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A REVIEW ON INFORMATION SYSTEMS ENGINEERING USING VSAT NETWORKS AND THEIR DEVELOPMENT DIRECTIONS

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Abstract: Modern satellite VSAT networks can be applied not only to provide satellite radio and television broadcasting, but also to other domains, such as a two-way Internet access. For this objective it has become necessary to develop appropriate standards and data transmission techniques. An unquestionable advantage of satellite systems is reception range, which translates into possibility of building networks in almost any place on Earth. Depending on the application, such networks can use many topologies. The aim of the article is to review distributed information in this area, as well as to determine the directions of development of the next generation VSAT networks. For this purpose, the literature review has been provided, with due regard to the IEEE Xplore digital library databases, and supported by practical examples.

Keywords: Information Systems Engineering, Internet Services, Network Topologies, The Next Generation VSAT Networks, Satellite Networks.

MSC: C61, D80.

1. INTRODUCTION

Universal corporate satellite networks allowing sending and receiving data from many locations have been operating since the 1970s. Since the 1980s terrestrial terminals equipped with small dishes have appeared on the market. Initially, they were receiving antennae, but as time went by, also transmitting and receiving antennae. The information and telecommunication systems using them have started to be called VSAT (Very Small Aperture Terminal). Such systems have become more and more popular due to legal requirements concerning their use, *e.g.*, the possibility of installing them at almost every location due to the direction of the antenna, as well as the lack of international coordination of terrestrial stations. Moreover, the construction of communication systems using satellites located in geostationary orbit is the cheapest way to build networks with local, regional, international, and even intercontinental coverage. They are used, among others, to create networks between areas located at a long distance from each other, where the construction of traditional communication networks would be uneconomic or impossible. At the beginning of the 90's many companies have started to produce VSAT systems on a mass scale, which have been designed for many purposes, and thus operated on different frequencies. In 1998 about 60,000 two-way VSATs were installed in the Ku-band, while at the beginning of 1999 there were already about 300,000 two-way VSATs operating worldwide, which shows a significant dissemination of this technology [1]. As time passed, the requirements for QoS (Quality of Service) increased, which was a result of significant propagation delays, and a lack of quality assurance, translated into slowing down the development of satellite IT (Information Technologies) services for the expansion of DSL (Digital Subscriber Line) technology and fast cable connections [12]. The VSAT networks offered interactive data services to remote terminals at rates of 192 kb/s to 2 Mb/s or even more in areas where the terrestrial technical infrastructure did not allow to reach transmission rates above those offered by POTS (Plain Old Telephone Service) lines and modems, *i.e.*, 14.4 to 28.8 kb/s. A consequence of the continuous development is the availability of various integrated circuits that implement the receiving part of the remote terminal. Since these chips are used for digital transmission, in the long term, this has reduced the cost of digital receivers operating at data transmission rates up to 90 Mb/s to less than $40 in two-way VSAT networks [1].

Nowadays, satellite networks in spite of typical IT applications, such as Internet access, are used in telecommunications, in the army, as well as in the meteorology. It is worth emphasizing that the use of satellites located in geostationary orbit may constitute an additional method of access to WWW (World Wide Web) networks or services in the telecommunication sector when a primary link is broken. Then the damage to the ground infrastructure, *e.g.*, fiber optic network, will not cause interruption of access to widely understood ICT (Information and Communication Technologies) services. In practice, satellite networks are needed to ensure communication if traditional terrestrial infrastructure would be completely damaged as a result of the disaster, *e.g.*, the event that took place on March 11, 2011 in Japan as a result of an earthquake. At that time, the destruction of the fiber optic and cellular networks access infrastructure prevented effective communication, especially outside the destruction area [11, 18, 23]. It was noticed that relying on traditional communication networks in the event of natural disasters may not be sufficient, and attention was paid to preventing such situations in the future through the use of satellite communications, for example, by using a portable VSAT system. The reliable operation of such systems should take into account the rapid increase in the traffic [16]. These terminals provide many ICT services, *e.g.*, Internet access, voice services, video services, and can be used to build corporate networks. Moreover, the satellite links are one solution to eliminate areas of digital divide, which are created as a result of the lack of terrestrial communication infrastructure [15].

2. A LITERATURE REVIEW OF THE VSAT NETWORKS WITH DUE REGARD TO THE IEEE XPLORE DIGITAL LIBRARY DATABASES

Many peer-reviewed publications, some of which have been presented at many international scientific conferences, provide an up-to-date knowledge of different factors influencing transmission quality, including meteorological ones (*e.g.*, solar outages, signal degradation) [13, 26, 27, 28, 29, 30, 31, 32]. The natural key phenomena affect the operation of satellite systems and should be taken into account because they cannot be eliminated (the cause of these phenomena have a natural background). Nevertheless, it is worth noting that no article has been found in the literature review that would present a total overview of many available network topologies for providing satellite transmission using VSAT. Thus, the main aim of this article is to fill the literature gap in this area and present the overview of the VSAT network topologies, supported by examples of existing solutions, taking into account the capabilities and services offered by these systems and the development directions of the next generation VSAT networks. In particular, a literature review method and a comparative method were used for this purpose. Many scientific publications have been analyzed, taking into account the practical use of satellite ICT networks, with particular reference to the collections available in the IEEE Xplore digital library. The literature has been chosen to present the possibilities of the VSAT topologies and networks to provide broadband ICT services. In this context, access to the Internet via satellites is particularly important, so as are technical factors.

