Architecture of Frequency Division Multiple Access (FDMA) for Mobile Satellite Communication (MSC) Networks

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Abstract: This paper describes in particular architecture of Frequency Division Multiple Access (FDMA) 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) terminals. The problem of simultaneous two-way communications between many single or multipoint mobile satellite users can be solved by using Multiple Access (MA) technique. Since the resources of the systems such as the transmitting power and the bandwidth are limited, it is advisable to use the channels with complete charge and to create a different MA to the channel. This generates the problem of summating and separating the signals in the satellite transmission and reception parts, respectively. Therefore, 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: FDMA, MSC, MES, LES, MA, GNSS, GPS, GLONASS, BeiDou, Galileo, CNS, PVT, TDMA, CDMA, RDMA, VDV, FDM, MCPC, SCPC, TDM, VSAT

1. Introduction

The Frequency Division Multiple Access (FDMA) 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.

Otherwise, to understand the importance of FDMA 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 frequency sharing, but also it's about optimizing communication paths to improve location accuracy and reliability. While going deeper, it is necessary to explore how FDMA modulation supports the functionality of a modern CNS, positioning and tracking system, ensuring that we are always on the right track.

Therefore, FDMA 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 – Where it allocates separate frequency bands for each satellite communication channel and enables 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, FDMA 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 FDMA modulation scheme is one of the most common analogue division multiple access methods. In fact, 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 FDMA modulation. The development of more sophisticated GNSS/GPS satellites equipped with advanced FDMA 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 Frequency Division Multiple Access (FDMA) Systems

Multiple access schemes are used to allow many fixed and mobile users to share simultaneously a finite amount of radio 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 users. For high quality satellite communications, this must be done without severe degradation in the performance of the system.
In that way, the FDMA modulation technique is the backbone of ensuring that multiple users can simultaneously transmit Voice, Data and Video (VDV) without interference as a critical factor in achieving high quality and reliable radio and satellite CNS systems. This technology is most important in fields that require precise CNS systems, PVT and other positioning data, tracking and determination solutions for comercial and military maritime, land transportation (roads and rails) and aeronautical applications.

Existing GNSS satellites emit signals in a unique frequency range, allowing receivers on ships, land vehicles (roads and rails) and aircraft to distinguish the signals and obtain accurate PVT data, including other navigation data. Such is the practice with satellites used for MSC ships, land vehicles and aircraft. This division of frequency bands is assigned in such a way that signals from neighboring satellites do not interfere with each other, thus increasing the reliability and accuracy of received data on positioning and non-sensing communication. Therefore, the use of FDMA covers various sectors beyond GNSS technology, such as cellular telephone system networks, MSC constellation systems and any communication network that requires multiple data streams to be transmitted simultaneously over a single communication channel.
The modulation scheme of existing FDMA technologies is ubiquitous to all potential civil and military uses by various telecommunications companies, the maritime trade sector, roads and rails transport, airlines, aerospace and defense entities, as well as any user that depends on precise, reliable paths of communication and navigation airspace without interference. Namely, all these services rely on FDMA modulation to optimize all their day-to-day operations, whether it is to use VDV communication services without interference or to ensure that ships, land mobiles and aircraft can navigate safely and precisely in their daily operations. Thus, comprehensive use of FDMA systems is a key factor for professionals in the fields of navigation, telecommunications and other technologes. Its role in optimizing communication paths cannot be underestimated, thus making it a key piece of knowledge for anyone looking to excel in these industries.
Therefore, FDMA technology is actually a channelization protocol used in communication and navigation systems, which allows multiple users to share the same frequency channel by dividing the available bandwidth into different frequency bands. This system works in way that each station, such as a cellular device, MSC networks, navigation instruments or satellites is assigned a specific frequency band for VDV transmission globally. This assigned frequency band remains reserved for that particular communication or navigation station at all times.
In that way, analog multiplexing in different satellite systems is mainly used at ground Earth and mobile stations to combine a large number of communication and navigation channels into a single baseband signal, which is then shifted to a higher frequency using Frequency Division Multiplexing (FDM) scheme. For example, up to 1800 telephone channels can be multiplexed using FDM mode scheme, resulting in a wide baseband occupying 8 MHz of bandwidth. Wide baseband signals are onto an Radio Frequency (RF) carrier using Frequency Modulation (FM). Different RF carriers are used for frequency modulation at each earth station. When multiple telephone and data channels are multiplexed for transmission over a single RF carrier, it is known as Multi Channel-Per-Carrier (MCPC). In short, FDMA divides the frequency spectrum into separate channels, each of which is assigned to a specific communication and navigation user or station.
Analog transmission is characterized by processing performed on the baseband signal before and after modulation in order to improve the quality of the link. The carrier can support only one or few channels for the transmission of baseband signals. In the case of a carrier transmitted from the station representing only a single user transmission channel, this is Single Channel Per Carrier (SCPC) transmission. On the other hand, if the carrier represents a number of multiplexed users, it is designated MCPC scheme and use several channels is FDM transfer. In FDMA system, the channel bandwidth is divided into a number of sub-channels for satellite communication and GNSS transmission systems. During this method, the general bandwidth of the channel is shared by multiple users, so that different users can communicate simultaneously. In FDMA, code words and synchronization are not required, while energy efficiency is reduced by using FDMA, which is an old and proven system used for analog signals.
A signal needs to be impressed on an RF carrier for transmission through the satellite and for this purpose the objective of any MSC is to transmit the modulated carrier to receiver (Rx) as reliably as possible, so that the demodulated signals can be satisfactorily recovered. In analog transmission systems, the information waveform in the form of VDV signals are modulated directly from the source onto the carrier at the modulator of transmitter (Tx), by using methods of Amplitude (AM), Frequency (FM) and Phase Modulation (PM), which are used most widely for direct analog transmission in satellite communications, while AM is a process used indirectly in the satellite link.

