Architecture of Time Division Multiple Access (TDMA) for Mobile Satellite Communication (MSC) Networks

Dimov Stojce Ilcev
University of Johannesburg (UJ), Johannesburg, South Africa

Abstract: This paper describes in particular architecture of Time Division Multiple Access (TDMA) scheme applicable in Mobile Satellite Communication (MSC) networks. In satellite communication systems, as a rule, especially in MSC systems many Mobile Earth Stations (MES) users are active and communicate at the same time via satellites and Land Earth Stations (LES). The problem of simultaneous communications between many single or multipoint mobile users, however, can be solved by using Multiple Access (MA) technique. Since the resources of the systems such as the transmitting power and the bandwidth of Radio Frequencies (RF) are limited, it is advisable to use the channels with complete charge and to create a different MA to the channel. This generates a problem of summation and separation of signals in the transmission and reception parts, respectively is discussed. Deciding this problem consists in the development of orthogonal channels of transmission in order to divide signals from various users unambiguously on the reception part.

Key Words: TDMA, MSC, MES, LES, MA, RF, VDV, GNSS, GPS, GLONASS, BeiDou, Galileo, CNS, PVT, TDMA, CDMA, RDMA, FDM, MCPC, SCPC, TDM, VSAT

1. Introduction

In radio transmission systems, such as cellular, fixed and mobile satellite nwtworks a link can be performed between the transmitter (Tx) and the receiver (Rx) through digital or analog signal. Thus, these transmission links can be affected by many factors such as the bandwidth, data rate and Signal-to-Noise Ratio (S/N) values. As a result, new radio technological transfer and innovations techniques comprehensively affect the improvement of various satellite transmission systems with the intention to increase the quality of the transmission signal and the efficiency of the bandwidth. Therefore, increasing the capacity of satellite transmission techniques with technological advances in Multiple Access (MA) techniques is important for modern improvements in fixed and mobile satellite communications.

In other words, MA scheme is a technique that allows many users to share the same communication link with a performance as good as possible. This technique is used when particular channels is allocated to fixed or mobile users in applications that require a continuous transmission with less noise, interference and other transmission impairments as possible. Also, these MA applications are so susceptible to delay distortion, and they could become so annoying and dangerous on the operation of satellite transmission and communications. For example, use of Voice, Data and Video (VDV) transfer and conference applications require dedicated onboard satellite channels for good transmission performance without any interruption.

Satellite switched TDMA technique is a method used in fixed and mobile satellite communication to efficiently allocate transmission time slots to different users. In this method the satellite acts like a system traffic controller, giving each Fixed Earth Station (FES) and MES terminals a specific time interval to send and receive data. This process prevents interference and ensures that multiple stations can use the same satellite without any overlapping in signals.

The Time Division Multiple Access (TDMA) modulation method divides the Radio Frequency (RF) bands available for satellite network transmission, allowing multiple users to simultaneously communicate and send data without interference. This technique plays a key role in the efficiency and reliability of Global Navigation Satellite Systems (GNSS) such as the US Global Position System (GPS or the Russian Global Navigation Satellite System (GLONASS) antennas and is also used in MSC system and telephone lines, which divides the total bandwidth over multiple channels. Besides the GNSS-1 GPS and GLONASS networks, there are other second generation GNSS-2 networks such as the Chinese Beidou and the European Glilveo. In these GNSS networks, each Earth station is assigned a specific frequency sector or dedicated band, which ensures that signals are accurately transmitted and received.

In general satellite communication systems, GNSS is used for TDMA time measurement on the satellite and cellular or any terrestrial communication links and Network Time Protocol NTP) type services for ICT, network, satellite monitoring and control. However, in professional MSC systems radio cellular networks GNSS is used for the synchronization of timeslots and for handovers between base stations. In Public Switched Telephone Networks (PSTN), GNSS is used as a backup in case timing information from atomic clocks is lost. GNSS reference time can be used for time of day, traffic timing and time slot management. Many telecom networks employ local oscillators that enable service to be temporarily maintained in case of GNSS loss.

Otherwise, to understand the importance of TDMA technology for GNSS (GPS or GLONASS) onboard mobile satellite antennas is essential for everyone involved in the satellite Communication, Navigation and Surveillance (CNS) systems sector. Thus, it's not just about time sharing, but also it's about optimizing communication paths to improve location accuracy and reliability. While going deeper, it is necessary to explore how TDMA modulation supports the functionality of a modern CNS, positioning and tracking system, ensuring that we are always on the right track.

Therefore, TDMA modulation finds its use across a spectrum of applications in the the CNS sector, as a go-to choice in scenarios requiring the simultaneous handling of multiple data streams over a limited bandwidth, such as follows:

1. Fixed and Mobile Satellite Communications – This is an FSC and MSC system that can allocate separate frequency bands for each satellite communication channel and it can enable the transmission of different Voice, Data and Video (VDV) streams, satellite broadcasting, broadband and Internet without crossing paths;

2. Cellular Network Systems – Where each call is assigned a unique frequency band, allowing multiple calls to be handled simultaneously without interference;

3. Satellite Navigation, Tracking and Positioning Antennas for GNSS Networks - In this context, TDMA plays a key role in preventing signal interference between satellites and GNSS antennas, which is essential for accurate positioning for maritime, land mobile (roads and rails) and aviation sectors, where very accurate Position, Velocity and Time (PVT) and other location data is most important; and

4. Aerospace and Defense Networks – Military networks require a highly reliable systems of radio and satellite CNS systems and devices, which would have to function without any interference critical to personnel, Navy, Land and Air force operations.

There are five the following principal forms of MA techniques:

1) Frequency Division Multiple Access (FDMA) is a scheme where each concerned LES or MES is assigned its own different working carrier RF inside the spacecraft transponder bandwidth.

2) Time Division Multiple Access (TDMA) is a scheme where all concerned Earth stations use the same carrier frequency and bandwidth with time sharing, non-overlapping intervals.

3) Code Division Multiple Access (CDMA) is a scheme where all concerned Earth stations simultaneously share the same bandwidth and recognize the signals by various processes, such as code identification. Actually, they share the resources of both frequency and time using a set of mutually orthogonal codes, such as a Pseudorandom Noise (PN) sequence.

4) Space Division Multiple Access (SDMA) is a scheme where all concerned Earth stations can use the same frequency at the same time within a separate space available for each link.

5) Random (Packet) Division Multiple Access (RDMA) is a scheme where a large number of satellite users share asynchronously the same transponder by randomly transmitting short burst or packet divisions.

Currently, these methods of different multiple accesses are widely in use with many advantages and disadvantages, together with their combination of hybrid schemes or with other types of modulations. Hence, multiple access technique assignment strategy can be classified into three methods as follows:

(1) Preassignment or fixed assignment;

(2) Demand Assignment (DA) and

(3) Random Access (RA); the bits that make up the code words in some predetermined fashion, such that the effect of an error burst is minimized.

In the preassignment method channel plans are previously determined for chairing the system resources, regardless of traffic fluctuations. Therefore, this scheme is suitable for communication links with a large amount of steady traffic. However, since most mobile users in MSC do not communicate continuously, the preassignment method is wasteful of the satellite resources. In Demand Assignment Multiple Access (DAMA) satellite channels are dynamically assigned to users according to the traffic requirements. Due to high efficiency and system flexibility, DAMA schemes are suited to MSC systems. In RA a large number of mobile users use the satellite resources in bursts, with long inactive intervals. In effect, to increase the system throughout, several mobile Aloha methods have been proposed.
In fact, the TDMA modulation scheme is one of the most common digital division multiple access methods. It is one of two ways to divide the limited spectrum available over a radio frequency (RF) cellular channel. In simplest terms, TDMA enables multiple users to share the same frequency by dividing each satellite channel into different time slots. In effect, a single frequency supports multiple and simultaneous data channels. So, with a two-time slot TDMA, two users can share the same frequency. With a three-time slot TDMA, three users can share the same frequency and so on and their frequency band is divided into channels of equal bandwidth so that each conversation is carried on a different frequency.
The ongoing advancements in satellite CNS systems, mobile tracking solutions and ICT technology also hold promising prospects for TMA modulation. The development of more sophisticated GNSS (GPS or GLONASS) satellites equipped with advanced TDMA capabilities is expected to further enhance navigational precision and reliability. This is particularly crucial for applications requiring high accuracy, such as autonomous driving, precision agriculture, and critical military operations.