On this basis, it becomes possible to acquaint the reader with: (1) the use of TCP (Transmission Control Protocol) in satellite links on the historical background; (2) the topologies of the VSAT networks, taking into account, among others, the organisational and technical aspects of their operation, the examples of systems, and the review of the services offered by them; and (3) the review of the next generation of the VSAT networks, including the examples of systems and descriptions of their possibilities. These issues are further detailed in the subsequent sections of this article.

3. AN IMPLEMENTATION OF THE TCP PROTOCOL IN SATELLITE LINKS

The TCP protocol was designed in 1981 for data transmission in terrestrial networks to ensure "robustness in the presence of communication unreliability and availability in the presence of congestion" [36]. Since a standard TCP implementation sees lost packets as an overload token to solve this problem, a slow start mechanism was introduced in 1992 [37]. The TCP protocol works by slowing down the transmission when lost packets are detected, and then the transmission rate is gradually increased to the maximum allowed by the network [5]. It could support several bit rates and delays, detect, correct and even delete corrupted segments of the sequence. At that time, data packets were transmitted only over short distances, which was associated with a slight propagation delay. One of the first global networks using the TCP/IP (Transmission Control Protocol/Internet Protocol) stack was Atlantic SATNET in 1981-1984 [9]. Paul D. Bacsich emphasizes that the satellite network's disadvantage is throughput because in VSAT networks using TCP/IP the delay is greater than in most terrestrial networks [2]. Since the hybrid network segment includes a geostationary satellite, a round-trip-time growth is many times faster than in terrestrial communication [9]. Large propagation delays are reduced by enabling the hybrid gateway to confirm the arrival of data from Internet hosts to hybrid terminals, which translates into the desired effect of reduced round-trip-time. Because the downstream path has very high throughput, many confirmation packets are generated, which may result in congestion in the low-bandwidth upstream path (selectively dropping redundant acknowledgment packets solves this problem) [9]. Norman Abramson presents an analysis of key design issues in the use of small terrestrial stations for a high-speed and low-delay Internet access [1]. One conclusion is that it is possible to find technologies and system architectures that can provide fast, shared access with a low delay to the ground stations [1]. There are two ways to realise upstream channels for satellite networks with asymmetric access. The channel can be implemented using a satellite link or alternatively, *e.g.*, leased line [6]. An attempt to "chat in real time" with the use of the client-server system leads to the following conclusions [2]: (1) TCP/IP is the preferred protocol stack for transmission in VSAT networks; (2) it is possible to connect several LANs at the same time for synchronous communication; (3) further work is needed to reduce transmission delays as long as they are acceptable (*e.g.*, client-server software can be used for this purpose); (4) an agreed router topology at all locations is feasible and does not translate into network delays. In low bandwidth VSAT networks, there are no problems with window sizes, but for higher bit rates there is a problem [5]. Therefore, in order to go through with the solution, some TCP implementations include features such as a window scale that supports windows larger than 64 kB [35]. J.S. Baras, S. Corson, S. Papadememou, I. Secka, and N. Suphasindhu similarly indicate that there are two main obstacles (bottlenecks) in achieving the assumed transmission rate [3]. The mechanism of controlling the flow of the TCP protocol from end to end depends on the size of the window and time of the return trip. The Internet Engineering Task Force (IETF) in connection with the application of the TCP/IP protocol stack in satellite networks has started to analyse it in terms of [38, 39]: (1) TCP header compression; (2) data compression; (3) modification of the TCP slow start algorithm; and (4) possibility to implement confirmations without existing TCP strategies. TCP-STAR, which has been designed to improve satellite Internet throughput, was proposed to modify the TCP only in the terminals on the sender side [15]. The routers and terminals on the receiver side remain unchanged. TCP-STAR operation is based on three mechanisms [15]: (1) suppression of unnecessary transmission control after segment loss due to bit error; (2) new method of window control based on available bandwidth; (3) prevention of bandwidth limitation by limiting retransmission time. In case of segment loss, TCP-STAR achieved better throughput than traditional TCP protocol (TCP-Hybla and TCP-NewReno). Hyoung-Kee Choi, Osama Qadan, Dolors Sala, John O. Limb and Jeff Meyers analysed, among others, the operation of MAC (Media Access Control) protocols for the purposes of implementing interactive web services via satellite [7]. The conclusion is that they can be successfully used to support Web traffic over a two-way satellite channel with the use of a VSAT terminal.

4. THE TOPOLOGIES OF THE VSAT NETWORKS

Since the early 1990s, satellite systems using VSAT technology could work in one of three configurations. Typically, star topology is used in the second generation of VSAT systems. In turn, in the third generation systems, the transmission channel properties have been taken into account. At the same time, the network designers focused on extending the catalogue of services offered by many IT applications, which forced the network to adapt to IP traffic, ensuring transmission quality QoT (Quality of Transmission). Then - as indicted above - Ethernet and TCP/IP protocols became popular for data transmission. Modern VSAT systems allow the transfer of IP traffic by modifying the TCP/IP protocol stack or by encapsulating IP packets. It is worth noting that initially, the communication channels were designed as symmetrical channels. If the channels were not symmetrical, there was a problematic issue of generating a large number of TCP overheads, as well as channel capacity [1]. Many VSAT systems were generally not compatible with other data transmission systems because operators used different technologies to equip ground stations. Only in the third generation of VSAT systems, the solutions allowing transmission of IP packets in Internet environment have been used [10, 17, 19, 20, 21, 34]. These systems operate on the basis of company solutions. One way, among others, is the use of DVB-RCS (Digital Video Broadcasting – Return Channel via Satellite) standard for the channel from the terminal to the central station and DVB-S (Digital Video Broadcasting – Satellite) standard for the channel to the terminal.