Modulation may also be used at very low frequencies, like the more common and various forms of Phase Shift Keying (PSK). In addition, modulation is often done on a carrier with an RF of about 70 MHz lower than the transmission RF. This RF is then up-converted to the transponder frequency on 6/4 GHz for amplification and retransmission. Previous types of satellite do not change the received modulation before retransmission. Satellites are now being designed to allow only one modulation method to be employed in the uplink and another for the downlink, so each link can be optimized. The space link between two LES and MES terminals can generally be accomplished by the combination of modulation and multiplexing techniques.

The process of combining baseband signals and sharing the satellite communication channels is known as multiplexing, while the reverse process of extracting individual baseband signals is called demultiplexing mode. The Consultative Committee for International Telephony and Telegraphy (CCITT) proposed all multiplexing standards including FDM, which is applicable only to telephony baseband signals, while the digital Time Division Multiplexing (TDM) standard is applicable to all types of baseband signals.

Digital transmission relates to the link for which the MES terminal is designed to produce the digital signals by PC or transmission modem and to send them through a transceiver. Moreover, it is possible to transmit analog signals (voice or broadcast) in digital form. Although this choice implies an increased baseband, it permits signals from diverse origins to be transmitted on the same satellite channels and the satellite link to be incorporated in ISDN, which implies the use of TDM. The digitization of analog signals implies the stages of sampling, quantization and source coding. The simple digital transmission chain includes a transmitting and receiving segment.

However, the first unit of the satellite transmitting segment is TDM system with input signals from digital (direct access) and analog (access via encoder) sources and after multiplexed signals pass devices such as: Data Encryption, Channel Encoding, Scrambling and Digital Modulation, where the digital signal is transmitted through up or down satellite links. On the other hand, in the receiving segment of reverse mode incoming satellite signal goes through devices such as: Demodulator, Descrambling, Channel Decoding, Data Decryption and TDM Demultiplexing in its direction to different users.

Each type of MES usually transmits and receives many kinds of signal transmissions to and from spacecraft. Multiplexing enables the division of channels or the combination of two or more input signals into a single output for transmission. In effect, the most common and known analog multiplexing method is FDM, used in satellite communication transmissions.

The simplest approach to multiplexing technique is to assign a specific part of the available radio frequency or bandwidth spectrum to each signal. If two signals initially have the same spectrum, the frequency of one or both is shifted, so in such a way they will not overlap. Therefore, the FDM scheme is a multiplexing solution where satellite signals occupy the channel at the same time but on different frequencies.

As FDMA systems use low bit rates (large symbol time) compared to average delay spread, it offers the following advantages:

1. Reduces the bit rate information and the use of efficient numerical codes increases the capacity;
2. Reduces the cost and lowers the Inter Symbol Interference (ISI);
3. Equalization is not necessary.
4. An FDMA system can be easily implemented and configured, so that the improvements in terms of speech encoder and bit rate reduction may be easily incorporated; and
5. Since the satellite transmission is continuous, less number of bits is required for synchronization and framing.

Although FDMA system offers several advantages, it has a few drawbacks as well, which are listed below, such as:

1. It does not differ significantly from analog systems, because any improvements in capacity of the system depend on the signal-to-interference reduction, or a Signal-to-Noise Ratio (SNR);
2. The maximum flow rate per channel is fixed and small;
3. Guard bands lead to a waste of capacity; and
4. Hardware implies narrowband filters, which cannot be realized in VLSI and therefore increases the cost.