2. Overview of Time Division Multiple Access (TDMA) Systems

Multiple access schemes are used to allow many fixed and mobile users to share simultaneously a finite amount of frequency spectrum. The sharing of spectrum is required to achieve high capacity by simultaneously allocating the available bandwidth (or the available amount of channels) to multiple fixed or mobile users. For high quality satellite communications, this must be done without severe degradation in the performance of the system.
In TDMA, fixed or mobile users transmit in rapid succession, each using their own time slot. This shuttling process is so fast each user thinks they occupy the same Radio Frequency (RF) channel at the same time. By allocating a discrete amount of bandwidth to each user, TDMA increases the amount of data that can be carried over the channel, while enabling simultaneous conversations.
All cellular networks in the world use TDMA technology in transmission systems, including the following systems:
1. Digital advanced fixed and mobile satellite VDV networks – This service can be provided by FES and MES terminals;
2. Cellular radio or Global System for Mobile Communication (GSM) networks - This service can be provided by various types of cell phones in all countries;
3. Personal Digital Cellular (PDC) system – This service is old 2^{nd} generation cellular networks;
4. Integrated Digital Enhanced Network (IDEN) networks – This service invented by Motorola is a TDMA digital wireless standard designed to work in special frequency bands originally for analog Specialized Mobile Radio (SMR) networks; and
5. Digital Enhanced Cordless Telecommunications (DECT) networks – This standard service is used in call centers, hospitals, job sites and other workplaces, such as onboard mobiles, ships, land vehicles (roads and rails) and aircraft.
Satellite Switched-TDMA divides the communication time into small slots, and assigns each slot to different FES or MES users. Instead of using the single satellite antenna beam, there is a huge number of narrow antenna beams that can be used by switching the interconnection of the antenna in synchronism with the TDMA frame rate, hence covering the zone sequentially. This helps in maintaining continuous communication on the entire coverage area. This whole thing is called Satellite Switched TDMA (SS/TDMA).
The following explanation shows how TDMA works in simple terms:

1. Allocating Time Slots – The TDMA satellite technology system offers flexibility in allocating bandwidth to different users. Namely, the number of time slots allocated to each fixed or mobile user can be dynamically adjusted based on their requirements, traffic load or Quality of Service (QoS) needs. This dynamic allocation helps in optimizing the utilization of resources. In effect, the satellite assigns specific time slots to each fixed or mobile user just like scheduling appointments to ensure everyone gets a turn without overlapping;
2. Switching Mechanism – Satellite Switched TDMA is a method used in satellite communication to efficiently allocate transmission time slots to different users. In this method the satellite acts like a system traffic controller, giving each user station a specific time interval to send and receive data. During its time slot, a user sends data to the satellite, which then switches and sends this data to the recipient station.
3. Synchronization – This service in TDMA networks is a critical requirement and important to accomplish synchronization for geographically-dispersed users with different propagation delays, guard times are required to ensure transmissions do not overlap. The satellite coordinates the timing so that each station knows exactly when to transmit and receive data, avoiding interference; and
4. Dynamic Adjustment – This TDMA radio and satellite service is based on resource allocation optimization method for dynamic adjustment of MF-TDMA single-beam satellite communication system. A technology of MF-TDMA and satellite communication system, applied in the field of resource allocation optimization based on dynamic adjustment of Multi-Frequency Time-Division (MF-TDMA) single-beam satellite communication system. In effect, the system can adjust the allocation based on traffic demand, ensuring efficient use of the available frequency bandwidth. Namely, TDMA offers flexibility in allocating bandwidth to all satellite users.

Regarding the previous explanation, ddynamic TDMA is a multiple access control protocol that allocates specific time slots for each device/user to transmit or receive data, dynamically to those nodes which have data to send, providing predictable access to the communication medium. This mechanism has proven to efficiently reduce collisions during data transmission through Wireless Sensor Networks (WSN) system. The goal is to improve the current node detection algorithm by considering the other important factors, incorporating advanced node tracking methodology, and increasing the flexibility of the slot allocation process. In effect, this can be achieved by improving the algorithm that allocates time slots only to nodes that potentially have data to send, and then dynamically allocates time slots of variable length, thereby reducing empty slots and increasing channel utilization. The number of satellite time slots allocated to each user can be dynamically adjusted based on their requirements, traffic load, or QoS needs. In tat way, this dynamic allocation helps in optimizing the utilization of resources.

However, as far as the transmission and reception segments of the TDMA techique are concerned, it is necessary to underline that the uplink is used to transmit data to the AccssPount (AP). The downlink is used to send control information for synchronization, node discovery, configuration and allocation of specific uplink slots to the nodes. The uplinks signals which are further received by satellite are then demodulated to recover the streams of bit. These are structured in form of a sequence of packets addressed to the different receiving Earth stations. The satellite creates a TDMA frame of data which contains addresses to the specific Earth stations and switches. It transmits the beam in the direction of receiving Earth stations in the form of packets.

Otherwise, regarding the characteristics of TDMA technique with satellite switching, it can be concluded that Satellite Switched TDMA provides an additional level of access because it consists of fast reconfiguration of antenna beams, which ffeatures are as follows:
1. Satellite switched TDMA modulation provides an additional level of access as it consists of rapid reconfiguration of antenna beams;
2. Interconnection between satellite TDMA uplink and downlink transmission is been performed by a high-speed matrix;
3. Satellite Switched TDMA provides full interconnection for various coverage of regions;
4. In the terms of beam width satellite switched TDMA provides better coverage of the region; and
5. For maintaining continuous fixed and mobile communication on the entire coverage region Satellite Switched TDMA provides a baseband processing transponder.

The satellite switched TDMA system provided the following advantages:
1. As TDMA is digital it has all the advantages over the FDMA;
2. According to changing traffic demands, this system can be easily reconfigured;
3. Can easily handle mixed VDV transmissions; and
4. Intermodulation distortion and noise is been reduced, with resistance to noise and interference.
Disadvantages of Satellite Switched TDMA are as follows:
1. Precisely synchronization is been required;
2. If satellite users we are accessing all the transponder bandwidth, then we require a high bit rate of transmission on each and every earth station. Which means it requires high transmission power than the FDMA technique; and
3. Because of the high satellite transmitting bit rate, it is not suited for narrow-band signals which come from the small earth stations.
Satellite Switched Time Division Multiple Access (SS-TDMA) is a useful technology in fixed and mobile satellite communications. It efficiently allocates time slots for different users, ensuring clear and uninterrupted transmission. This system improves bandwidth utilization and adapts to varying data demands, making it suitable for a wide range of applications, from cellular networks, terrestrial telecommunications, broadcasting to Internet services and military communications.
The benefits of TDMA technology are efficient sharing of the channels, reduced interference and propagation effects, increased capacity and simultaneous connection are some of the benefits of satellite switched TDMA system. The difference between Satellite Switched TDMA and traditional TDMA are that traditional TDMA assigns fixed time slots to each users whereas satellite switched TDMA dynamically assigns time slots based on demand, optimizing bandwidth usage. The main limitations of SSTDMA are that the dynamic assignment of time slots increases complexity of the mechanism and may introduce additional delays compared to fixed-time TDMA technology.

3. Concepts of the Time Division Multiple Access (TDMA) Technique

Time-division multiple access (TDMA) is a channel access method for shared-medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots. The fixed and mobile users transmit in rapid succession, one after the other, each using its own time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity. Dynamic TDMA is a TDMA variant that dynamically reserves a variable number of time slots in each frame to variable bit-rate data streams, based on the traffic demand of each data stream.
Except in satellite systems, TDMA is used in the digital terrestrial and cellular systems, such as GSM, IS-136, PDC and IDEN, and DECT standard for portable phones. However, TDMA was first used in satellite communication systems by Western Union in its Westar 3 communications satellite in 1979. It is now used extensively in satellite communications, combat-net radio systems, and Passive Optical Network (PON) transmission for upstream traffic from premises to the operator.
In addition, TDMA is a type of Time Division Multiplexing (TDM scheme with the special point that instead of having one transmitter connected to one receiver, there are multiple transmitters. In the case of the uplink from a mobile phone to a base station this becomes particularly difficult because the mobile phone can move around and vary the timing advance required to make its transmission match the gap in transmission from its peers.
In TDMA satellite technique, the entire radio spectrum is divided into time slots and in each slot only one fixed or mobile user is allowed to transmit or receive signals. Each user gets a cyclically repeating slot. When one user is transmitting its VDV information, the other users have to buffer their data, namely TDMA satellite users have to transmit data in a buffer and burst method, thus the transmission for any user is non-continuous. It is a digital access technique that permits individual satellite LES transmissions to be received by satellite in separate, non-overlapping time slots, called bursts, which contain buffered information. The satellite receives these bursts sequentially, without overlapping interference, and is then able to retransmit them to the MES terminal. Synchronization is necessary and is achieved using a reference station from which burst position and timing information can be used as a reference by all other stations.

