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Analyses of Space Division Multiple Access (SDMA) Schemes for Global Mobile Satellite Communications (GMSC)

D.S. Ilcev
Durban University of Technology, Durban, South Africa

ABSTRACT: This paper describes analyzes of the Space Division Multiple Access (SDMA) technique and their hybrids with other Multiple Access Technique (MAT) such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA) for implementation in Global Mobile Satellite Communications (GMSC). In fixed satellite communication systems, as a rule, especially in mobile satellite systems many users are active at the same time. The problem of simultaneous communications between many single or multipoint mobile satellite users, however, can be solved by using different MAT schemes. Since the resources of the systems such as the transmitting power and the bandwidth are limited, it is advisable to use the channels with a complete charge and to create a different MAT scheme to the channel. This generates a problem of summation and separation of signals in the transmission and reception parts, respectively. 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.

1 INTRODUCTION

In fixed and mobile satellite communication, the newest MAT scheme Spatial Division Multiple Access (SDMA), has become one of the most promising techniques that can accommodate a continuing increase in the number of users and traffic demands. Thus, the technology is based on transmission resource sharing that separates communication channels in space. It relies on adaptive and dynamic beam-forming technology and well-designed algorithms for resource allocation among which frequency assignment is considered.

The SDMA technique allows increasing the capacity of satellite communication system, exploiting the users spatial separation. This technique can be integrated into hybrid combination with conventional MAT schemes, such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA) techniques, and can be used in all the satellite and wireless communication systems currently operated or to be introduced in the future. As satellite communication systems move towards an increasing number of users and a larger throughput for each of them, the SDMA scheme is one of the most promising techniques that can reach three goals, such as they move towards greater capacity, higher flexibility (with respect to the position of the users) and better service to the end-user.

Today SDMA is currently used by the Iridium GMSC system in Radio Frequency (RF) L-band, a constellation of 66 Low Earth Orbit (LEO) satellites, thanks to time beam-switching. In addition, the SDMA technique is also foreseen as a key enabling technology to increase the capacity of future two-way satellite communications systems in low-frequency bands (typically lower than 5-6 GHz) through the interference mitigation and high-frequency reuse. The satellite beam-former optimizes the antenna diagram with respect to the positions of the users in order to maximize the gain while mitigating interferences. The resource allocation algorithm carefully designs a frequency plan that (a) prevents or limits interferences between users, and (b) tailors the allocated bandwidth to the user need in order to save the spectrum. However, the main future terrestrial communication standards in wireless communication systems, such that Worldwide Interoperability for Microwave Access (WiMAX), 3rd Generation Partnership Project (3GPP), Long-Term Evolution (LTE), and New Generation Cellular Systems, also use the SDMA scheme. The SDMA technique basically relies on adaptive and dynamic beam-forming associated to a clever algorithm in charge of resource allocation.

The Geostationary Earth Orbit (GEO) and Not-GEO mobile satellite communication systems are currently characterized by an ever-growing number of users, which however is coupled with limited available resources, in particular in terms of the usable frequency spectrum. The technologies are therefore oriented towards developing new access techniques, for more efficient employment of available frequency bands, such as the SDMA scheme that allows enhancing the capacity of a GMSC system by exploiting spatial separation between mobile users. The mobile users can be oceangoing ships, land vehicles (road and rail), aircraft, and ships containers. In an SDMA system, the Ground Erath Station (GES) terminal does transmit the signal throughout the coverge area via satellite, as is the case of conventional access techniques, but rather concentrates power in the direction of the mobile units, known as Mobil Eart Stations (MES), the signal is meant to reach and reduces power in the directions where other units are present. The same principle is applied to the reception.

In traditional GMSC systems the GES terminal, having no information on the position of mobile units, is forced to radiate the signal in all directions, in order to cover the entire area of the satellite coverage. This entails both a waste of power and the transmission, in the directions where there are no mobile satellite terminals to reach, of a signal which will be seen as interfering for spot beams, which are using the same group of RF bands. Analogously, in reception, the antenna picks up signals coming from all directions, including noise and interference. These considerations have to lead the development of the SDMA technique, which is based on deriving and exploiting information on the spatial position of MES terminals. In particular, the radiation pattern of the GES terminal, both in transmission and reception, is adapted to each different MES to obtain the highest gain in their directions.