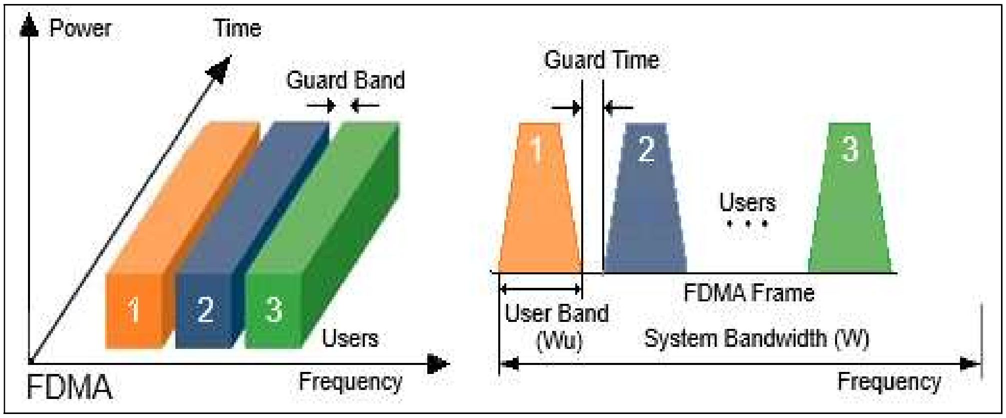

Figure 1. Scheme of FDMA MA Technique and FDMA Frame Structure

3. Concepts of the Frequency Division Multiple Access (FDMA) Technique

The most common and first employed MA scheme for satellite communication systems is FDMA concept shown in **Figure 1 (FDMA),** where transmitting signals occupy non-overlapping frequency bands with guard bands between signals to avoid interchannel interference.

Both modulation schemes, FDMA and TDMA are widely used for digital satellite transmission, and these subjects are covered in wireless and satellite communication systems. The most common and first employed MA scheme for satellite communication systems is the FDMA concept illustrated in **Figure 1 (Left),** where transmitting signals occupy non-overlapping frequency bands with a special guard band between signals to avoid interchannel interference. On the other had, the bandwidth of a repeater channel is therefore divided into many sub-bands each assigned to the carrier transmitted by an LES terminal. Therefore, as illustrated in Figure **1 (Right),** the FDMA modulation technique consisting of many traffic stations or users slots providing channelization protocol for channeling communication signals in cellular, MSC or GNSS networks. This bandwidth is divided into different frequency bands, so that each user is assigned a corresponding band to send data and that band is reserved for a particular station for all time.

The bandwidth of a repeater channel is therefore divided into many sub-bands each assigned to the carrier transmitted by an Earth station. The MES transmit continuously and the channel transmits several carriers simultaneously at a series of different frequency bands. Because of interchannel interference, it is necessary to provide guard intervals between each band occupied by a carrier to allow for the imperfections of oscillators and filters. The downlink Rx selects the required carrier in accordance with the appropriate frequency. When the satellite transponder is operating close to its saturation, nonlinear amplification produces intermodulation (IM) products, which may cause interference in the signals of other users. In order to reduce IM, it is necessary to operate the transponder by reducing the total input power according to input back off and that the IF amplifier provides adequate filtering.

Therefore, FDMA allocates a single satellite channel to one user at once. In fact, if the transmission path deteriorates, the controller switches the system to another channel. Although technically simple to implement, FDMA is wasteful of bandwidth because the voice channel is assigned to a single conversation, whether or not somebody is speaking. Moreover, it cannot handle alternate forms of data, only voice transmissions. This system's advantages are that it is a simple technique using equipment proven over decades to be reliable and it will remain very commonly in use because of its simplicity and flexibility.

It does have some additional disadvantages however:

1. The FDMA method is the relatively inflexible system and if there are changes in the required capacity, then the frequency plan has to change and thus, involve many LES terminals;

2. Multiple carriers cause Intermodulation (IM) in both the MES terminal High Power Amplifier (HPA) and in the transponder HPA. Reducing IM requires back off of the HPA power, so it cannot be exploited at full capacity;

3. As the number of transmission carriers increase, the IM products between carriers also increase and more HPA back off is needed to optimize the system. The throughput decreases relatively rapidly with the number of transmission carriers, therefore for 25 carriers it is about 40% less than with 1 carrier;
4. The FM system can suffer from what is known as a capture effect, where if two received signals are very close in frequency but of different strengths, the stronger one tends to suppress the weaker one. For this reason the carrier power has to be controlled carefully.

Therefore, with the FDMA technique, the signals from the various users are amplified by the satellite transponder in a given allocated bandwidth at the same time but at different frequencies. Depending on the multiplexing and modulation techniques employed, several transmission hybrid schemes can be considered and in general may be divided into two categories, based on the traffic demands of Earth stations on MCPC and SCPC schemes.

A specific frequency band is given to one person, and it will be received by identifying each of the frequency on the receiving end. It is often used in the first generation of analog mobile phone. The total time period that includes all traffic station bursts and network information is called the FDMA frame. Namely, the FDMA mobile devices are using available bandwidth into a given number of orthogonal channels of smaller bandwidths. The satellite channel is used by users continuously over the duration of the message, and so the FDMA scheme is limited to narrowband applications due to its limited transmission rate. In such a way, if the same channel is reused at another physically separate location, an increase in transmit power will negatively affect the carrier-to-interference ratio at that location.

Therefore, in FDMA scheme, each user is permanently allocated a certain frequency band, out of the total bandwidth of the transponder. To reduce the adjacent channel interference, it is necessary to have guard bands between the sub-bands. Frequency drifts of the satellites and mobile earth station’s frequency converters have also to be taken into consideration. The FDMA scheme is the traditional technique due to its simple implementation and FDMA allocates a single satellite channel to one user at once. In fact, if the transmission path deteriorates, the controller switches the system to another channel. Although technically simple to implement, FDMA scheme is wasteful of bandwidth because the voice channel is assigned to a single conversation, whether or not somebody is speaking.