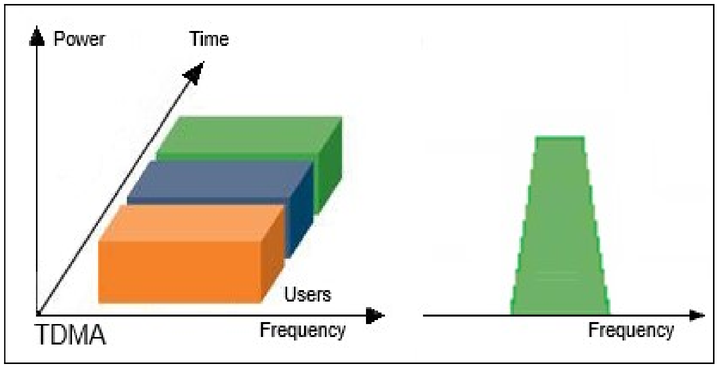

Figure 1. Scheme of TDMA MA Technique and Frame Structure

The TDMA modulation scheme is a digital access technique that permits individual satellite GES transmissions to be received by satellite in separate, non-overlapping time slots, called bursts, which contain buffered information. The satellite receives these bursts sequentially, without overlapping interference, and is then able to retransmit them to the MES terminal. Synchronization is necessary and is achieved using a reference station from which burst position and timing information can be used as a reference by all other stations. Each MES must determine the satellite system time and range so that the transmitted signal bursts, typically Quadrature Phase Shift Keying (QPSK) modulated, are timed to arrive at the satellite in the proper time slots.

The offset QPSK modulation is used by Inmarsat-B MES. So as to ensure the timing of the bursts from multiple MES, TDMA systems use a frame structure arrangement to support telex (Tlx) in the mobile-to-shore direction. Therefore, a reference burst is transmitted periodically by a reference station to indicate the start of each frame to control the transmission timing of all data bursts. A second reference burst may also follow the first in order to provide a means of redundancy. In the proper manner, to improve the imperfect timing of TDMA bursts, several synchronization methods of random access, open-loop and closed-loop have been proposed.

In **Figure 1 (Left)** is shown a concept of TDMA, where each MES or user transmits a data burst with a guard time to avoid overlaps. Since only one TDMA burst occupies the full bandwidth of the satellite transponder at a time, input back off, which is needed to reduce Intermediate Frequency (IM) interference in FDMA, is not necessary for TDMA. At any instant in time, the transponder receives and amplifies only a single carrier.

Thus, there can be no IM, which permits the satellite amplifier to be operated in full HPA saturation and the transmitter carrier power need not be controlled. Because all MES terminals to transmit and receive at the same frequency, tuning is simplified. This results in a significant increase in channel capacity. Another advantage over FDMA is its flexibility and time-slot assignments are easier to adjust than frequency channel assignments. The transmission rate of TDMA bursts is about 4,800 b/s, while the frame length is about 1.74 seconds and the optimal guard time is approximately 40 msec, using the open-loop burst synchronization method.

Accordingly, in the TDMA scheme, the transmission signals from various mobile users are amplified at different times but at the same nominal frequency, being spread by the modulation in a given bandwidth. Depending on the multiplexing techniques employed, two transmission hybrid schemes can be introduced for use in GMSC systems. The time slot in TDMA scheme is pre-assigned or can be changed on demand, and guard times are used between the time slots to avoid interference.

The TDMA modulation scheme is most practical for digital data transmission only, because of the burst nature of the transmissions. Downlink satellite transmission consists of interleaved set of packets from all the ground stations. Two Reference Stations (RS), which could be one of the GES or a separate ground location, are used to establish the synchronization reference clock and provide burst time operational data to the network, and complex computer procedures, for automated synchronizations between MES terminals. The second disadvantage of TDMA scheme us that peak power and bandwidth of individual MES terminals need to be larger than with FDMA, owing to high burst bit rate.

However, the TDMA network offers a much more flexible structure than FDMA in terms of ease of reconfiguration for changing traffic requirements. In **Figure 1 (Right)** is shown the signal structure of a TDMA network, which consists of N traffic stations or user slots. The total time period that includes all traffic stations and network information is called a TDMA frame, which is repeated in a time series and represents one complete transmission in the network. Frame times range from 1 to 20 ms and each station burst (slot) contains a preamble and traffic data (data bits).

The preamble contains synchronization and station identification data. The reference burst, from the RS, is usually at the start of each frame and provides the network synchronization and operational information. Guard bands are included to prevent overlap and to account for different transmission times for each of the stations, based on their range to the satellite. Station bursts do not need to be identical in duration and can be longer for heavier traffic stations or during higher use periods. The specific allocation of burst times for each of the stations within the frame is called the burst time plan. The burst time plan is dynamic and can be changed as often as each frame to adapt to changing traffic patterns. In general, preamble time should be long enough to establish reliable synchronization but should be short compared to the data transmission time. The ratio of preamble time to total slot time is sometimes called the preamble efficiency (η_p), or overhead. We often measure these times in numbers of bits or symbols and write this efficiency as follows:

$$\eta_P = b_T / b_F = 1 - b_O / b_F \quad (1)$$

or, in terms of the TDMA frame elements the efficiency will have the following relation:

$$\eta_P = 1 - n_R\, b_R + n_T\, b_P + (n_R + n_T)\, b_G / r_T\, t_F \quad (2)$$

Where values b_T = number of bits available for traffic, b_F = total number of bits in frame, b_O = number of overhead bits, n_R = number of reference stations, b_R = number of *bits* in reference burst, n_T = number of traffic bursts, b_P = number of bits in traffic burst preamble, b_G = number of *bits* in guard band, r_T = total TDMA bit rate, in b/s, and t_F = TDMA frame time, in seconds (s).

The channel capacity for a TDMA network is most often evaluated in terms of an equivalent voice-channel capacity (n_C). This allows evaluation of capacity for any type of data source bitstream: voice, data, video, or any combination of the three. The equivalent voice channel capacity is defined with the following relation:

$$n_C = r_I / r_C \quad (3)$$

Where values r_I = available information bit rate, and r_C = equivalent voice channel bit rate.

The frame efficiency is the percentage of bits per frame which contains useful transmitted data. It is a measure of the percentage of transmitted data that contains information as opposed to providing overhead for the access scheme. It should be noted here that the transmitted data may include source and channel coding bits, so the raw end-user efficiency of a system is generally less than the calculated efficiency of a frame. Frame efficiency can be expressed as:

$$\eta_f = (1 - b_{OH} - b_T) \text{ x } 100\% \quad (4)$$

Where, b_{OH} = Number of overhead bits, and b_T = Total number of bits.

Number of channels In TDMA system can be found by multiplying the number of TDMA slots per channel by the number of channels available, which is given as:

$$N = m(B_{tot} - 2B_{guard}/B_c \quad (5)$$

Where m = The maximum number of TDMA users supported on each radio channel, B_{tot} = Total bandwidth, B_{guard} = Guard band, and B_c = One channel's bandwidth.

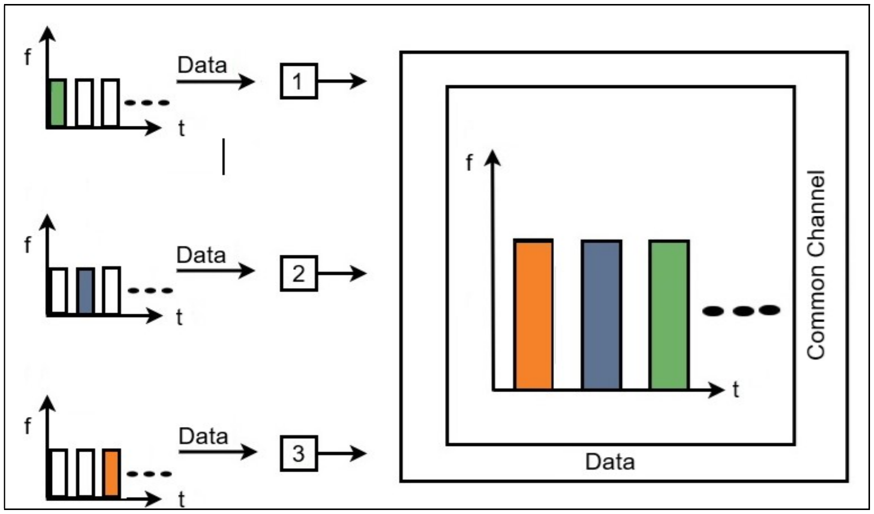

Figure 2. Channelization Protocol in TDMA Techniques

4. Outlines of the Time Division Multiple Access (TDMA) Technique

In the TDMA concept the satellite canalization protocol in which bandwidth of channel is divided into various stations on the time basis, which scenario of channelization protocol is illustrated in **Figure 2.** There is a time slot given to each station, the station can transmit data during that time slot only which is as follows. Each FES or MES terminal must aware of its beginning of time slot and the location of the time slot, because TDMA requires synchronization between different stations. It is type of access method in the data link layer. At each station data link layer tells the station to use the allocated time slot.