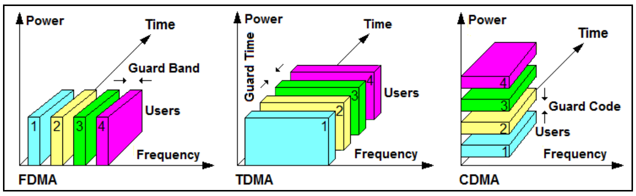

Figure 1. Common FDMA, TDMA and CDMA Techniques

2 TYPES OF MULTIPLE ACCESS TECHNIQUE (MAT) SCHEMES

The GEO and Non-GEO GMSC systems are a communications node through which all types of thge mobile users in the network must be interconnected as flexibly as possible. At the same time, two key resources, such as bandwidth and spacecraft power - must be utilized efficiently. However, for some applications, it may be necessary that a satellite is simultaneously accessed by hundreds of mobile satellite users, making accessing problems more complex. Further complications are added when factors such as a requirement for handling a mix of Voice, Data, and Video (VDV) satellite transmissions, traffic variations, and a necessity to incorporate communication growth are considered. Therefore, at this point in the fixed and mobile satellite communication systems are implemented the common MAT access schemes to improve modulation and transmission problems.

A single technique cannot optimize all these parameters and therefore a trade-off analysis using the applicable conditions is necessary, provided that the choice of an accessing scheme is not obvious. For example, if the application at hand is the provision of communication to a large number of low-cost mobile terminals, the accessing scheme should be simple but robust so as to permit the use of low-cost mobile receivers. At the same time, a certain degree of flexibility is necessary to enable sharing of the spectrum between a large number of mobile terminals and to accommodate the addition of mobiles to the network. Compare this with an application where a relatively few large MES terminals, each carrying heavy traffic, need to be interconnected. In this case, the accessing scheme can be complex and the main optimization criterion would be the optimal use of the available bandwidth and satellite power rather than the need for the simple mobile terminal.

A number of the following MAT accessing schemes have evolved over the years:

1 Frequency Division Multiple Access (FDMA) - This is a MAT scheme where each concerned GES or MES terminal is assigned its own different working carrier RF inside the spacecraft transponder bandwidth, which schematic diagram is shown in Figure 1 (Left). At the introductory phase of satellite technology, FDMA appeared to be the best candidate because of the initially established FDMA technology, from-the terrestrial radio relay system, its simple network control requirement, and the consequent low cost. The technology became widely used in all first-generation wireless and after that in satellite systems. This scheme, however, is inefficient with

respect to both the satellite power capacity and bandwidth utilization. An improvement in FDMA was introduced by incorporating an element of flexibility in the form of a demand assigned FDMA in which a central pool of frequencies is shared by the user on a call-by-call basis.

2 Time Division Multiple Access (TDMA) - This is a second MAT scheme where all concerned MES terminals use the same carrier frequency and bandwidth with time-sharing, non-overlapping intervals, which schematic diagram is shown in Figure 1 (Middle). Following an increase in traffic demand, leading to a scarcity of available bandwidth, and a trend towards digital techniques was implemented TDMA technique as a more efficient but complex MAT scheme. Thus, currently, the TDMA scheme is being introduced into most fixed and mobile satellite service networks used for interconnecting high traffic earth stations, although FDMA was started to be used well into the 2000s.

3 Code Division Multiple Access (CDMA) - This is a MAT 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. For some specialized applications where secrecy is vital or where a channel may suffer frequency selective fading or interference in communications, the CDMA scheme based on spread spectrum principles was developed.

4 Space Division Multiple Access (SDMA) - This is a new MAT scheme where all concerned MES terminals can use the same frequency at the same time within a separate space available for each link, which schematic diagram for wireless and satellite SDMA techniques is illustrated in Figure 2.

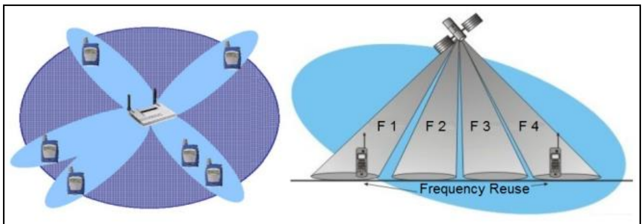

Figure 2. Wireless and Satellite SDMA Techniques

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

Currently, these methods and their hybrid solutions of MAT shemes 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.