Moreover, it cannot handle alternate forms of data, only voice transmissions. This system’s advantages are that it is simple technique using equipment proven over decades to be reliable and it will remain very commonly in use because of its simplicity and flexibility.

The FDMA technique has many additional advantages that can be summarized as the following:
1. The FDMA method is the relatively inflexible system and if there are changes in the required capacity, then the frequency plan has to change and thus, involve many LES terminals;
2. Multiple carriers cause IM in both the MES High Power amplifier (HPA) and in the transponder HPA. Reducing IM requires back off of the HPA power, so it cannot be exploited at full capacity;
3. As the number of satellite carriers increases, the IM products between carriers also increase and more HPA back off is needed to optimize and provide stable the system. The throughput decreases relatively rapidly with the number of transmission carriers, therefore for 25 carriers it is about 40% less than with 1 carrier;
4. The FM system can suffer from what is known as a capture effect, where if two received signals are very close in frequency but of different strengths, the stronger one tends to suppress the weaker ones. For this reason, the carrier power has to be controlled carefully;
5. The channel operations in FDMA are simple, FDMA technique doesn’t need any base-control station, there is no need for network timing and no need for any equalization;
6. After the transmission of FDMA data, the effect of the delay distortion will be so small and it can be ignored, and data that is transferred between each station to another during the transmission process will not be lost; and
7. In FDMA, the reduction of the information bit rate has a good effect on the capacity, because of the satellite transmission is continuous, there is almost no need for bits that are responsible for synchronization, and simplicity in FDMA algorithms.

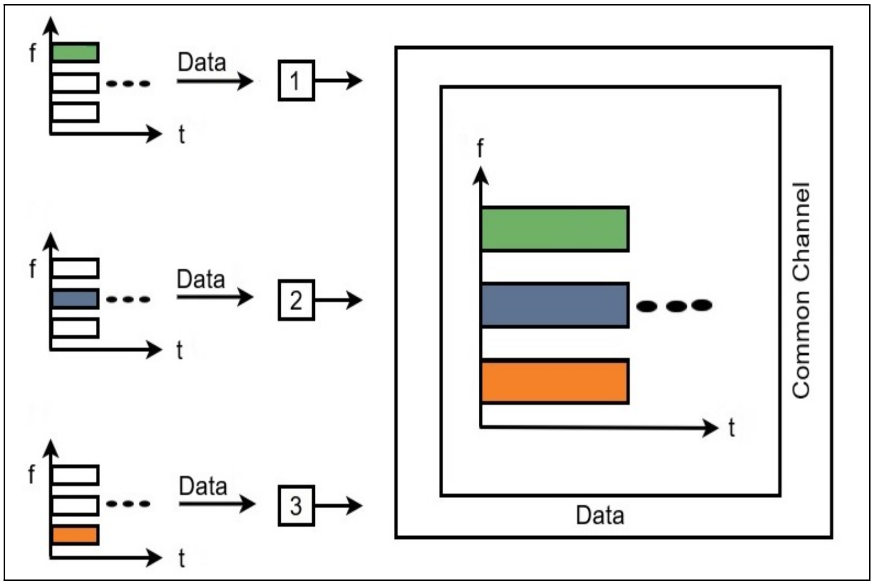

Figure 2. Channelization Protocol in FDMA Techniques

Here can be concluded, that with the FDMA technique, the satellite signals from the various fixed and mobile users are amplified by the satellite transponder in a given allocated bandwidth at the same time but at different frequencies. Depending on the multiplexing and modulation techniques employed, several transmission hybrid schemes can be considered and in general may be divided into two categories, based on the traffic demands of Earth stations on MCPC and SCPC.

4. Outlines of the Frequency Division Multiple Access (FDMA) Technique

In the FDMA concept the satellite channel bandwidth is subdivided into a variety of sub-channels, n protocol thus FDMA is used for VDV transmission, which scenario of c hannelization protocol is illustrated in **Figure 2.** During this method the general channel bandwidth is shared by multiple users, therefore a variety of users can transmit their data simultaneously. In effect, no code words and synchronization are required in FDMA scheme and power efficiency is reduced using FDMA, it’s an old and proven system used for analog signals.

The FDMA bandwidth s divided into various frequency bands. Each station is allocated a band to send data 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.

Therefore, the FDMA modulation scheme is the simplest and most established technique to be employed in fixed and mobile satellite communication networks. Namely, 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. Thus, 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 FDM/FM/FDMA and also as an MCPC mode.

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 FDM scheme. This composite 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.