Thus, TDMA modulation systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. In the TDMA modulation scheme can be seen that each user occupies a cyclically repeating time slot, so a channel may be thought of as a particular time slot that reoccurs every frame, where N time slots comprise a frame. This systems transmit data in a buffer-and-burst method, thus the transmission for any user is non-continuous. This implies that, unlike in FDMA systems which accommodate analog FM, digital data and digital modulation must be used with TDMA system.

The transmission from various fixed or mobile users is interlaced into a repeating frame structure, which frame consists of a number of slots. Each frame is made up of a preamble, an information message, and tail bits. In TDMA/TDD, half of the time slots in the frame information message would be used for the forward link channels and half would be used for reverse link channels. In TDMA/FDD systems, an identical or similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links. In general, TDMA/FDD systems intentionally induce several time slots of delay between the forward and reverse time slots for a particular user, so that duplexers are not required in the subscriber unit.

In a TDMA frame, the preamble contains the address and synchronization information that both the base station (LES) and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames. Different TDMA standards have different TDMA frame structures. Therefore, TDMA frame structure provide a data stream divided into frames and those frames divided into time slots, which contain one or two reference bursts that synchronize the network and identify the frame.

The TDMA modulation system has the following characteristics

1. Flexible Rate Allocation – During deployment TDMA technique supports dynamic allocation of time slots, allowing the system to adapt to varying user demands. Different fixed or mobile users can be assigned multiple time slots based on their data transmission needs, which can vary due to factors such as call duration or data requirements. This flexibility optimizes resource usage and can improve overall user experience.

2. Low Battery Consumption: Unlike FDMA, which requires continuous transmission, TDMA operates in a noncontinuous manner. Each transmitter can be turned off when not in use, leading to significant power savings. This is particularly advantageous for mobile devices, as it prolongs battery life and reduces the need for frequent recharging.
3. Simplified Implementation – The time-based nature of TDMA simplifies the implementation of synchronization mechanisms between users. As users take turns using the channel, the system can more easily manage timing and coordination compared to more complex modulation methods like CDMA (Code Division Multiple Access), where signals overlap.
4. Scalability of the System – The TDMA modulation systems can be scaled effectively to accommodate a growing number of users. As demand increases, additional time slots can be introduced without the need for significant changes to the existing infrastructure, making it easier to expand the network capacity.
5. Improved Quality of Service (QoS): With the ability to assign specific time slots and manage user access dynamically, TDMA can enhance the overall quality of service. This can lead to reduced latency and increased throughput, ensuring that users experience reliable and efficient communication.
6. Guard Intervals – To prevent interference between adjacent TDMA slots, guard intervals must be added. These intervals, typically ranging from 30 to 50 microseconds, serve as buffers to ensure that transmissions do not overlap. However, this requirement for extra time means that the overall throughput of the system can be reduced, as valuable time is spent in guard intervals rather than transmitting data. This is particularly problematic in cellular networks where time and energy efficiency are paramount.
7. Energy Consumption – While TDMA scheme allows for some energy savings by turning off transmitters during idle periods, the inclusion of guard intervals can offset these benefits. The need for synchronization and the overhead associated with managing time slots can lead to increased energy consumption, particularly in scenarios where numerous users are competing for access to the channel. This can be a critical issue for mobile devices that rely on battery power.
8. Synchronization Challenges – TDMA modulation requires precise synchronization between all various users to ensure that each fixed or mobile user transmits within their designated time slot. This can complicate system design and implementation, especially in dynamic environments where users may frequently join or leave the network. Maintaining synchronization becomes increasingly difficult as the number of users grows, leading to potential disruptions and communication errors if not managed effectively.
9. Limited Data Rates – TDMA generally provides medium data rates compared to other multiple access techniques like Code Division Multiple Access (CDMA) modulation. This limitation arises from the fixed time slot allocation, which can restrict the amount of transmitted data that can be transmitted in a given timeframe. As a result, various users with higher data requirements may experience slower transmission speeds, leading to potential dissatisfaction and reduced performance for data-intensive applications.
10. Moderate System Flexibility – TDMA offers moderate flexibility in terms of user allocation and data transmission rates. Unlike CDMA, which allows for a more dynamic and adaptive use of bandwidth, TDMA's fixed time slot assignment can lead to inefficiencies. In scenarios where user demand fluctuates significantly, the rigid structure of TDMA may result in underutilization of resources, as not all time slots may be filled during periods of low demand.
11. Latency Issues – Due to the time-sharing nature of TDMA modulation, users may experience increased latency. When multiple users are connected, each must wait for their designated time slot to transmit data. In applications that require real-time communication, such as voice calls or video conferencing and in general VDV, this added delay can affect the quality of service, leading to lag and reduced responsiveness.
12. Scalability Constraints: While TDMA can accommodate a growing number of various users by adding more time slots, this scalability is limited by the need for synchronization and the fixed nature of time slot assignments. As user demand increases, the system may face challenges in maintaining performance levels without significant investment in infrastructure upgrades or more complex management systems.