Therefore, the MA techniques permit more than two Earth stations to use the same satellite network for interchanging information. Several transponders in the satellite payload share the frequency bands in use and each transponder will act independently of the others to filter out its own allocated frequency and further process that signal for transmission. Thus, this feature allows any LES located in the corresponding coverage area to receive carriers originating from several MES and vice versa and carriers transmitted by one MES can be received by any LES. This enables a transmitting Earth station to group several signals into a single, multi-destination carrier. Access to a transponder may be limited to single carrier or many carriers may exist simultaneously. The baseband information to be transmitted is impressed on the carrier by the single process of multi-channel modulation.

3 SPACE DIVISION MULTIPLE ACCESS (SDMA) SCHEME

The SDMA technique has several characteristics that make its introduction in a mobile radio system advantageous. In particular, all modifications required are limited to base stations and do not involve mobile units. Moreover, the SDMA technique can be integrated with different MAT schemes, such as FDMA, TDMA, CDMA, and therefore it can be used in all mobile radio systems currently operating or about to be introduced. This thechnique that employ smart multiple antenna elements at the base station in wireless systems or GES in fixed and mobile satellite systems provide much higher capacity than single-antenna-element systems. A fundamental question to be addressed concerns the ultimate capacity region of an SDMA system wherein a number of fixed or mobile users, each constrained in power, try to communicate with the base station or GES in a multipath fading environment.

The significant factor in the performance of the MAT scheme in a satellite communications system is interference caused by different factors and other users. In the other words, the most usual types of interference are co-channel and adjacent channel interference. The co-channel interference can be caused by transmissions from non-adjacent cells or spot beams using the same set of frequencies, where there is the minimal physical separation from neighboring cells using the same frequencies, while the adjacent channel interference is caused by RF leakage on the subscriber's channel from a neighboring cell using an adjacent frequency. This can occur when the user's signal is much weaker than that of the adjacent channel user. Signal to Interference Ratio (SIR) is an important indicator of call quality; it is a measure of the ratio between the mobile phone signal (the carrier signal) and an interfering signal. A higher SIR ratio means increasing overall system capacity.

Taking into account that within the systems of satellite communications, every user has their own unique spatial position, this fact may be used for the separation of channels in space and as a consequence, to increase the SIR ratio by using SDMA. In effect, this method is physically making the separation of paths available for each satellite link. Terrestrial telecommunication networks can use separate cables or radio links but on a single satellite, independent transmission paths are required. Thus, this MA control radiates energy into space and transmission can be on the same frequency: such as TDMA or CDMA. and on different frequencies, such as FDMA scheme.

In using SDMA, either FDMA or TDMA are needed to allow LES to roam in the same satellite beam or for polarization to enter the repeater. Thus, the frequency reuse technique of the same frequency is effectively a form of SDMA scheme, which depends upon achieving adequate beam-to-beam and polarization isolation. Using this system reverse line means that interference may be a problem and the capacity of the battery is limited.

On the other hand, a single satellite may achieve spatial separation by using beams with horizontal and vertical polarization or left-hand and right-hand circular polarization. This could allow two beams to cover the same Earth surface area, being separated by the polarization. Thus, the satellite could also have multiple beams using separate antennas or using a single antenna with multiple feeds. For multiple satellites, spatial separation can be achieved with orbital longitude or latitude and for intersatellite-links, by using different planes. Except for frequency reuse, this system provides onboard switching techniques, which, in turn, enhance channel capacity. Additionally, the use of narrow beams from the satellite allows the Earth station to operate with smaller antennas and so produce a higher power density per unit area for given transmitter power. Therefore, through the careful use of polarization, beams (SDMA), or orthogonal (CDMA), the same spectrum may be reused several times, with limited interference among users.

The more detailed benefits of an SDMA system include the following:

1 The number of cells required to cover a given area can be substantially reduced.
2 Interference from other systems and from users in other cells is significantly reduced.