4.1. Star topology

VSAT networks for the provision of IT services using GEO (Geostationary Earth Orbit) satellites are very often built on the basis of star topology. In this case, there is a central station (hub) and many ground stations. The simplest one-way VSAT networks, used for data transmission between two VSAT terminals with antennae precisely pointing to the satellite, can function in this topology. Since the signal from the satellite is directed very precisely, any movement of the antenna is undesirable and results in signal losses (Figure 1).

The signal attenuation due to considerable distance between the ground antenna and the satellite is very high. The NOC (Network Operator Centre) directs the received traffic from the VSAT terminal to the satellite with a large diameter antenna, which contributes to compensate the losses. As a result, the reception

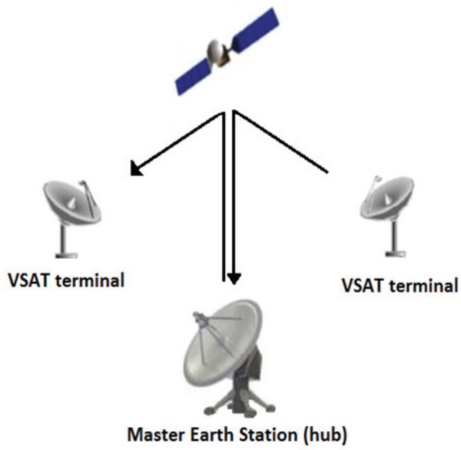

Figure 1: VSAT network for data transmission in a star topology.

of signals between the VSAT station and the central station is possible even in extremely unfavorable weather conditions. Figure 2 shows examples of Ka-band gain for the Ka-Sat satellite.

Freq (GHz)	19.70	19.95	20.20	29.50	29.75	30.00	Comments
Directivity (dB)	42.97	43.08	43.19	46.48	46.55	46.63	Using Effective Area of Main reflector
Sp & ILL Loss (dB)	1.67	1.67	1.65	1.12	1.13	1.14	Calculated using GRASP, including CHAMP feed model
Surface RMS (dB)	0.16	0.16	0.16	0.35	0.35	0.36	10 mil RMS on main reflector
X-polarization (dB)	0.03	0.03	0.03	0.03	0.03	0.03	21.50 dB
Horn & window (dB)	0.07	0.07	0.07	0.09	0.09	0.09	Measurement using machined Al part and 15 mil Lexan Radome
Circular Polarizer (dB)	0.10	0.10	0.10	0.15	0.15	0.15	Estimate
VSWR (dB)	0.04	0.04	0.04	0.04	0.04	0.04	20 dB RL at OMT flange
Total Loss (dB)	2.07	2.07	2.05	1.78	1.80	1.81	--
Gain (dBi)	40.79	40.90	41.03	44.53	44.59	44.65	--

Figure 2: Ka-band gain for the Ka-Sat satellite (materials provided by Eutelsat).

The example of a broadcasting system with two antennae is presented in Figure 3. These networks can be applied to distribute data, such as: one-way Internet, audio or video transmission.

Javier Gavilán, Alejandro Becerra and Ignacio Berberana analyzed several options of LAN internetworking with the use of a VSAT network [5]. They describe two main topologies of VSAT networks. In practice, the VSAT networks in star

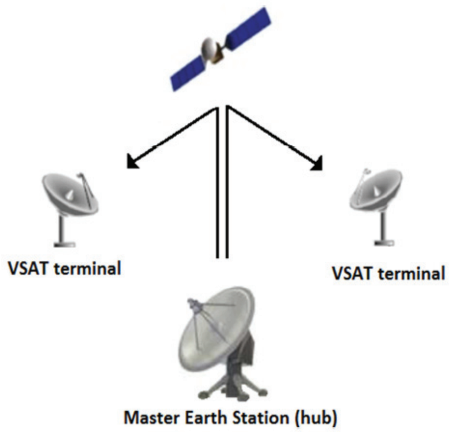

Figure 3: One-way VSAT network for distribution of data in a star topology.

topology are simpler than the networks in mesh topology and allow the use of cheaper terminals. With star topology, a two-way data transmission between the VSAT station (terminal) and the central station or hub becomes possible, where the terminal could both receive and send data to other stations or groups of terminals (Figure 4). Any RS (Remote Station) can communicate with other RS terminal and concentrator. Such transmission can be applied to the following areas: (1) dedicated interactive systems, for example, in the retail or banking sectors; (2) broadcasting services; (3) Internet coverage extensions.

The inter-station (hub) may be applicable to regenerate data or be used as a VSAT terminal, or a terminal in a privileged connection. Using the inter-station, the received signal regenerated in the central station is transmitted to the terminal. In the case of the VSAT network connecting the terminal with the central station, the propagation delay is half the value of the delay for the VSAT network that connects two ground terminals. The RS-RS connection must be performed by double jumping, which in turn results in a double delay of transmission time [5]. Therefore, there is a need to reduce propagation delay, among others, by supplementing the technical infrastructure with terrestrial links with a much lower propagation delay (exemplification may be a fiber optic links).