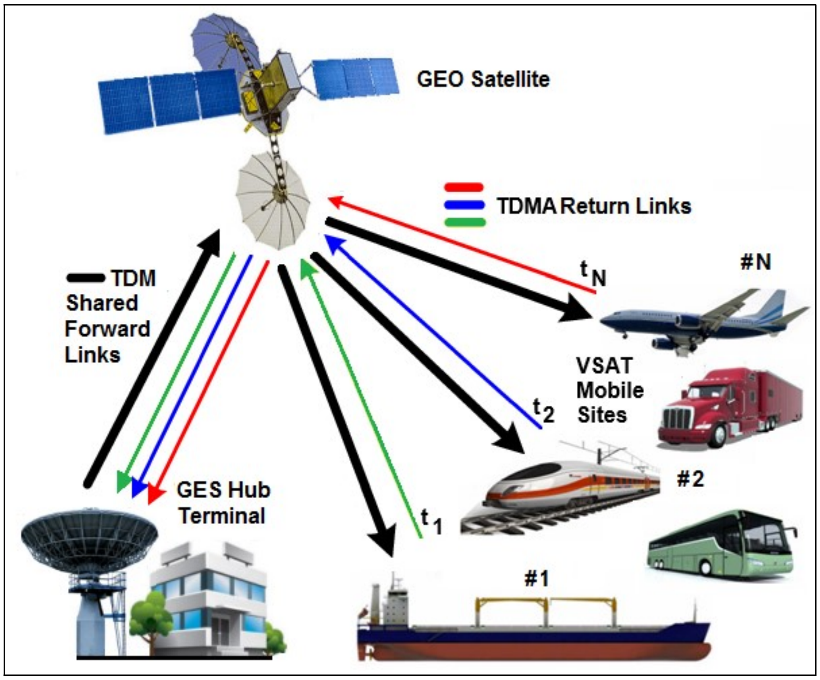

Figure 3. Satellite Mobile VSAT TDM/TDMA Network Architecture

The Time Division Multiple Access (TDMA) modulation scheme is a foundational technology that has revolutionized the way users communicate. At its core, TDMA is a channel access method for shared-medium networks, including satellite communication systems like Very Small Aperture Terminal (VSAT). It allows multiple users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using their own time slot. This approach can significantly increase efficiency as it reduces the likelihood of collision and maximizes the utilization of the available bandwidth.
In the TDMA modulation concept is a channel access method that allows a certain number of users to communicate at different times via using the same frequency. It is using the special canalization protocol in which the satellite channel bandwidth is subdivided into a variety of MES terminals on the time basis. There is a time slot given to each station, so the station can transmit data during that time slot only. Thus, the TDMA modulation concept is used for satellite VDV transmission, which scenario of channelization protocol is illustrated in **Figure 3.** During this method the general channel bandwidth is shared by multiple users, therefore a variety of users can transmit their data simultaneously. Thus, TDMA digital transmissions require that all receiving stations must obtain decoder synchronization in each interval, in addition to the required network synchronization for slot timing. In simplest terms, the TDMA modulation scheme enables multiple cellular or satellite users to share the same frequency by dividing each channel into different time slots, so a single frequency supports multiple and simultaneous data channels.
The TDMA bandwidth s divided into various a single channels or band into time slots. Each time slot is used to transmit one byte or another digital segment of each signal in sequential serial data format, and that band is reserved for the particular station for all the time which is as follows:
1. Multi Channel Per Carrier (MCPC) transmission; and
2. Single Channel Per Carrier (SCPC) transmission.
As stated before, the TDMA modulation scheme is a digital modulation technique used in digital satellite or cellular networks and mobile radio communication, which is one of two ways to divide the limited spectrum available over a Radio Frequency (RF) satellite or cellular channels. In effect, it operates by dividing the available satellite transponder bandwidth, typically 36 or 72 MHz for a Geostationary Orbit Satellite (GEO) into channels, which are then assigned to fixed and mobile users. At this point, one established mode of application used by LES and MES terminals for the transmission of telephony is to multiplex several voice circuits onto an assigned channel, known as TDM/MF/TDMA and also as an MCPC mode.

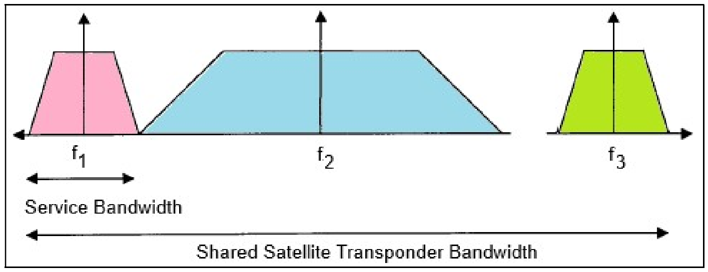

Figure 4. Shared MCPC Satellite Transponder Bandwidth

This tertiary expression of that system can be explained that initially, a number of voice circuits arriving at an Earth station are combined into a single band using TDM modulation scheme. This composite cellular or satellite signal is then frequency modulated prior to upconverting onto a network assigned carrier for transmission. At the receiver, the reverse operation is performed, that is the Earth station down converts the carrier prior to performing frequency demodulation and then demultiplexes the individual voice circuits.

As was noted earlier, the number of the satellite channels that can be employed per transponder bandwidth needs to take into account inter-modulation considerations. Moreover, there needs to be a guard-band between carriers to avoid mutual, adjacent channel interference.

4.1. Multi Channel Per Carrier (MCPC) Transmission Technique

The main elements of the MCPC scheme is multiplexer, modulator and transmitter using a satellite uplink, when LES terminal multiplexes baseband data is received from a terrestrial network and destined for various MES terminals. Moreover, the multiplexed data are modulated and transmitted to the allocated frequency segment, when the bandwidth of the transponder is shared among several MES terminals, each with different traffic requirements.

The satellite transponder bandwidth is divided into several fixed segments, with several time frequency divisions allocated to these MES terminals, which shared MCPC or TDM/MF/TDMA Satellite Transponder Bandwidth is shown in **Figure 4,** where synonym for MF is multifrequency. Namely, between each band segment is a guard band, which reduces the bandwidth utilization efficiency and the loss is directly related to the number of accessing MES terminal in the network. Depending on the number of receiving MES terminals, a total number of carriers will pass through the satellite transponder.

In this scenario, an integrated TDMA modulation system is introduced, which consists of many elements that are involved in Geostationary Earth Orbit (GEO) satellite point-to-multipoint Internet Protocol (IP) multimedia communications design and also takes a deep dive into the analysis of a real-life scenario, using the TDM/MF-SCPC and TDM/MF-TDMA media access techniques. This thesis starts with a discussion of satellite network topologies utilized within point-to-multipoint satellite communications followed by an overview of the satellite communications channel. A discussion on the intelligent and proper selection of modulation and coding follows. Descriptions and characteristics of the satellite access technologies chosen to be analyzed are next followed by a detailed description of Forward Error Correction (FEC) techniques and a discussion on network-wide tradeoffs so selecting different options.

On the other hand, the signals received from different MES terminals extract the carrier containing traffic addressed to LES terminals by using an appropriate RF filter, demodulator, baseband filter and demultiplexer. The output of the demodulator consists in multiplexed telephone channels for a few MES together with the channels addressed to them. A baseband filter is used to filter out the desired baseband frequency segment and finally, a demultiplexer retrieves individual telephone channels and feeds them into the terrestrial network for onward transmission.

Each baseband filter of LES terminal receive stations in this scheme corresponds to a specific one in the LES transmitting station. However, any change in channel capacity requires the return of this filter, which is difficult to implement. Thus, many schemes may be categorized according to the type of baseband signal.

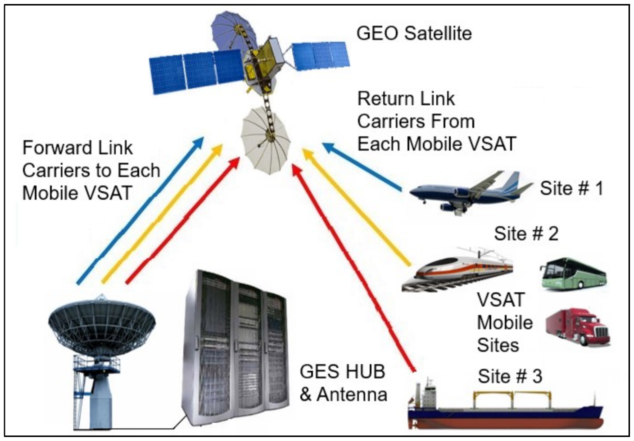

Figure 5. Mobile VSAT SCPC Network

4.2. Single Channel Per Carrier (SCPC) Transmission Technique

For certain applications, such as the provision of MSC service to remote areas or individual MES, traffic requirements are low. In reality, assigning multiple channels to each MES is wasteful of bandwidth because most channels remain unutilized for a significant part of the day. For this type of application the SCPC type of TDMA is used.

In the SCPC system each carrier is modulated by only one voice or by low to medium bit rate data channel. Some old analog systems use Companded FM but most new systems are digital PSK modulated. In the SCPC scheme, each MES carrier transmits a single carrier, as in **Figure 5** is shown Mobile VSAT SCPC Network. The assignment of satellite transponder channels to each MES terminal may be fixed Pre-Assigned Multiple Access (PAMA) or variable Demand-Assigned Multiple Access (DAMA), the channel slots of the transponder are assigned to various MES terminals according to their instantaneous needs. In the case of PAMA scheme, a few SCPC channels, about 5 to 10, are permanently assigned to each MES terminal. In case of DAMA, a pool of frequency is shared by many MES terminals. When necessary, each MES requests a channel from frequency management of the Network Control Station (NCS), which may always attempt to choose the best available channel or a lower quality channel until an unoccupied channel has been found. The allocation is then announced on a signaling channel known as a broadcast channel.

As stated before, the MCPC modulation scheme is a satellite transmission platform used with fixed and mobile VSAT systems. Digital audio, video or VDV and other broadcast carrier signals are multiplexed into a single digital data stream, which results in reduced satellite transponder usage and lower transmission costs per channel.

Analog signals, such as those used by satellite TV and terrestrial microwave-relay communications depend on various users. In effect, MCPC technology modulates analog signals as signals with higher frequencies and bandwidth. Various users are transmitted with video carrier signals on a satellite transponder at frequencies of 5.8 MHz, 6.2 MHz or 6.8 MHz with extra audio at 7 MHz or 8 MHz, as needed. These are the MCPC transmissions, and the satellites involved are known as MCPC satellites.

By 2011, MCPC technology was largely replaced by digital TV, which multiplexes audio and video data as a single Moving Picture Experts Group (MPEG) transport stream. This process involves streaming multiple video signals from film, sports and news broadcasts, as well as multiplexing data as a single transport stream, which is directed to a large antenna. This antenna broadcasts the stream to a TV with an Advanced Television Systems Committee (ATSC) tuner that receives and decodes signals for screen display. The periodical vary of signal and noise situation influence on data link layer and network layer parameters of communication channel in the conditions of adaptive ways of selection of signal modulation and type anti-interference coding rate are introduced in the article. The transfer capability and the time delay were researched as data link layer parameters. The metric of communication channel and the intensity of messages of its variation were researched as network layer parameters.

