadays satellites are omnipresent. NASAs National Space Science Data Centers Master Catalog lists hundreds of active and thousands of abandoned satellites [2] orbiting earth at various distances. Satellites are used for navigation, telephony, Internet access, television, imaging, environmental services, and many more.

In this paper we give an overview of the components used in modern satellites, as well as the services provided by satellites. The rest of this paper is organised as follows: In Sec. II we present related work, in Sec. III we discuss the components of modern satellites (namely the communication system, power and thermal system, and propulsion system), and in Sec. IV we give an overview of currently active satellite services.

II. RELATED WORK

In [3] mobile satellite networks and services have been surveyed. They focused on the specific characteristics of systems which are unique in comparison to other systems and presented important standards for mobile satellite communications and services. Furthermore they surveyed the main characteristics of operational and planned mobile satellite systems and proposed an analytical framework allowing their comparison, which they believe to be a good tool for the design and market study of future mobile satellite systems. To our best knowledge, this study from the year 2010 is the most recent one. Since then many new technologies for satellite components as well as services have emerged. In the following chapters we will summarise the existing components and services and present more recent ideas for technologies and services.

III. SATELLITE COMPONENTS

A satellite consists of many different subsystems [4, p. 284] like the power and thermal system, attitude and orbit control system (propulsion system), communication system, structural system, and many more. In the following section we will describe the three main subsystems of a satellite, namely the communication system, the power and thermal system, and the propulsion system. We will give an overview of currently used technologies and summarise recent research activities and open research questions.

A. Communication System

The communication system of a satellite, which is called the communication payload, is used for communication between the satellite and earth stations as well as inter-satellite communication. It consists of the antennas as well as transmitter-receiver units which are called transponders.

In [5], the following types of communication payloads have been identified:
- Transparent “Bent-Pipe” transponder.
- Regenerative repeater with routing capabilities.
- Transparent repeater with analog routing capabilities.
- Transparent digital repeater (“Digital Bent-Pipe”) with routing and beamforming capabilities (also known as “Translucent”).

We will refer to these as Bent-Pipe, Regenerative Repeater, Transparent Repeater + Router, and Digital Bent-Pipe and describe the concepts in the following paragraphs.

1) Bent-Pipe: The Bent-Pipe is the oldest and most simple concept of a communication payload. A Bent-Pipe simply receives a signal, does frequency conversion and amplification, and then retransmits the signal.

2) Regenerative Repeater: In addition to the features of a Bent-Pipe, a Regenerative Repeater can regenerate the received signal before retransmitting it.

3) Transparent Repeater + Router: In addition to the features of a Regenerative Repeater, a Transparent Repeater + Router can base his decision on which transponder he retransmits the received signal based on analogue routing techniques.

4) Digital Bent-Pipe: The Digital Bent-Pipe is the most recent and most sophisticated type of communication payload. As the Bent-Pipe, it does not regenerate the received signal. However, it uses multiple access schemes, such as time division multiple access, frequency division multiple access and code division multiple access.

In addition to these payload types there are some recent research results regarding reconfigurable antennas [6], dual polarisation per beam [7] [8], cognitive communications [9] [10] [11], wide band amplifiers [12] [13] [14], and a proof of concept model of a digital transparent processor [15]. We will summarise this research in the following paragraphs.

5) Reconfigurable Antennas: Existing satellites have their antennas fixed, i.e. the antennas are designed for one application and deployed with the satellite. If different applications or frequencies should be realised by a single satellite, multiple antennas need to be deployed with the satellite. Recently there have been approaches to design antennas that can be reconfigured after the satellite has been deployed to space.

In [6] a helical antenna is proposed which can tune its operating frequency by mechanically changing its height above the ground plane in a rotational manner. It is intended for usage on small satellites and covers a frequency range of 240 MHz to 450 MHz. Due to the reduced size of the overall satellite (one reconfigurable antenna instead of multiple fixed antennas) fuel can be saved which in turn would lead to a longer operational time of the satellite or reduced operational costs.

6) Dual Polarisation per Beam: Traditionally satellites use different polarisations on different beams to minimise distortion between beams (e.g. use horizontal polarisation on the upstream beam and vertical polarisation on the downstream beam). The idea to use dual polarisation per beam, i.e. use two polarisations on the same beam to transmit two parallel streams of information simultaneously has been extensively researched over the last years.

In [7] the results of recent studies have been summarised and it has been shown that the use of two polarisations on every beam of a satellites payload is indeed feasible. In [8] the idea of dual polarisation per beam has been combined with the approach of hybrid mobile satellite systems (systems in which a mobile station can communicate with both a satellite and a terrestrial base station). This scenario implies four different polarisation schemes are being used on the mobile station (e.g. two different linear polarisation schemes for the communication with the terrestrial base station and two different circular polarisations for communication with the satellite). They concluded that these techniques could indeed be used in the next generation of hybrid mobile satellite systems. The implication of these results is that the capacity of the satellites can be increased by transmitting two independent information streams on every beam.

7) Cognitive Communications: Satellite spectrum is becoming scarce due to the increased demand for broadcast, multimedia and interactive services. This leads to the problem of how to increase spectral efficiency in satellite networks. One idea to conquer this problem is the method of cognitive communications. In cognitive communications, one part of the spectrum is shared by two satellite systems or by a satellite system and a terrestrial system. In [10] the most common techniques for cognitive communication have been identified as spectrum sensing, underlay, overlay, and database related. The spectrum sensing approach allows a secondary user to transmit whenever the primary user is not occupying the frequency band, the underlay approach allows the secondary user to transmit as long as the interference requirements of the primary user are fulfilled, the overlay approach uses advanced coding and transmission strategies to mitigate interferences, and the database related approach uses a database which is queried by the cognitive users for free spectrum bands.