Practical implementations of VSAT networks result from their destination. One-way networks have many applications, among others, distribution of satellite radio and television, stock exchange, education, and introduction of a new products on a global scale. In turn, two-way data networks enable much more than just a combination of two one-way channels, in a client-server architecture, because they can be interactive. As the examples can be mentioned: interactive computer transactions, distributed remote process control, database inquiries, and reservation systems. A channel between the hub and the terminal is one to many or is broadcast as opposed to the channel between the VSAT terminal and the hub, which is many to one or multiple access channel [1]. In practice, the access method shall define the capabilities of the VSAT systems and the services provided by them. Multiple access is possible by means of FDMA (Frequency-Division Multiple Access), TDMA (Time-Division Multiple Access), and CDMA (Code-Division Multiple Access), respectively [5]. Data reception rate for AA/TDMA varies depending on the transmission direction using the TCP/IP and X.25 protocols. The NEXTAR BOD telephone network allows rates of up to 14.4 kb/s and 9.600-2048 kb/s depending on transmission mode [25]. On the other hand, it is possible to classify the access technique in accordance with the resource allocation policy (frequency bands, time slots or coding). Random and reservation systems can be indicated in this context. Javier Gavilán, Alejandro Becerra and Ignacio Berberana used the Hughes ISBN (Integrated Services Business Network) system settings with reservation schemes (each competing station asks for permission before transmission and after permission, then the allocated resources are used for transmission) [5].

Building such a network enables the extension of the existing IP network, which can be used in enterprise applications, *e.g.*, (1) to provide access to the Internet; (2) to create VPN (Virtual Private Network), and PVC (Permanent Virtual Circuit) solutions; and (3) to create ERP (Enterprise Resource Planning) systems ensuring rational management of the enterprise's resources. Satellite links can also be applied for VoIP (Voice over IP Protocol) applications, which services are often compatible with PCs (Personal Computers), and MACs (Macintosh Computers), as well as many devices using the TCP/IP protocol stack. It becomes possible to build a home network with satellite Internet access and the possibility of wireless

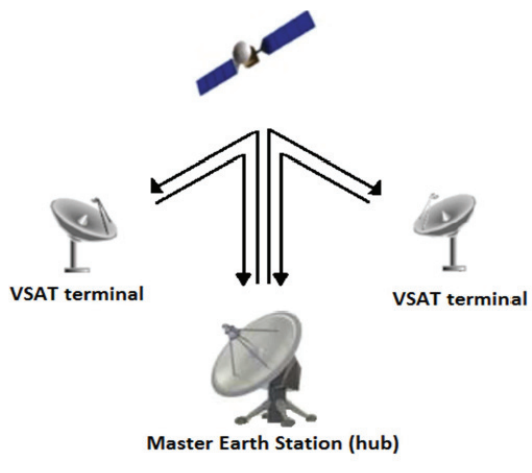

Figure 4: Two-way VSAT network for data transmission in a star topology.

data transmission for home use via a router. Routers are generally used to isolate the space segment from the ground segment. The example of broadband satellite network with their use is presented below (Figure 5).

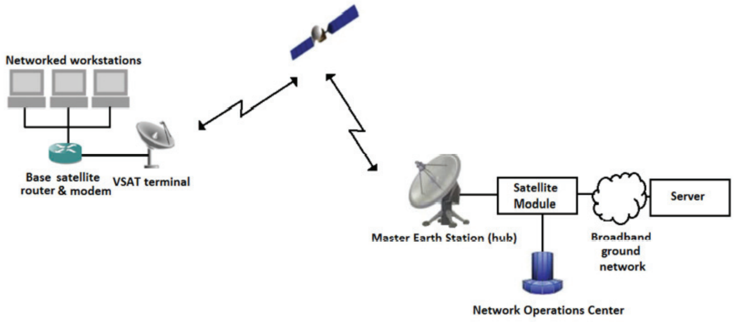

Figure 5: Applications of broadband satellite Internet network.

The example of using the star topology is $Linkway^{TM}$ platform, which offers TDMA support and handles multiple carrier sizes and data rates [22]. Benjamin A. Pontano underlines that it can be successfully used for military communication [22]. It supports asymmetric traffic and single-hop traffic. Moreover, it can work in both star and fullmesh topologies on a single platform, which has functions to create an architecture that handles multiple network topologies: mesh, star and virtual star (or hybrid). Its unquestionable advantage is a full compatibility with a new generation of Internet and multimedia. The platform offers possibilities that broadband systems will offer in the near future not only to the military, but also to standard users. It allows to extend the operation of traditional terrestrial networks via satellite. The comparison of products may be found in [22].

If we summarize a typical star-based network that uses a central node location with multiple remotes to handle two-way traffic, we can conclude that they may be useful for: (1) creating remote monitoring and surveillance systems; (2) gathering information; (3) extension of Internet access networks; (4) broadcasting services and simultaneously transmitting data to multiple VSAT terminals; and (5) creating interactive systems without the necessity to provide communication between VSAT terminals, *e.g.*, in banking, retail, and other industrial sectors. The undoubted benefit is the increase in the number of automated tools for network monitoring.

4.2. Mesh topology

The mesh topology is more flexible than the star topology but at the expense of its complexity and implementation of RF (Radio Frequency) and terminal control subsystems [5]. It allows all kinds of communication, but there are interferences in the terminal control subsystems. This topology is characterized by a lack of a central station (Figure 6). It means that one of the stations can act as the central station, but only for the purpose of providing management services, such as establishing connections, and supervising transmission quality. Only optional gateways with more traffic are possible. This can be exemplified by the use of distributed control networks. The antennae are usually larger in diameter to compensate for the losses in radio transmission. The traffic transmitted using them is generally small. The satellite in GEO orbit may function as a routing device and direct traffic to the specific ground-based VSAT terminals. Data transmission from subscriber terminals, which includes a return channel, is then carried out by the satellite. It serves as a bridge over the IP network.