Over the years, mobile operators have used SCPC or TDM/TDMA technologies to backhaul sites in remote and rural locations. At this point, TDMA solutions are becoming the preferred approach by mobile operators for sites backhauled via satellite, particularly as Radio Access Network (RAN) implementations are shifting to cellular networks where traffic is dominated by Internet data, which is both asymmetric and bursty. To deliver an optimum solution based on the lowest cost and best value, mobile operators are revisiting every aspect of their network delivery. Although SCPC modulation technology was typically deployed in the past for backhaul to remote and hard-to-serve areas, recent developments in TDMA technology demonstrate how TDMA systems offer the lowest overall cost of ownership for most networks that require satellite backhaul.
For these sites, perhaps the most significant cost is that of recurring space segment. By efficient and dynamic sharing of space segment, TDMA systems make optimum use of this scarce resource. Other key factors are latency and jitter. Latency is the time period that information travels from one point to another in a network, measured either one-way or Round Trip time (RTT). Lower latency increases the efficiency and performance of the network by achieving a higher data throughput and delivering better real-time voice and video applications. Jitter is the variation in latency, which can be due to congestion or loading on the network; lower jitter increases the throughput and quality of data transmitted through the network.
On the other hand, SCPC modulation solutions use dedicated frequencies, particularly for return channel traffic, and are particularly well suited to constant load traffic such as that found in all cellular network implementations, so TDM/TDMA modulation systems employ a statistical multiplexing scheme to share information among multiple remotes on the out route with the same spectrum pool, and use a demand-assigned, multi-frequency TDMA approach to allow remotes to transmit information to the core network. The same amount of spectrum that connects one site in an SCPC deployment is easily shared among multiple TDMA sites on as-needed basis. Instantaneous dynamic traffic capacity variability is not possible with SCPC technology as the link is dedicated to an individual remote site. Consequently, as the traffic load within an SCPC link varies, the unused satellite spectrum is wasted.
The SCPC modulation systems previously contained a 64 Kb/s Pulse-Code Modulation (PCM) voice or data channel, superimposed on a carrier by 4-PSK modulations, using a satellite transponder bandwidth of about 38 kHz. With a carrier spacing of about 45 kHz, a 36 MHz transponder could therefore carry about 800 channels of traffic. The dramatic improvement in digital compression techniques is reducing the voice channel bit rate down to 1 Kb/s or so. The minimum subjective quality level is the main point of discussion these days. Even at a voice bit rate of 16 Kb/s, which is relatively high by today's capability, this equates to 3200 channels per satellite transponder. This figure can be improved by more than a factor of 2 by carrier voice activation. During the gaps in speech, a carrier is not transmitted, making space in the transponder for another carrier that has been voice-activated.

5. Duplex Methods in MSC Networks

Duplexing in MSC networks is a method to separate the satellite uplink and downlink transmissions such as follows:
1. Simplex communication is when information is transmitted in only one preassigned direction, when only one fixed or mobile user speaks or when a satellite AM and FM broadcasts TV signals to home users.
2. Half duplex communication is when information is transmitted in only one direction at a time, so not simultaneously users take turns speaking.
3. Full duplex communication is when information is transmitted and received in both directions simultaneously, so this requires two independent links. In general, duplex operation requires two frequencies in radio communication.
Duplexing method can be implemented in the Frequency domain or in the Time domain, giving rise to either: DD: Frequency Division Duplexing (FDD) or Time Division Duplexing (TDD). Many wireless systems are full duplex or duplexing techniques, which are needed to support simultaneous bidirectional communications on the same medium:

Frequency Division Duplex (FDD) – In FDD technique, transmitters and receivers operate at different carrier frequencies. One for satellite uplink signals and another for down link signals, which are separated to minimize interference between Tx and Rx signals. This mode mainly separates the receive and transmit channels by using the protected band. For TDD mode, which can separate channels by times, it works on inferring the downlink channel from the uplink channel. It allows satellite uplink and downlink transmission at the same time, but over different frequency bands. The bands are typically separated by a large margin to avoid leakage. Otherwise, FDD creates a channel that is always available and thus does not incur any delay. On the downside, the frequency bands are usually fixed by regulators, thus making FDD inflexible when uplink or downlink traffic requirements change. In addition, the nodes must be equipped with dedicated filters, which may be costly. The system was used in all second exclusively in analog mobile radio n cellular systems, which requires good frequency separation Tx/Rx and diplexer filters. Each user is assigned two frequency channels: A) One frequency for the uplink/reverse message signal (f_u), and B) Another frequency for the downlink/forward message signal (f_d). Tt the base station, separate transmits (Tx) and receives (Rx) antennas are used to accommodate the two separate frequency channels. At the mobile unit, a single antenna (with duplexer bandpass filter) is used to enable Tx and Rx signals simultaneously. Sufficient signal isolation between the Tx and Rx radio frequency bands is necessary.

2. Time Division Duplex (TDD) – In TDD technique, transmission system uses a single frequency band for both uplink and downlink signals. Then, it shares that band by assigning alternating time slots to uplink (forward time slot) and downlink (reverse time slot) signals. In fact, it is a method of alternating transmission and reception data on the same frequency channel by dividing time into alternating slots. This technique allows for efficient use of bandwidth by assigning specific periods for satellite uplink and downlink communication, ensuring that data flows smoothly and without interference. By understanding what time division duplexing is, it is possible to assess its role in modern radio and satellite communication systems, which require both high speed and reliability. It eeliminates the need for 2 separate frequency channels (uplink frequency channel and downlink frequency channel), and propagation delay and latency limits cell size. Thus, it is very efficient for asymmetric traffic, e.g. Internet download.

6. Hybrid FDMA Network Configurations

Further satellite network enhancement can be obtained when TDMA technique grouping is considered in the combinations with TDMA, SCPC and FDMA modulation schemes in order to improve switching, transmission, and frequency bands conditions of baseband signals, and improve control of the satellite transmision uplink and downlinks. There are several MA modulation schemes of TDMA combined in hybrids with TDM/TDMA, TDM/SCPC, FDMA/TDMA and TDM/FDMA techniques.

6.1. Hybrid TDM/TDMA Network Architecture

The Time Division Multiplexing (TDM) scheme is a method of transmitting and receiving independent signals over a common signal path by means of synchronized switches at each end of the transmission line so that each signal appears on the line only a fraction of time in an alternating pattern. It is a communication process that transmits 2 or more digital signals or analog signals over a common channel.

The TDM program is used for long-distance communication links and bears heavy data traffic loads from end-users, so it can be further extended into the TDMA *s*cheme, where several stations connected to the same physical medium, for example sharing the same frequncy channel, can communicate. Satellite links normally relay many signals from many MES but to avoid interfering with each other it is necessary for some kind of separation or division. This separation is known as multiplexing and its common forms are Frequency Division Multiplexing (FDM) and TDM. The TDM is easier to implement with digital modulation and to form hybrid solutions applicable to all types of baseband signals.

The first generation of the Inmarsat analog standard-A MES uses the TDM/TDMA arrangement for telex transmission, which scenario is shown in **Figure 3**. Each MES terminal has at least one TDM carrier and each of the carriers has 20 telex channels of 50 bauds and a signaling channel. Moreover, there is also a common TDM carrier continuously transmitted on the selected idle listening frequency by the Network Coordination Station (NCS) for out-of-band signaling. The MES remains tuned to the common TDM carrier to receive signaling messages when the mobile is idle or engaged in a telephone call. When an MES is involved in a telex forward call it is tuned to the TDM/TDMA frequency pair associated with the corresponding GES to send messages in shore-to-mobile direction. Telex transmissions in the return mobile-to-shore direction form a TDMA assembly at the satellite transponder. Each frame of the return TDMA telex carrier has 22 time slots, while each of these slots is paired with a slot on the TDM carrier. The allocation of a pair of time slots to complete the link is received by the MES on receipt of a request for a telex call. Otherwise, the Inmarsat-A uses for forward signaling a telex mode, while all other Moile Satellite System (MSS) Inmarsat standards for forwarding signaling and assignment channels use the TDM Binary Phase Shift Keying (BPSK) scheme.