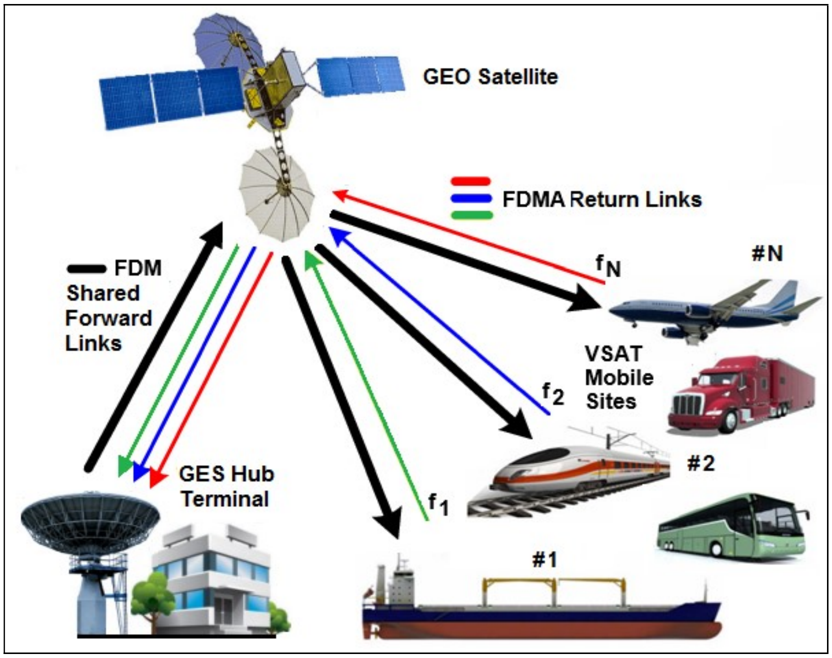

Figure 3. Satellite Mobile VSAT FDM/FDMA Network Architecture

When employing Non-GEO satellites, the guard-band is governed by the Doppler shift, which increases with frequency of operation. Since the guard-band is in effect an unused resource, or network overhead, the network designer needs to carefully trade-off the need for interference protection against redundant bandwidth usage.

The other form of FDMA implementation is an SCPC, where a carrier frequency is assigned per circuit, and consequently the transmission equipment performs no multiplexing. This mode of operation allows carriers to be assigned to users either on a fixed or on a per-demand temporary basis, the latter being governed by the traffic usage. Such a scenario exists in a mobile-satellite environment, as used by Inmarsat in support of its former Inmarsat-A FM telephony service. In fact, SCPC can be viewed as a more efficient use of the satellite resource than that of FDM/FM/FDMA, when traffic demand is variant.

As outlined earlier, the FDMA technique is the earliest implemented in the wireless systems and still one of the most commonly employed forms of multiple access techniques for communications via satellite. In the case of FDMA different Earth stations are able to access the total available bandwidth of satellite transponder by virtue of their different carrier frequencies, thus avoiding interference among multiple signals. However, the FDMA technique is the first MA technology implemented on fixed and mobile satellite systems. Its principle and operation are simple, which mobile satellite BVSAT FDM/FDMA network architecture is shown in **Figure 3**. At this point, the Ground Earth Station (GES) Hub terminal with shared forward FDM link is connecting 3 fixed or mobile Very Small Aperture Terminal (VSAT) stations via GEO satellite transponder.

Therefore, each mobile VSAT station within the satellite's footprint transmits one or more signals at different carrier frequencies. Thus, each carrier is assigned a small guard band to avoid the overlapping of adjacent carriers. The satellite transponder receives all carrier frequencies within its bandwidth, does the necessary frequency translation and amplification, and then retransmits them back towards GES Hub terminals.

Different VSAT stations are capable of selecting the carrier frequency containing messages of their interest. The frequency diagram determines that each VSAT station in communication via GEO satellite with GES Hub terminals monopolizes its own frequency band or frequency slot, which can be pre-allocated or changed as needed. As stated, a guard band is usually added between user bands to avoid mutual interference. The size of the guard band is related to the accuracy and stability of the carrier frequency of the transmitting and receiving ground station, and also to the difference of the maximum Doppler shift between adjacent signals.

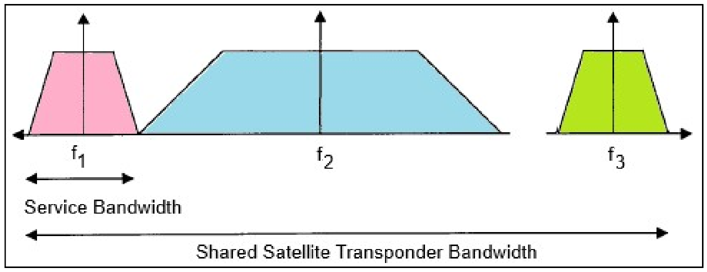

Figure 4. Shared MCPC Satellite Transponder Bandwidth

Therefore, the guard band set in the FDMA should be larger than any carrier signal. The maximum drift value relative to its nominal frequency for each station. When the signal goes down, because the carrier spectrum passes through the frequency-converting satellite, the ground station needs to tune the receiver to a specific downlink frequency to receive the transmitting carrier of the corresponding uplink ground station. And because the entire FDMA spectrum is transmitted by each VSAT station on the re return link to the GEO satellite. Than from GEO satellite on the downlink, that is, multiple carriers exist at the same time for each VSAT station, the GES Hub receiving station must be able to receive the entire spectrum from and filter it to distinguish the carrier actually sent to the station, and send it to other VSAT stations. According to whether situation, each mobile ground station uses multiplexing technology in the transmission carrier, FDMA is divided into two main categories: FDMA (Multiple Channels Per Carrier-Frequency Division Multiple Access, MCPC-FDMA) and single channel per carrier or FDMA (Single Channel Per Carrier-Frequency Division Multiple Access, SCPC-FDMA).