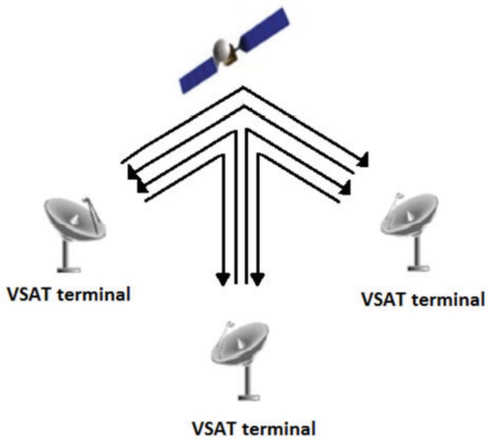

Figure 6: VSAT network to transmit data in a mesh topology.

The lack of central station causes the link budget not to be satisfactory in comparison to VSAT networks in the star topology. On the other hand, the advantage is that the propagation delay is half that of the star topology because the signal is not transmitted two times between the Earth and the satellite. Moreover, these networks are more robust against cyber-attacks because data are transmitted between VSAT terminals [33].

When transferring data between VSAT terminals or a group of terminals, one of them may act as a monitoring and supervising station (this solution does not use a dedicated central station). It requires a prior connection and reservation of the necessary resources. At the end of transmission, this connection is closed by the control and supervision station, so the resources return to the system. In the mesh topology stations can communicate with each other remotely, just like with a concentrator.

Paul D. Bacsich described the work of the JANUS (Joint Academic Network Using Satellites) project, which main aim was to build, using VSAT and ground network technology, a pilot trans-European operational network equivalent for

Internet access [2]. While the original aim of this project was to build a new generation of VSATs operating in mesh topology, consultations with the European Commission agreed on the application of available VSAT star technology in mesh applications. In this case, the VSAT network was a part of a much larger JANUS network.

A typical network operating in mesh topology using the *Linkway*^{TM} platform has many terminals, with one or two being assigned to administer the network, with no central hub location (it is possible to use the higher traffic gateways) [22]. These networks allow for any-to-any connections. The use of this technology is dedicated to the needs of: (1) telemedicine and videoconferencing services; (2) corporate communication (voice and data transmission); and (3) extension of the LAN network.

It is possible in the mesh topology to separate control and surveillance functions between all available VSAT terminals that monitor access to the satellite by tracking free and busy time slots with the use of TDMA, or frequency channels involving the FDMA. If a free slot or frequency channel appears, the VSAT station transmits the reservation information of the resource to other VSAT station. By means of a specific access method, it is possible to determine the beginning of transmission depending on the link load [1, 34]. These networks are usually dedicated to build company networks for information exchange between branches of a company [22], *inter alia*, (1) broadband voice/data communication networks in enterprises; (2) video conferences; (3) provision of medical services and healthcare; and (4) extension of the existing LAN (Local Area Network) infrastructure. In practice, networks can be a combination of star and mesh topology (part of them is then directed to the NOC centre).

4.3. Point-to-Point and Mixed topologies

Many IT services can also be delivered using point-to-point topology, both for one-way and two-way links. This topology is characterized by a lack of a central station. Network management and monitoring is then performed at a primary level. Such systems have many advantages, among others, (1) data rate; (2) lack of complicated access methods; and (3) security guarantee. Networks operating in this topology typically have the ability to select bandwidth in the dynamic BoD (Bandwidth on Demand) method, based on the link load. This technique, in contrast to a constant bandwidth allocation, allows to change transfer parameters. The transmission may be carried out on several levels of fairness depending on reports from the stations. One important issue is to increase the efficiency of satellite links, which frequently have limited resources, especially for high capacity links due to significant transmission delays. Two parameters, such as round trip time, and throughput, affect the interoperability of satellite systems, *e.g.*, real-time digital video over the Internet, and many other applications.

Apart from the fact that VSAT networks can operate in star, mesh, and point-to-point topology, they can work in a mixed (hybrid) configuration. The *Linkway*^{TM} platform which is intended, in particular, for the use in military and maritime sectors is the example [22]. When virtual star (or hybrid) networks use this platform, they consist of at least two hubs or gateways and apply mesh communication between hubs, as well as remote communication with multiple hubs and asymmetric data transmission rate. The two-layered topologies are dedicated to handling high-traffic gateways with mesh connectivity to each other, and to provide connectivity to small remote locations that are connected to a high-traffic gateways [22]. There is a need to guarantee, for each of the link layers, the fiber-like bit error ratio (BER) performance and asymmetric transmission rate. We can conclude that they may be useful for: (1) building international corporate WANs (Wide Area Networks); (2) and creating VPNs, which are operated by service providers. Other properties of mixed networks include, *inter alia*, remote connectivity with multiple hubs and asymmetric data rates. Mixed networks standardized by ETSI (European Telecommunications Standards Institute) are mostly used for building (1) corporate WANs, including international Intranets; and (2) VPNs operated by a service provider.

5. THE NEXT GENERATION VSAT NETWORKS

While communication satellites were seen as a backbone for computer networks, with the development of VSAT technologies, they have become economically competitive also for large data networks, and for connecting local networks. The direct data transmissions to the end users have appeared with the new generation of the high power DBS (Direct Broadcast Satellites), and the changing traffic and usage satellites, such as [9] (1) networks where the satellites provide the sole connection to the Internet; and (2) configurations where the satellites ensure high-speed overlay networks, in addition, to a terrestrial Internet connection. Both configurations are particularly important for regions and countries with a low population density and inadequate telecommunications infrastructure. Although, they also have potential for new applications, especially in developed countries. Horst D. Clausen and Bemhard Nocker present the system architecture and performance reports for various data services and applications available in DBS systems [9]. The development of VSAT networks has led to the establishment of many broadband services provided via satellite (Figure 7). Two-way interactive data networks are a combination of two different ways of communication with the client/server configuration, which distinguishes them from one-way networks [1]. Most services are related to interactive data traffic, voice communication, and satellite news gathering. In a direction from a concentrator to the terminals, the communication channel is commonly one to many or a broadcast channel, and in a direction from the terminals to a concentrator, it is many to one, or a multiple access channel. Norman Abramson emphasizes that broadcast channel architecture is almost always configured in TDMA mode [1]. In turn, Leonid Volkov presents the solutions of Russian Satellite Communications Company (RSCC) [25], which offers, among others, direct access to the Internet and digital telecommunications network. The NEXTAR-AA/TDMA system is dedicated to the needs of interactive data transmission. It works in star topology. The other system is Nextar-BOD (Bandwidth On Demand). It is used for many transmission, *e.g.*, (1) video conferencing; (2)