The new generation of Inmarsat digital standard-B (inheritor of standard-A) uses the same modulation TDM/TDMA technique but instead of Aloha BPSK (BCH) at a data rate of 4800 b/s for the return request channel used by Inmarsat-A, new standard-B is using Aloha Offset. Quadrature Phase Shift Keying (O-QPSK), 1/2 – FEC, at a data rate of 24 Kb/s. This MAT satellite network is also useful for the Inmarsat standard-C MES terminal for maritime, land (road and rail), and aeronautical applications. In this case, the forward signaling link and sending of messages in the ground-to-mobile direction use a fixed assigned TDM carrier. The return signaling channel uses hybrid, slotted Aloha BPSK (1/2 FEC) with a provision for receiving some capacity and the return message channels in the mobile-to-ground direction are modulated by the TDMA system at a data rate of 600 b/s.

The TDM/TDMA technology uses a single high-speed TDM carrier transmitted from the central GES site or Hub, from which many Very Small Aperture Terminal (VSAT) stations can receive information. For this TDM forward link, the DVB-S2 of Digital Video Broadcasting-Return Channel via Satellite (DVB-RCS) standard is most commonly used. It is also the most flexible for multiplexing many concurrent streams of traffic to different sites, and the most efficient with its support of Adaptive Coding and Modulation (ACM). The ACM mode dynamically adjusts the modulation and coding on the "virtual link" to each VSAT individually, as local conditions (e.g., weather, interference) at the VSAT change. To transmit back to the central site efficiently, the VSATs in a TDM/TDMA network are synchronized, and they transmit information in "burst mode" within a series of short, scheduled timeslots. Timeslots may be assigned across multiple TDMA carriers and accessed using "fast frequency hopping". Timeslots are assigned to each VSAT exclusively (i.e., without contention) based on their current traffic needs. This is called Dynamic TDMA, and it is the most advanced form of TDM/TDMA. The TDMA technology is fully standardized internationally by the DVB group under the DVB-RCS family of standards. In **Table 1** are presented the advantages and disadvantages characteristics of the TDM/TDMA technology with the cost of remote (VSAT) station.

Table 1. List of TDM/TDMA Characteristics

Advantage	Disadvantage
Sharing of satellite bandwidth	High Latency and Increased Jitter
Lower overall OPEX compared to dedicated pipes	Demanding remotes can burden the system
Good for low data rate applications	Fragmentation of packets. Less effective for voice and video
Low cost remotes	Expensive hub equipment
Large population of users	All remotes must be designed around worst case link

For instance, the low-cost TDMA/DVB-RCS Indoor Unit (IDU) or VSAT stations have dropped in price to $1,000 including Outdoor Unit (ODU) or VSAT antenna, while the cost of SCPC modems is $6,000. The Antenna unit and its ODU sizing are based on either shared carrier size or dedicated carrier size. Thus, the supplying cost advantages of TDM/TDMA presented earlier still apply when comparing against SCPC with bandwidth cancellation.
The TDMA satellite networks allow all VSAT stations to dynamically share multiple TDMA carriers as if they were a single large pool of bandwidth. Each TDMA carrier group may contain dozens of carriers, with up to 32 carriers per carrier group in a satellite network. Therefore the "return link" may contain huge amounts of capacity, in aggregate. In the TDM/TDMA satellite network, the TDMA carriers may operate at widely different symbol rates, e.g., from 500 ks/s to 5 Ms/s and even higher. To determine which VSAT will use which timeslots on which carrier at any moment, the satellite link uses Adaptive Carrier Selection (ACS) mode. The ACS mode is applied dynamically for each VSAT, given its local weather conditions, configuration, e.g., antenna and Block Upconverter (BUC) size, and service policy, e.g., maximum rate requirements. In fact, the ACS mode determines what carrier & symbol rate will work best at the current signal levels of those available in the carrier group.
In addition, in a satellite DVB-RCS2 (2nd Generation) network, ACM per burst is supported for each VSAT and on all TDMA carriers in the carrier group. This further optimizes efficiency, throughput, and reliability for each VSAT and greatly simplifies network operations. Any VSAT can use any MODulation and CODing (MODCOD), on any carrier, if necessary. DVB-RCS2 SatLink TDM/TDMA networks now surpass SCPC networks not only in efficiency, but also in throughput and link availability for almost any conceivable network configuration and satellite bands, such as C, Ku, and Ka-band domain.

6.2. Hybrid TDM/SCPC Network Architecture

The TDM/TDMA and Single Channel Per Carrier (SCPC) architectures are the main alternative technologies for satellite networking in the world today. The modem and management technologies underlying both approaches have been advancing rapidly in recent years, causing some confusion as to which technology is better for a given set of networking requirements. The SCPC network refers to using a single signal at a given frequency and bandwidth. Most often, this is used on broadcast satellites to indicate that radio stations are not multiplexed as subcarriers onto a single video carrier, but instead independently share a transponder.
The SCPC mode is using for a VSAT satellite transmission system that uses a separate frequency carries for each of its communication channels, as opposed to frequency division multiplexing that combines many channels on a single carrier. It can be used for broadcast data and full-duplex audio and video communications. In an SCPC system, transmissions are sent to the satellite continuously on a single satellite carrier.
The satellite signal is received at a single location, in the case of a point-to-point system, or at many different locations in a broadcast system, providing hubless connectivity among multiple sites. This technology a system where each sub-division carries only one 4-kHz voice channel enables companies and corporate organizations to establish their own private network to connect sites into a single network with highly reliable performance with very low latency.
Due to the increasing dominance of IP traffic, many former SCPC networks have already been converted to TDM/TDMA network architecture. However, some SCPC networks have converted only "half-way", whereby a DVB-S2 TDM carrier is used on the forward link, but SCPC links are used for return link communications.
Nonetheless, the TDM/SCPC hybrid configuration is commonly promoted and used in certain types of VSAT networks, in particular in cellular backhaul networks and in some other networks where fast access to large amounts of capacity for the return link (upstream) traffic must be guaranteed. There are four possible reasons for the continued use of this form of SCPC configurations:
1. The possibility that SCPC in "continuous mode" will provide better modem efficiency (in b/s per Hz) than TDMA burst mode due to lower overhead and ability to use higher-rate, more efficient MODCOD scheme;

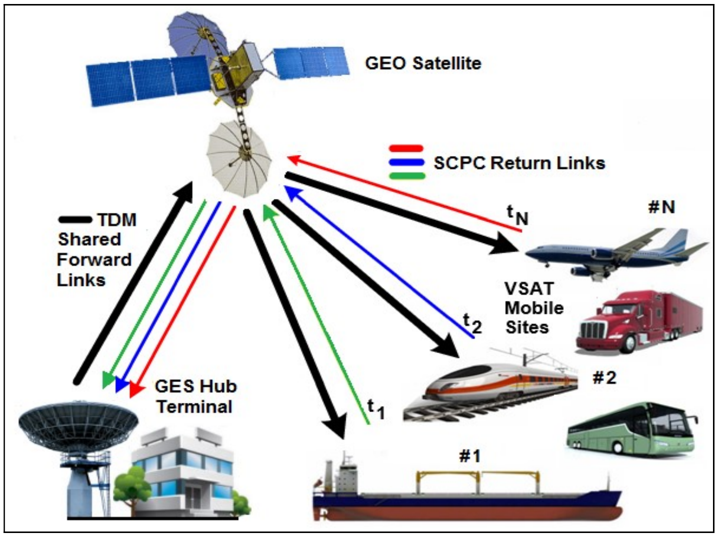

Figure 6. Hybrid TDM/SCPC Network Architecture

2. The possibility that SCPC links are better at providing guaranteed capacity and will operate more reliably against rain fades, interference, or congestion;
3. The possibility that SCPC links will provide lower latency or less total delay; and
4. The possibility that SCPC links can be operated at a higher speed, when necessary, for any or all sites within the satellite transponder footprint.

This hybrid configuration is called TDM/SCPC scheme and its network architecture is illustrated in **Figure 6.** If using DVB-S2 it gets the full benefits of statistical multiplexing and ACM on the forward link, but these benefits are non-existent on the return link in this hybrid network. Therefore, the technical and business rationales for using the TDM/SCPC hybrid networks are weak at best.

These possibilities or some of them are true with respect to the limitations of some popular TDM/TDMA technologies. For those technologies, the hybrid TDM/SCPC option is useful and may even be "cost-effective" in networks with nearly constant levels of traffic in the peak hour at each site, a consistent peak hour time each day. In **Table 2** are presented the advantages and disadvantages characteristics of the TDM/SCPC technology with the cost of remote (VSAT).