Another approach for cognitive communication has been made in [11]. They propose a dual satellite system with a primary satellite which uses larger beams and a secondary satellite which uses smaller beams. To achieve cognitive communication their system uses a signalling link between the gateways of the two systems. This signalling link is used to inform the secondary system of the primary systems beamhopping pattern, as well as to exchange timing information. They conclude that their proposed system can significantly increase spectral efficiency over existing satellite systems. In [9] they did interference modelling for these four
techniques and found that spectrum sensing and database techniques provide best performance in high interference regions while in low- or medium interference regions the underlay technique provides better performance. The also found that the overlay technique is only suitable for integrated systems with a high level of interaction.

8) Wideband Amplifiers: Most satellites today use the channelised approach, whereby the frequency band is divided into multiple narrow band channels and each channel is amplified separately. In [12] an alternative to this traditional approach, the idea of wide band amplifiers, is presented. To implement this approach, higher power, wider bandwidth, and more linear travelling wave tube amplifiers need to be developed. The results of using wide band amplifiers would be higher bandwidth utilisation since the need for guard bands between the narrow band channels is omitted, less hardware, lower mass, and the possibility of new services which need higher bandwidth.

In [13] the model 1693HD travelling wave tube amplifier is presented. This amplifier produces 75 watts of CW saturated RF power over bandwidths greater than 6 GHz in the V frequency band. It provides better efficiency, better linearity, lower noise, and lower mass than previous amplifiers. It has been tested with multiple qualification tests, such as random vibration testing, pyrotechnic shock simulation, and cycling between thermal extremes in a vacuum. As a result of those tests it has been flight qualified for space applications.

In [14] the KA-SAT satellite is described, which is a high throughput satellite. The overall system capacity is 90 Gbit/s and up to a million users. This system still uses the channelised approach, with a bandwidth of 250 MHz per channel. Due to the drive for capacity, the next generation of satellites will need high power amplifiers which can cover 2.9 GHz in V band.

Combining those results, there is both the need for wide band amplifiers, as well as the implementation of one such amplifier which has already been flight qualified. Hence, most likely those wide band amplifiers will be used in the next generation of high throughput satellites.

9) Digital Transparent Processor: In [15] an on board digital transparent processor for a multi-beam satellite has been proposed. This processor segregates uplink signals coming from different earth terminals, switches them per user requirements, and combines them for downlink transmission. This results in inter-beam and intra-beam mesh connectivity of user terminals without the need for a hub earth station. Their processors consists of four main subsystems, namely the frequency demultiplexer, the channel switch, the frequency multiplexer, and the mesh network manager. They described the architecture, algorithm, and implementation details of the processor. Furthermore they presented simulation and hardware test results. Their processor essentially serves as an exchange-in-the-sky, providing hubless mesh connectivity of user terminals.

B. Power and Thermal Systems

The [16] main source of power is sunlight which is harnessed by the satellite’s solar panels. A satellite also has batteries on board to provide power when the sun is blocked by the Earth. The batteries are recharged by the excess current generated by the solar panels when there is sunlight.

Satellites operate in extreme temperatures from -150 °C to 150 °C and may be subject to radiation in space. Satellite components that can be exposed to radiation are shielded with aluminium and other radiation-resistant material. A satellites thermal system protects its sensitive electronic and mechanical components and maintains it in its optimum functioning temperature to ensure its continuous operation. A satellites thermal system also protects sensitive satellite components from the extreme changes in temperature by activation of cooling mechanisms when it gets too hot or heating systems when it gets too cold.

C. Propulsion System

[16] Satellite propulsion system mainly includes the rockets that propel the satellite. A satellite needs its own propulsion system to get itself to the right orbital location and to make occasional corrections to that position.

A satellite in the geostationary orbit can deviate up to a degree every year from north to south or east to west of its location because of the gravitational pull of the Moon and Sun. A satellite has thrusters that are fired occasionally to make adjustments in its position. The maintenance of a satellite’s orbital position is called “station keeping”, and the corrections made by using the satellite’s thrusters are called “altitude control”.

A satellite’s life span is determined by the amount of fuel it has to power these thrusters. Once the fuel runs out, the satellite eventually drifts into space and out of operation, becoming space debris.

The papers [17] and [18] might be of interest for this chapter.

IV. SATELLITE SERVICES

Satellites are used to provide a big amount of services. The International Telecommunication Union (ITU) has listed them in [19], we describe only few of them. Most of them are provided by terrestrial or by satellite systems. Usually, we define two different types of services:

- The Fixed-Satellite Service (FSS), which is mainly used for broadcast (television, radio stations) and broadband Internet. This service sets up a radio communication link between a satellite and a fixed earth station as defined in [19]. The first generation of such FSS uses the C-band (
Electronic systems, heads, guidance would not exist. Since the launch of the first satellite, considerable advances in electronic systems, user demand for higher mobility, smaller mobile devices, and satellite guidance would not exist. From the launch of the first satellite, considerable advances in electronic systems, including the size of the satellites, and in increasing their lifetime have been performed.

In this paper, we reviewed the systems and components used in modern satellites by looking into research papers on communication payloads, key components like antennas or communication systems, and satellite guidance would not exist. Since the launch of 1945.

References