high-speed access to the Internet; (3) data transfer between local user computer networks; and (4) switching and voice/faximile transmission. This system can operate both in mesh and star topologies [25]. Satellite connection rates are constantly increasing. While until about 15 years ago, VSAT systems were not able to send data via satellite, the data were transmitted using mobile communication (then transmission rate was about 512 kb/s) [8]. Many commercial systems implemented by Hughes Network Systems (HNS) Inc., have used 400 kb/s transmission link, and PSTN (Public Switched Telephone Network) as a return link to the Internet service provider [7]. $Linkway^{TM}$ 2000 terminal is stackable for higher throughput applications (2Mb/s), up to 32 Mb/s [22]. For comparison, WINDS (Wideband InterNetworking Engineering Test and Demonstration Satellite) that was launched in 2008 allows transmission rate to equal 1.2 Gb/s [15]. Hiroyasu Obata, Kazuya Tamehiro and Kenji Ishida [15] emphasize that it may be applied to: (1) education; (2) medicine; as well as (3) disaster countermeasures. Gerson Souto and John Stevenson describe the capabilities of multicasting, Internet Direct to Home (DTH) systems and VSAT combinations with wireless terrestrial TV extensions to further expand of the Internet through satellite services on the basis of the INTELSAT product line [24]. This includes a hybrid system, where the Internet data stream is combined with video and audio streams - for transmission to the end user's terminal with a terrestrial return channel. However, there are also systems that can be used for the purposes of Internet data transmission with or no satellite return channel (as a case of one-way push systems). In practice, it is possible to bundle unicast and multicast traffic at the same platform [24]. First time ETSI adopted DVB/MPEG standard in 1998, which encouraged the development of various transmissions based on TDMA for the high-speed digital broadcast channel. In the connectionless architecture, a throughput of 1 Mb/s has been achieved. Nowadays, besides typical informatics (Internet) or telecommunication applications, many VSAT networks are applied in industry. They can be used for, *e.g.*, (1) enterprise networks; (2) monitoring systems; (4) video conferences; (5) e-learning; and many others applications. Since satellites use digital transmission techniques, it is clear what kind of digital information is transmitted. They may be useful for sending data packages [9]. The aim is to cooperate with terrestrial networks, which includes systems supporting IP traffic using standardized transmission protocols. As mentioned above, ground networks connected to the satellite system should operate according to the TCP/IP protocol stack. The key issue is to adapt protocols to the satellite transmission. It is possible to use multi-mode VSATs to ensure communication during disasters. Moreover, the VSAT can be developed through the application of SDR (Software Defined Radio), designed on the basis of terrestrial technologies of cognitive routers, having functions of the next-generation wireless network and mobile terminal [18]. It can be used to connect two satellite systems (EsBird by SKY perfect JSAT and the local authorities satellite communications network system by LASCOM). The SDR VSAT system has been tested on March, 2014. Communication rate is between 32 kb/s and 2 Mb/s (the maximum is equal to 8 Mb/s) [18]. It is also possible to indicate a research and development project entitled "Satellite communication networks valid for disaster recovery" as the example of work focused on the new generation of VSAT systems, which emerged in the aftermath of the earthquake and tsunami that struck Japan on March, 2011 [40].

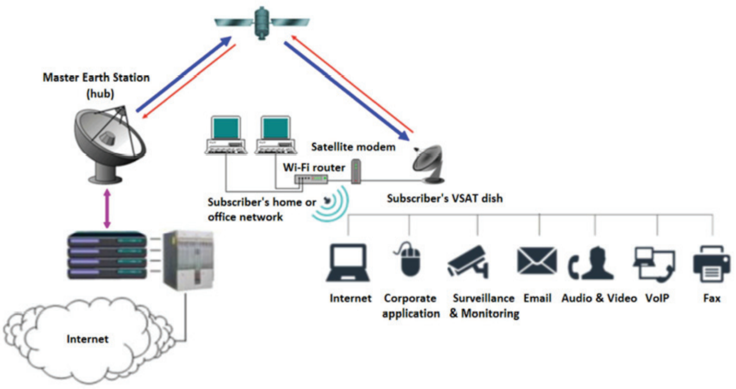

Figure 7: Example of VSAT network cooperating with wireless LAN. (own elaboration on the basis of: https://www.envision.in/vsat)

In planning satellite networks many non-functional properties of the network should be considered that determine the selected solutions, *inter alia*, (1) reliability (many different levels can be guaranteed by the transport protocol); (2) scalability (in terms of space and number of users); (3) performance, including an ease of network reconfiguration; (4) data transmission standards (*e.g.*, modification of the TCP/IP protocol stack, the use of DVB-S/DVB-S2 platform); (5) co-operation of VSAT networks with other networks. Due to the VSAT network architecture, it is important to provide support for IP traffic by satellite network designers using a layered model with separated functions, which consists of a physical layer and a data link layer, and ensure satellite autonomous functions with high transparency, which is typical for VSAT networks (IPv4 or IPv6) [33].