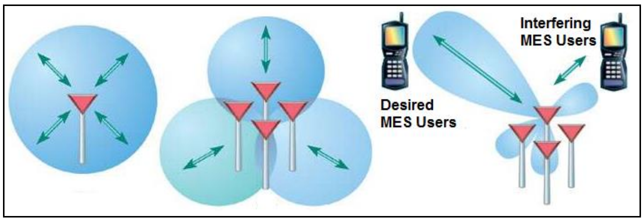

Figure 3. Nonsmart and Smart Antenna Beams

3 The destructive effects of multipath signals, copies of the desired signal that have arrived at the antenna after bouncing from objects between the signal source and the antenna can often be mitigated.
4 Channel reuse patterns of the systems can be significantly tighter because the average interference resulting from co-channel signals in other cells is markedly reduced.
5 Separate spatial channels can be created in each cell on the same conventional channel. In other words, the intra-cell reuse of conventional channels is possible.
6 The SDMA station radiates much less total power than a conventional ground station. One result is a reduction in network-wide RF pollution. Another is a reduction in power amplifier size.
7 The direction of each spatial channel is known and can be used to accurately establish the position of the signal source.
8 The SDMA technique is compatible with almost any modulation method, bandwidth, or frequency band including GMSC, Global System for Mobile Communications (GSM), and other Cellular networks, Digital Enhanced Cordless Telecommunications (DECT) solutions, IS-54, IS-95, and other transmission formats. The SDMA solution can be implemented with a broad range of array geometry and antenna types.

4 SATELLITE COMMUNICATION ARCHITECTURE WITH SMART ANTENNA ARRAYS

Another perspective of the realization of SDMA systems is the application of smart antenna arrays with different levels of intelligence consisting of the satellite antenna array and digital processor. Since the frequency of transmission for satellite communications is high enough, mostly 6 or 14 GHz, that the dimensions of an array placed in orbit are commensurable with the dimensions of the parabolic antenna, is a necessary condition to put such systems into orbit. There are two constants in the satellite communication community: demand for higher data rates and demand for greater user capacity. In fact, both depend on a unique factor known as spectrum efficiency, the ratio of information bits transmitted per amount of band spectrum space used, usually expressed in bits/Hertz b/Hz). Improving that efficiency generally involves tradeoffs between quality of service, power, and coverage.

In view of explosive growth in the number of MES subscribers, satellite operators and service providers are becoming increasingly concerned with the limited capacities of their existing networks. This concern has led to the deployment of smart antenna systems throughout important GMSC markets. In fact, the smart antenna systems have typically employed multibeam satellite technologies, which have been shown, through extensive reserach, analysis, simulation, trials, and experimentation, to provide substantial performance improvements in FDMA, TDMA, and CDMA networks. Multibeam architectures for FDMA and TDMA systems provide the straight-forward ability of the smart antenna to be implemented as a non-invasive add-on or applicable to an existing cell site, without major modifications or special interfaces.

In satellite communications and especially in GMSC networks are used nonsmart antenna systems, such as traditional omni-directional antennas. In Figure 3 (Left) shown are shown these type of antennas which act as transducers, that is, they convert electromagnetic energy into electrical energy, and are not an effective way to combat inter-cell and intra-cell interferences. One cost-effective solution to this interference challenge is to split up the wireless cell into multiple sectors using sectorized antennas. As Figure 3 (Middle) illustrates, sectorized nonsmart antennas transmit and receive in a limited portion of the cell, typically one-third of the circular area, thereby reducing the overall interference in the system.

Transmission efficiency can increase still further by using either spatial diversity or by focusing a narrow beam antenna on a single mobile user. The second approach is known as beam-forming, and it requires an array of antennas that together perform "smart" transmission and reception of signals, via the implementation of advanced signal processing algorithms. Although beam-forming is being seriously considered only lately for commercial cellular systems, the concept of using multiple antennas and innovative signal processing to serve cells more intelligently has existed for many years. In fact, smart antennas date back to the 1930s, although most significant developments occurred during World War II. Varying degrees of relatively costly smart-antenna systems have already been applied in defense systems for years. Thus, the cost has prevented their use in commercial systems until fairly recently, however. With smart antenna technology, each user's signal is transmitted and received by the base station or GES terminals only in the direction of that particular user. This drastically reduces the overall interference in the system. A smart-antenna system, as shown in Figure 3 (Right), includes an array of satellite antennas that together direct different transmission and reception beams toward each MES user in the GMSC network.

Compared with traditional omni-directional and sectorized antenna configurations, the smart-antenna infrastructure can provide the following advantages: (a) Greater coverage area for each satellite beam; b) Better rejection of co-channel interference; (c) Reduced multipath interference via increased directionality; (d) Reduced delay spread as fewer scatterers are allowed into the beam; (e) Increased frequency reuse with fewer MES terminal; (f) Higher range in mobile and remote environments; (g) Improved building penetration; (h) Location information for emergency situations; (i) Increased data rates and overall system capacity; and (j) Reduction in dropped calls.