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 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 FDM/FM/FDMA Satellite Transponder Bandwidth is shown in **Figure 4.** 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.

On the other hand, the signals received from different MES terminals extract the carrier containing traffic addressed to LES terminal 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 terminals 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 transmitting station. However, any change in channel capacity requires the return of this filter, which is difficult to implement. However, many schemes may be categorized according to the type of baseband signal.

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 terminals, traffic requirements are low. In reality, assigning multiple channels to each MES terminal 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 FDMA is used.

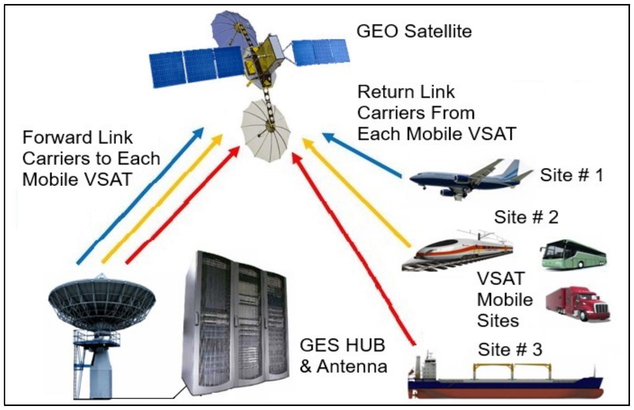

Figure 5. Mobile VSAT SCPC Network

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, 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.

The announcement is received by the calling and called MES, which then tune to the allocated channel. The communication takes place on the allocated channel and the end of call is announced by a signaling message, following which the NCS returns the channel to the common pool.

In addition, the SCPS solution requires an Automatic Frequency Control (AFC) pilot to maintain the spectrum centering on a channel-by-channel basis. This is usually achieved by transmitting a pilot tone in the centre of the transponder bandwidth. It is transmitted by designated reference LES and all the MES terminals use this reference to correct their transmission frequency. A receiving station uses the pilot tone to produce a local AFC system which is able to control the frequency of the individual carriers by controlling the frequency of the Local Oscillator (LO).

Hence, drift in MSC translation frequency and frequency variations caused by the Doppler Effect and the carriers retain their designated frequencies relative to each other. This feature is essential, because if uncorrected, the sum of the total frequency error can cause carrier overlapping, as carrier bandwidths are small. Thus, a stable receive frequency permits the LES demodulator design to be simplified. Centrally controlled networks, such as Inmarsat MES terminal A, B, C, M, Fleet 33/55/77, FleetBroadband and other MES networks are simple to manage missions, because they provide a higher usage of channels and can use simple demand-assignment equipment. The SCPS scheme is cost-effective for networks consisting in a significant number of Earth stations, each needing to be equipped with a small number of channels.

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 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 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:
1. 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 FDMA technique is considered in the combinations with MCPC, SCPC, TDMA, CDMA and other 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 modulation schemes of FDMA combined in hybrids with FDMA/MCPC, FDMA/SCPC, FDMA/TDMA, SCPC/FM/FDMA, SCPC/PSK/FDMA, TDM/FDMA, TDMA/FDMA, and TDM/SCPC techniques.

6.1. Hybrid FDMA/MCPC Network Configuration

The MCPC modulation technique, as its name implies, is another FDMA technique in which each carrier contains several channels. Again, star networks with thin routes find MCPC to be a good alternative in some situations. Voice, data, or fax channels are time-multiplexed into one or several preassigned signals and then sent via a modem for transmission. Using speech coding to allow 16 Kb/s for each voice call, four calls can be multiplexed into a 64 Kb/s signal for one carrier. Satellite data channels must be preassigned because speech encoders cannot be used with data traffic.
Usually, satellite data is sent at 1.2, 4.9, 9.6, 56, or 64 Kb/s, and several different-rate users can be multiplexed for only one carrier. Carrier preassignment is more suitable for star or point-to-point applications where a few mobile VSAT stations use up to only six channels. In the future, the mobile VSAT network would evolve as traffic increases, often beginning with a star network using MCPC to an SCPC/PAMA and eventually to an SCPC/DAMA. Further upgrades to a thin-route mesh network could follow. A TDMAstar configuration would be a major upgrade that would be cost-effective only with more than 25 remote stations each allocated at least 15 voice circuits.