With this in mind, one example of the next-generation VSAT networks is iDirect. For instance, the 5IF Infinity system uses technology that supports IP packet transmission. It also applies the TCP/IP protocol stack. The signals are transmitted in the L-band with a transmission rate, between the VSAT terminal and the central station, up to 8.4 Mb/s [34]. This system can work in star, mesh, or point-to-point network topology. The central station may cooperate with 5 satellites in geostationary orbit. The transmission power of the system terminals is equal to 2 W or 4 W with the antenna diameter of 1.2 m. Table 1 shows how these networks are equipped with software management modules.

The VSAT terminals can operate in a variety of network topologies, fulfilling many functions, such as data compression, to optimize transponder bandwidth usage and data encryption. The implementation of the modules that perform the compression of data determines the bandwidth efficiency. The 5IF Infinity system allows the real-time traffic classification based on the following data: (1) IP

Module	Destination
iBuilder	management the central station and VSAT terminals
iMonitor	control the system operation

Table 1: Characteristics of the selected modules.

addresses of sender and recipient networks/users; (2) port numbering ranges/port numbers for sender and recipient; (3) DiffServated Services network architecture bits and type of service field bits in the IP header v4, which describe packet validity and packet requirements; (4) local network identifier VLAN (Virtual Local Area Network); (5) protocol type used (TCP, UDP, HTTP, and others). It is possible to specify the queue length, bandwidth allocated and modify packet handling rules, which includes the data rate for a selected application or a group of applications. This allows to adjust the cell size to the size of the packet. The central station may contain dedicated software for: (1) TCP acceleration; and (2) packet segmentation and transport packet scattering. The levels of received signals and the bit error rate can be monitored. This means that many characteristics may be corrected depending on the prevailing conditions, such as (1) transmitting power; (2) type of modulation; (3) redundant coding efficiency. In addition, the protective bandwidth can be reduced from 40% to 20% by using digital FPGA (Field-Programmable Gate Array) filters, so that 20% of the bandwidth may be used additionally to transmit data [34]. The transmission bandwidth is limited by the transponder with the 11.5 Mb/s transmission rate for high-frequency radio link. The FEC (Forward Error Correction) redundant coding is used to code, which is approximately 1.5 dB higher than the efficiency of Reed-Solomon coding method preceded by Viterbi coding (it ensures the same bit error rates by the use of turbo codes) [33]. The frame format is not permanent because it may be different depending on the TCP/IP traffic transmitted. However, during data transmission from VSAT terminals, a reservation protocol with dynamic link access multiplication can be used so as more than one frequency channel. Transmission is carried out at the rate of 5.75 Mb/s, and the bandwidth is limited by the transponder band. While the frequency range can be associated with each terminal, the allocation of the resources on terminals is tested several times per 1 second. As the transmission modules support 9 Mb/s traffic to VSAT terminals and 4.2 Mb/s from VSAT terminals to the central station, for example, 20 modules can obtain the total traffic to 180 Mb/s to VSAT terminals, and 84 Mb/s from VSAT terminals to the central station [34]. The use of higher-row modulation allows the increase in the offered rates. As the advantages of the system may be indicated: (1) simultaneous handling of many connections; (2) system scalability; (3) acceleration (*e.g.*, TCP and HTTP acceleration) for both directions of transmission; (4) encryption of data; (5) possibility to define QoS level for both directions of transmission; and (6) flexibility (the system can be used for transmitting packets, providing Internet access, ensuring multimedia services and broadcast).