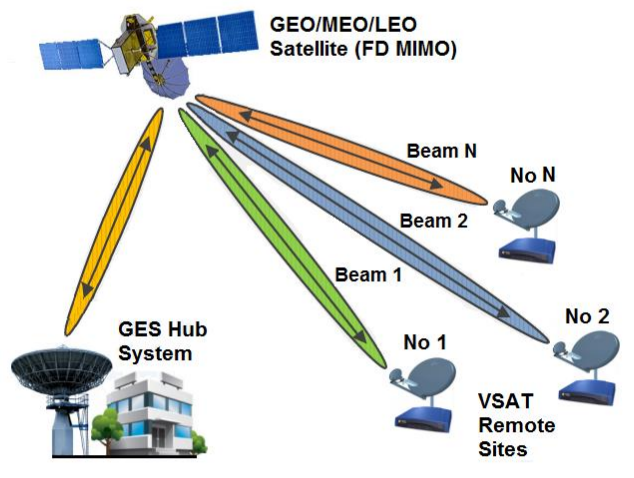

Figure 4. Full Dimension MU MIMO Transmision to MES Terminals

5 MASIVE MIMO AND MU-MIMO FOR MULTIBEAM MOBILE SATELLITES NETWORKS

The RF and satellite communication systems are implementing new microwave systems such as RF front-ends, tunable RF filters, antennas and antenna arrays. Recently, satellite systems have begun to incorporate new technologies such as high-speed signal processing platforms ad Multiple Input-Multiple Output (MIMO) techniques widely known and applied in terrestrial communication systems. However, there are also scenarios in satellite communication, where these modern technologies are applicable. Since they dramatically enhance communication link reliability and capacity compared to conventional schemes, it is an actual cutting-edge topic. In particular, the GMSC networks will focus on Multi-User (MU) MIMO techniques also called precoding, which can be implemented in GMSC networks via GEO and Non-GEO satellite constellations, such as Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) satellites. In Figure 4 is depicted the Full Dimension (FD) Multi User (MU) MIMO transmission from GES terminal via GEO/MEO/LEO satellites to many Very Small Aperture Terminals (VSAT) onboard ships, land vehicles (road and rail) and aircraft.

The new designed High Throughput Satellites (HTS) networks are employing multi-beam antennas and full frequency reuse for broadband fixed and mobile satellite services. Such architectures offer, for example, a cost-effective solution to optimize data delivery and extend the coverage areas in future satellite and cellular networks. In order to realize such requirements, it is necessary to develop and deploy the MIMO technology in both the satellite feeder links and the multiuser service downlinks. Spatial multiplexing of different data streams is performed in a common feeder beam. In the user links, MIMO with multiple beams is exploited to simultaneously serve different users in the same frequency channel. Under particular design constraints, effective spatial separation of the multiple user signals is possible. To mitigate the inter stream interference in the MIMO feeder link as well as the multiuser downlink, precoding of the transmit signals is applied in satellite and wireless communication systems.

Therefore, the MU-MIMO was created to support environments where multiple mobile users are trying to access a GEO and Non-GEO satellite network at the same time. Initially, this technology was developed for wireless networks supported by routers and endpoint devices and recently was proposed for satellite networks as well. In fact, MU-MIMO is the next evolution from single-user MIMO (SU-MIMO), which is generally referred to as MIMO. Otherwise, MIMO technology was created to help increase the number of antennas on a wireless router that is used for both receiving and transmitting, improving capacity for wireless and satellite connections.

There are two fundamental advantages of MU-MIMO over the more traditional single user (SU-MIMO) or point-to-point MIMO: (1) It can favourably work in the Line-of-Sight (LOS) propagation environment; and (2) MU-MIMO requires only single antenna terminals. Whereas, the next generation of Ku-band GEO fixed and mobile satellite communication systems geostationary SATCOM systems are aggressive in terms of throughput and capacity, the HTS and High Capacity Satellites (HiCapS) are the two main categories of satellite systems that have emerged. An HTS system typically consists of several fixed spot beams covering multiple small footprints on the ground. The main aim of an HTS system is to increase the overall throughput of a satellite by frequency reuse across the spot beams, using at least four or more colours. The frequency reuse factor of a multi-spot beam antenna, as compared to a standard large contour beam antenna, is the number of spots divided by the number of colours. Each colour in the spot zone denotes a certain frequency or polarization, so spot beams with different colours differ in frequency or polarization. Reducing the number of dedicated colours in an HTS system will increase the bandwidth in each spot and can boost the overall throughput, at the cost of increased interference for users at the edge of the beams. The application of MU-MIMO, precoding and Multi User Detection (MUD) techniques have been been analysed to mitigate the interference and these studies show an improvement in the system performance.