Table 2. List of TDM/SCPC Characteristics

Advantage	Disadvantage
Dedicated bandwidth for each remote inbound	Each remote requires its own space segment
Provides superior Quality of Service for mission critical applications	Expensive OPEX if each remote bandwidth is not fully utilized
Low Latency and Low Jitter	SCPC modems typically more expensive than TDMA modems
Best transmission method for real-time applications, voice, data, video, broadcast, etc.	Fixed data rates on the inbound links

However, in comparison to satellite TDM/TDMA networks using the DVB-RCS2 standards, these conditions do not hold true. In fact, the opposite is true, because, in terms of total network efficiency, a satellite DVB-RCS2 return link operating in TDMA burst mode will deliver 2x more in bps/Hz than some popular SCPC options, even before adding in the benefits of statistical multiplexing with TDMA configuration.

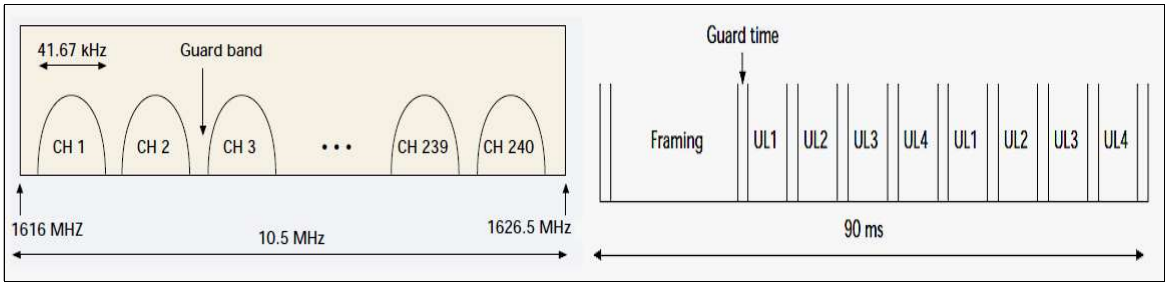

Figure 7. Iridium FDMA Scheme and TDMA Frame Structure

6.3. Hybrid FDMA/TDMA Network Architecture

The Iridium GMSC system employs a hybrid FDMA/TDMA access scheme, which is achieved by dividing the available 10.5 MHz bandwidth into 150 channels introduced into the FDMA components. Each channel accommodates a TDMA frame comprising eight-time slots, four for transmission, and four for the sgnal reception. Each slot lasts about 11.25 msec, during which time data are transmitted in a 50 Kb/s burst. Thus, each frame lasts 90 msec and a satellite is able to support 840 channels. In such a way, a mobile satellite user is allocated a channel occupied for a short period of time, during which transmissions occur. The Iridium satellite system supports full-duplex voice channels at 4800 b/s (2400 b/s according to and half-duplex data channels at 2400 b/s. The IRIDIUM network utilizes multiple spot beams on each satellite that divide the satellite footprint into smaller cells. However, to provide two-way satellite communications, the IRIDIUM system uses a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) techniques.

The Hybrid FDMA/TDMA Network Architecture is established when two slots (same position in time) of the user are allocated in two different narrow-band radio channels. Iridium satellite system uses frequencies in the L-band of 1616 MHz to 1626.5 MHz for the user's uplink and downlink with the satellites. This gives the system 10.5 MHz of bandwidth. As shown in **Figure 7 (Left)**, the Iridium FDMA scheme divides the available bandwidth into 240 channels of 41.67 kHz for a total of 10 MHz. This leaves 500 kHz of bandwidth for guard bands, which amounts to approximately 2 kHz of guard band between channels.

The TDMA modulation frame is 90 ms long and it contains four full-duplex user satellite channels at a burst data rate of 50 Kb/s. The four full-duplex channels consist of four uplink time slots and four downlink time slots, as depicted in **Figure 7 (Right)**. The eight user time slots take up a total of 69.12 ms, which leaves 20.88 ms of the TDMA modulation frame for framing bits and guard time slots. A possible frame structure is to use a framing time slot twice as long as an individual user time slot.

This would result in 864 framing bits taking up 17.28 ms. Subtracting this value from the 20.88 ms remaining in the TDMA frame leaves 3.6 ms for guard time slots. This can be divided into eight 400 microsecond guard time slots between time slots in the frame, and two 200 microsecond guard time slots at each end of the frame. Although the exact frame structure is not published in the open literature, this approach is reasonable. Thus, it uses 4.6 percent of the 90 ms frame for guard time and utilizes 76.8 percent of the frame for actual data bits.

6.4. Hybrid TDM/FDMA Network Configuration

The TDM arrangements is a method of transmitting and receiving independent signals over a common signal path by means of synchronized switches at each end of the transmission line so that each signal appears on the line only a fraction of time according to agreed rules, e.g. with each transmitter working in turn. It allows the use of TDM groups to be assembled at the satellite in FDMA, while the PSK is used as a modulation process at the Earth station. Systems such as this are compatible with FDM/FDMA carriers sharing the same transponders and the terminal requirements are simple and easily incorporated.

The Inmarsat standard-B satellite system for telex low-speed data uses this scheme in the shore-to-ship direction only and in the ship-to-shore direction uses TDMA/FDMA scheme. The CES TDM and SES TDMA carrier frequencies are pre-allocated by Inmarsat. Each CES is allocated at least one forward CES TDM carrier frequency and a return SES terminal TDMA frequency. So, additional allocations can be made depending on the traffic requirements.
The satellite channel unit associated with the CES TDM channel for transmission consists of a multiplexer, different encoder, frame transmission synchronizer, and modulator. So at the SES, the receive path of the channel has the corresponding functions to the transmitted end. The CES TDM channels use BPSK with differential coding, which is used for phase ambiguity resolution at the receiving end.

7. Conclusion

The performances and capacities of the TDMA modulation architectures and their hybrids with TDM scheme for MSC applications have been analyzed an implemented many years ago for an C, Ku and newest Ka-band. The MA techniques are is the use of multiplexing techniques to provide communication service to multiple fixed and mobile satellite users over a single channel. It allows for many users at one time by sharing a finite amount of spectrum. The TDM/TDMA, SCPC and their hybrid solutions are the main alternative technologies for fixed and mobile satellite network architectures in the world today.
The VSAT satellite modems and management technologies underlying both approaches have been advancing rapidly in recent years, causing some confusion as to which technology is better for a given set of networking requirements. In fact, the main architecture for design hybrid TDMA satellite networks is TDM technique and its combination with TDM/TDMA, TDM/SCPC and FDMA/TDMA hybrid network architecture for GMSC applications. In such a way, implementing these hybrid MA networks promise many improvements in satellite transmission systems.
The FDMA modulation technique is widely used in the general analog telecommunication and satellite communications systems for all mobile applications at sea, on the ground, and in the air. The working principle of the FDMA as usual is dividing the signaling dimensions along the frequency axes to create many separate channels. After that, allocates these channels to fixed or mobile satellite users. The guard bands have an important effect on decreasing the transmission impairments. The FDMA technique has many advantages such as good capacity, simple algorithms, and so on. Despite the advantages, FDMA has many disadvantages such as constant data rate and channel capacity. Therefore, the FDMA technique is used in many applications such as analog cellular and satellite systems.
On the other hand, the TDMA technique is an advanced digital multiple access technology that allows more than one user to access RF channels in satellite and other telecommunications systems. The principle work of TDMA is that the signals should be divided into milliseconds-long packets. Then, allocating a single frequency channel for short time and then moving to another channel to give it its own interval. Like the FDMA technique, the TDMA scheme has guard times that prevent any interference between channels, and decrease the factors of transmission impairments. The TDMA technique has many advantages such as good capacity with high data rates. However, the TDMA modulation scheme has many disadvantages such as attenuation impairment.

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BIOGRAPHY OF AUTHOR

Prof. Dimov Stojce Ilcev is a senior research professor at University of Johannesburg (UJ). He has three BSc degrees in Radio Engineering, Nautical Science and Maritime Electronics and Communications. He got MSc and PhD in Mobile Satellite Communications and Navigation as well. Prof. Ilcev also holds the certificates for Radio operator 1st class (Morse), for GMDSS 1st class Radio Electronic Operator and Maintainer and for Master Mariner without Limitations. He is the author of 9 academic books and more than 330 research papers in mobile Radio and Satellite CNS, DVB-RCS, Satellite Asset Tracking (SAT), Stratospheric Platform Systems (SPS) for maritime, land (road and railways), and aeronautical applications.