Another example of the next-generation VSAT networks is the HX systems family of Hughes. The HX100 system is based on the DVB-S standard. It operates in star topology and is dedicated to building: governmental, corporate, and forwarding networks to stations of mobile network operators. It may serve as an alternative to typical radio links. As the HX100 system operates in the frequency bands C, K_u, and K_a, it can be used for many applications. Typically, TDMA access method is used. Transmission is carried out at a maximum rate of about 121 Mb/s for downlink, and 3.2 Mb/s for uplink. The unquestionable advantage is the dynamic allocation of transmission bandwidth and QoS assurance. In addition, similarly to the 5IF Infinity system, it is possible to choose the type of modulation, adaptive coding, and the configuration of terminals depending on the availability of services. Aloha protocol is used in the transmission channel to the central station. As the characteristics of the central station, the following can be distinguished, *e.g.*, (1) small size; (2) modular design; (3) scalability; (4) reliability; (5) distribution of transmission resources based on the type of protocol; (6) uniform service of RT (Real Time) and N-RT (Non-Real Time) traffic. Link capacity may be modified depending on data priority and their type. The symbolic baud rate to modulate the information element is from 1 to 45 Msymbols/s, while the step is equal to 1 Msymbol/s. Despite of the fact that the transmission bandwidth is dynamically allocated, the VSAT terminals do not overload the bandwidth when there is no traffic. As the transmission rate may be adjusted in a small step, it can be useful for building adaptive VSATs using the HX system. The HX100-based VSATs are compatible with the IPoS (IP over Satellite) standard, which is recommended by a wide range of international organizations, such as ETSI, ITU (International Telecommunication Union) and TIA (Telecommunications Industry Association). A newer version is the Hughes HX200 system that offers better data transmission rates. Its improvement is the HX260 system, which is suitable for mesh topology. In turn, the HX280 system is additionally equipped with AES256 (256 Advanced Encryption Standard) protection. The ISO OSI RM (International Organization for Standardization – Open System Interconnection Reference Model) reference layers are divided into two parts, the first one is a satellite-dependent part (SPHY, SMAC and SLC layer), and the second is a satellite independent part (responsible for IPv4 or IPv6). Both parts are connected via points in order to provide an SI-SAP (Satellite Independent – Service Access Point) and thus, may cooperate with terrestrial networks [34]. The system is equipped with many mechanisms, such as (1) TCP acceleration; (2) advanced routing methods; (3) data compression; (4) support for ICMP (Internet Control Message Protocol), and DNS (Domain Name System); (5) closed loop transmission quality supervision. It is worth noting that it is possible to switch the modulation and coding techniques from the VSAT terminal to the central station depending on the parameters of the received signal. This system uses the Reed-Solomon coding preceded by Viterbi coding in the link to VSAT terminals in DVB-S standard. In turn, the BCH (Bose-Chandhuri-Hocquenghen) coding with low density parity check control is used in DVB-S2 standard. In practice, the coding efficiency is dependent on the modulation type (QPSK, 8PSK). BER (Bit Error Rate) equals about 10^{-10} typically. DVB-S networks for video transmission often use the MPEG-2 loss-making compression. IP packet transmission involves placing the packet in the MPEG-compliant transmission frame, after that, the packet is sent to the DVB-S stream. The transport stream from individual segments supports multiple users, which is associated with the efficiency of channel use. Practically, there are 8 containers needed to transmit a 1500 B packet because the length of a primary DVB-S data transmission unit equals 188 B [34]. When using the DVB transmission platform, it is possible to lease the frequency band of the transponder and the channel bandwidth from the operator, which allows for the provision of Internet services to mass customers. This characteristic is not available for solutions implementing the TCP/IP protocol stack in the link. In order to provide interactive services, a return channel should be used. Usually, access multiplication techniques (TDMA, FDMA) and OQPSK modulation are used for the link to the central station. Generally, data rates range is from 128 kb/s to 3.2 Mb/s. The advantage of the HX systems is a remote power control of VSAT terminals. The transmitters' power in C-band is equal to 2 W, in K_u-band is equal to 1 W or 2 W, and in K_a-band is equal to 1 W, 2 W or 3.5 W. For example, the system's HX100 performance enables the use of up to 500 terminals or data rate of up to 12.8 Mb/s with a maximum of 16 channels towards the central station [34]. Standard transmitters have power limits set without the possibility of Dynamic TX Power Control technology. However, this technique, offered by several satellite operators, enables automatic adjustment of the transmitter power from 2 W to 6 W according to the weather conditions, which is especially important during heavy rain and storms [29, 30, 31, 32]. Based on the information provided, it can be concluded that new technologies are being researched and developed to adapt the VSAT system to many communication methods, which becomes possible with the use of many modulation and control schemes [11, 18]. Noriharu Suematsu, Suguru Kameda, Shigeru Eguchi et al. [11] indicate the greatest advantages of such systems: (1) multiple dual connection modes with government or private networks; (2) portability and automatic antenna control system; as well as (3) low power consumption. Mamadou A. Barry, James K. Tamgno, Claude Lishou and Renaud K. K. Maleka use the VDI (Video Data Image) network of ASECNA4 (Agency for the Safety of Air Navigation in Africa and Madagascar), which is built in star topology [4]. This way, it is possible to obtain: (1) a centralized architecture (the hub); or (2) a distributed architecture with a server on each side. In the first case, delays and unnecessary bandwidth consumption increase because the hub receives traffic from all network with a large number of configurations. The disadvantage is the unavailability of a single server and its possible backup [4]. In the case of distributed architecture with a server on each side, the bandwidth of the VDI network is used for internal communication, while the configuration and server load are limited due to limited traffic (unavailability of the server affects only the given side).

6. CONCLUSIONS

Nowadays, in the 21^{st} century, the broadband satellite networks that use GEO satellites provide many IT services. Undoubtedly, satellite data networks can compete with terrestrial networks not only in terms of economic factors (the cheapest and quickest way of building global networks), environmental degradation (the lack of typical excavations to build terrestrial technical infrastructure), but also, in some cases, their use is becoming the only way to ensure broadband communication. As the example, it is worth mentioning emergency situations caused mainly by natural disasters (floods, fires, earthquakes, whirlwinds). In addition, such networks can provide a backup link for typical ground connections. Information systems engineering using VSAT networks allow the provision of multimedia services and the construction of computer networks. As the examples of IT applications for end users, both home and corporate, can be mentioned: (1) direct access to the Internet; (2) data exchange between computer networks and satellites; (3) long-range circuit routing. Moreover, the idea of building satellite networks using VSAT technology is particularly relevant in areas where investments using alternative means of communication would be impossible for various reasons (*e.g.*, deserts, oceans and seas, mountains, remote uninhabited regions of the world). Their importance is significant even in highly developed countries, wherever there is no access to traditional ground infrastructure. In practice, satellites can be used to download large amounts of data, including satellite imaging data. A wide range of applications is made directly possible by services offered over the Internet, which is, in this sense, the cheapest source of access to global communications. From the point of view of data rate and capability, the cooperation of satellite networks, operating in the various topologies described in the article, seems to be crucial. VSAT networks can combine secure traffic between private satellite networks and corporate headquarters networks within various options chosen by consumers, (*e.g.*, point-to-point, PVC, VPN, and many others). However, it is necessary to adjust standards and analyze the development trends of the next-generation VSAT networks in order to cooperate in terms of services offered and transmission techniques used. There is therefore a need to analyze the prospects and trends in the development of the VSAT networks, which was done by reviewing the state of the art.

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