6.2. Hybrid FDMA/SCPC Network Configuration

This hybrid network access does not require any multiplexing that is used for point-to-point, or point-to-multipoint, and mesh networks. It is the VSAT equivalent of the conventional leased line, delivering up to about 2 Mb/s of bandwidth to individual VSAT terminals. Satellite channels are either preassigned (PAMA) or demand assigned (DAMA) mode. The SCPC/PAMA modulation scheme dedicates channels to specific VSAT stations regardless of the network call activity.
The SCPC/DAMA hybrid systems are simple and cost-effective for small networks with less than four or five sites and several channels per site. The DAMA is a more efficient way of using the limited frequency resource. In SCPC/DAMA systems, users from different earth stations share a common pool of channels. For each call a request is sent and if a channel is available, it is assigned on demand. The DAMA system is more complex and the VSAT mobile station equipment is more expensive, but the recurring space segment costs are lower. This is a type of concentrator mechanism, and traffic requirements need to be carefully studied; otherwise blocking can reduce the system effectiveness.
The DAMA system is suitable for many remotes when only a few channels are required for each remote VSAT station. If the traffic is too light, the additional cost of the DAMA control equipment negates the reduction in satellite charges. The GES Hub station controls the DAMA system by a common Aloha signaling channel. Moreover, the Aloha multiplexing system allows random contention (first come, first served) until the traffic becomes relatively heavy, at which time it changes to a reservation mode. The SCPC VSAT satellite networks are well suited to thin-route, rural telephony, and can even be the primary communication method for some developing countries. The SCPC system can accommodate voice or data traffic, whereas TDMA is best suited to data. Because SCPC is in direct competition with leased lines, it is not surprising that costs are similar, whereas TDMA services are comparatively cheaper.

6.3. Hybrid FDMA/TDMA Network Configuration

The Iridium GMSC system employs a hybrid FDMA/TDMA access scheme, which is achieved by dividing the available 10.5 MHz bandwidth into 150 satellite channels introduced into the FDMA components. Each satellite channel accommodates a TDMA frame comprising eight-time slots, four for transmission, and four for the signal 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 fixed and 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.

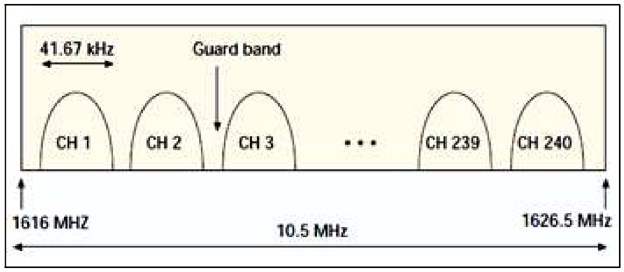

Figure 6. Iridium FDMA Scheme

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 satellite network architecture is established when two slots (same position in time) of the mobile user are allocated in two different narrow-band 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 width.

As illustrated in **Figure 6**, 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 frame is 90 ms long and it contains four full-duplex mobile 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**.

The eight user time slots take up a total of 69.12 ms, which leaves 20.88 ms of the TDMA 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-ms 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% of the 90 ms frame for guard time and utilizes 76.8 percent of the frame for actual data bits.

6.4. Hybrid SCPC/FM/FDMA Network Configuration

The baseband satellite signals from the satellite network or users each modulate a carrier directly, in either analog or digital form according to the nature of the SCPC signal in question. Therefore, each carrier accesses the satellite on its particular frequency band at the same time as other carriers on the different frequencies from the same or other mobile station terminals. Information routing is thus, performed according to the principle of one carrier per link.

The Inmarsat-A MES standard used SCPS system that utilizing analog transmission with FM for telephone channels. Thus, in calculating the satellite channel capacity of the SCPC/FM system it is necessary to ensure that the noise level does not exceed specified defined values. Therefore, the International Radio Consultative Committee (CCIR) Recommendations for an analog channel state that the noise power at a point of zero, the relative level should not exceed 10,000 WOP with a 50 dB test tone, namely the noise ratio. In this way, it is assumed that the minimum required carrier-to-noise ratio per channel is at least 10 dB.

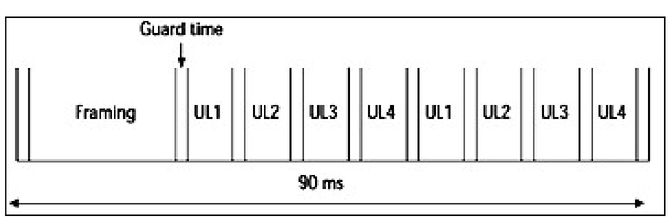

Figure 7. Uplink Time Slots for TDMA Frame Structure

6.5. Hybrid SCPC/PSK/FDMA Network Configuration

In this hybrid scheme, each voice or data channel is modulated onto its own RF carrier. The only multiplexing occurs in the transponder bandwidth, where frequency division produces individual channels within the bandwidth. Various types of this multiplex scheme are used in channels of the Inmarsat standard-B system. In this case, the satellite transponder carrier frequencies may be PAMA or DAMA. For PAMA carriers the RF is assigned to a channel unit and the PSK modem requires a fixed-frequency Local Oscillator (LO) input. For DAMA modulation, the channels may be connected according to the availability of particular carrier frequencies within the transponder RF bandwidth. For this arrangement, the SCPC channel frequency requirement is produced by a frequency synthesizer.

The forward satellite link assigned by the TDM scheme in shore-to-ship direction uses the SCPC/DA/FDMA solution for Inmarsat standard-B voice/data transmission. This hybrid standard in the return link for channel request employs the Aloha O-QPSK multiplexing scheme and for-low speed data/telex uses the TDMA scheme in ship-to-shore direction.

The Inmarsat-Aero standard in forward ground-to-aircraft direction uses packet mode TDM scheme for network broadcasting, signaling data and the circuit mode of SCPS/DA/FDMA scheme with distribution channel management for service communication links. Thus, the request for channel assignment, signaling and data in the return aircraft-to-ground direction the Slotted Aloha Binary Phase Shift Keying (BPSK) (1/2 – FES) of 600 b/s is employed and consequently, the TDMA scheme is reserved for data messages.

6.6. 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 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.

6.7. Hybrid TDMA/FDMA Network Configuration

As previously stated, however, the TDMA signals could occupy the complete satellite transponder bandwidth. In fact, a better variation of this is where the TDMA satellite signals are transmitted as a sub-band of transponder bandwidth, the remainder of which being available for example for SCPC/FDMA signals.

Thus, the use of a narrowband TDMA arrangement is well suited for a system requiring only a few satellite channels and has all advantages of satellite digital transmission but can suffer from intermodulation with the adjacent FDMA satellite channels. Accordingly, the practical example of this multiple schemes is the Tlx (Telex) service of the Inmarsat Standard-B system in ship-to-shore direction, which, depending on the transmission traffic, offers a flexi flexible allocation of capacity for satellite communication and signaling slots.

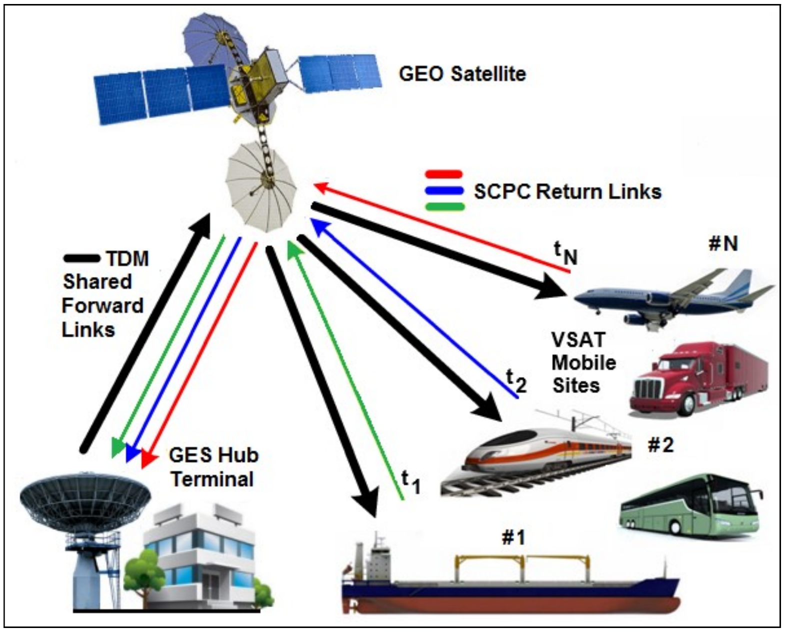

Figure 8. Hybrid TDM/SCPC Network Architecture

6.8. Hybrid TDM/SCPC Network Configuration

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 sub carriers 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. This hybrid configuration is called TDM/SCPC scheme and its network architecture is illustrated in **Figure 8.** 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 1** are presented the advantages and disadvantages characteristics of the TDM/SCPC technology with the cost of remote or mobile (VSAT) stations.

Table 1. List of TDM/SCPC Characteristics

Advantages	Disadvantages
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

Nonetheless, the TDM/SCPC hybrid configuration is commonly promoted and used in certain types of VSAT satellite networks, in particular in cellular backhaul networks and in some other mobile radio 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;
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.
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.

7. Conclusion

The performances and capacities of MSC systems for CDMA, FDMA and TDMA/FDMA have been analyzed many years ago for an L/C-band network with global coverage. For the particular MSS under discussion and for the particular antenna configurations, both CDMA and FDMA offer similar performance, FDMA yielding slightly higher channel capacities at the design point and CDMA being slightly better at higher Effective Isotropic Radiated Power (EIRP) levels. As the MSS grows and the antenna beam size decreases, CDMA appears to be a very efficient system, because it is not limited by L-band bandwidth constraints.
The communication satellites for MSC system provide multiple-beam antennas and employ frequency reuse of the allocated L-band frequency spectrum. It appears that despite the fact that FDMA and FDMA/TDMA are orthogonal systems, they nevertheless suffer from bandwidth limitations and sensitivity to interbeam interference in L-band. However, at the chosen design point for aggregate EIRP, number of beams, and allocated bandwidth, FDMA provides still the highest system channel capacity.
The narrowness of the frequency spectrum allocated to MSC system means that it has to be explored to the full. Methods available for effective spectrum utilization include efficient signal design and subdivision of the total coverage area into narrow illumination zones. Modern satellites for MSC have also onboard processors, which connect an uplink band to a downlink beam. Processors use A/D conversion and digital filtering. The A/D converters quantize the signal and produce quantization noise.

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