It is common for a satellite communications channel between the ground and a satellite to have a strong LOS path because the LOS path is essential in achieving a healthy link budget. However, in a MIMO scenario, the LOS nature of the satellite channel and the large range distance in the channel path can increase the spatial correlation between the channel paths. Geometrical optimisation is required to achieve extra spatial degrees of freedom. To achieve spatial orthogonality in the LOS fixed and satellite communication channel, antenna separation on the order of several kilometres, depending on the wavelength, is required either in space or on the ground.

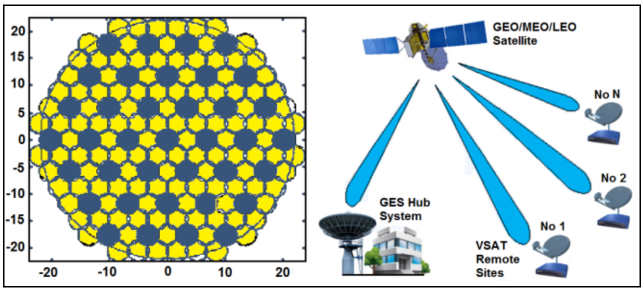

Figure 5. Satellite SDMA Multibeam Smart Anetnna and Fixed VSAT Multibeam Satellite Network

6 TYPES OF SMART ANTENNA SYSTEMS FOR MOBILE SATELLITES NETWORKS

The terms smart antenna heard today embrace various aspects of a smart antenna system technology include intelligent antennas, phased array, SDMA system, spatial processing, digital beamforming, adaptive antenna systems, and others. Smart antenna systems are customarily categorized, however, as either switched beam or adaptive array systems. The following are distinctions between the two major categories of smart antennas regarding the choices in transmit strategy:

1 Switched Beam, which signifies a finite number of fixed, predefined patterns or combining strategies (sectors); and
2 Adaptive Array, which signifies an infinite number of patterns (scenario-based) that are adjusted in real time.

The SDMA scheme mostly responds to the demands of MEO and LEO satellite constellations, when the signals of users achieve the satellite antenna under different angles (±22o for the MEO). In this instance, the ground level may be split into the number of zones of service coverage determined by switched multiple-beam pattern lobes in different satellite directions, or by adaptive antenna separations with multi-beam smart antenna system, which is shown in Figure 5 (Left). There are two different beam-forming approaches in SDMA for satellite communications: (1) The multiple spot beam antennas are the fundamental way of applying SDMA in large satellite systems including MSS and (2) Adaptive array antennas dynamically adapt to the number of users.

The smart antenna works in the way that each antenna element "sees" each propagation path differently, enabling the collection of elements to distinguish individual paths to within a certain resolution. As a consequence, smart antenna transmitters can encode independent streams of data onto different paths or linear combinations of paths, thereby increasing the data rate, or they can encode data redundantly onto paths that fade independently to protect the receiver from catastrophic signal fades, thereby providing diversity gain. A smart antenna receiver can decode the data from a smart antenna transmitter this is the highest-performing configuration or it can simply provide array gain or diversity gain to the desired signals transmitted from conventional transmitters and suppress the interference. No manual placement of antennas is required, so the smart antenna electronically adapts to the environment.

In satellite communications is deployed multibeam coverage configuration as a beamforming technique by which an array of antennas can be steered to transmit radio signals in a specific direction, which scenario of fixed VSAT multibeam SDMA satellite network is shown in Figure 5 (Right), and in Figure 6 is shown mobile VSAT multi-beam satellite network. Rather than simply broadcasting energy and signals in all directions, the antenna arrays that use beamforming, determine the direction of interest and transmit or receive a stronger beam of signals in that specific direction directly to the fixed and mobile VSAT stations. This technique is widely used in radars and sonar, biomedical, and particularly in Wi-Fi, wireless and new generations cellular communications, where very high data rates are required and the only way to support this would be to maximize transmit and receive efficiency by using beamforming. In this modern technique, each antenna element is fed separately with the signal to be transmitted. Thus, the phase and amplitude of each signal is then added constructively and destructively in such a way that they concentrate the energy into a narrow beam or lobe.

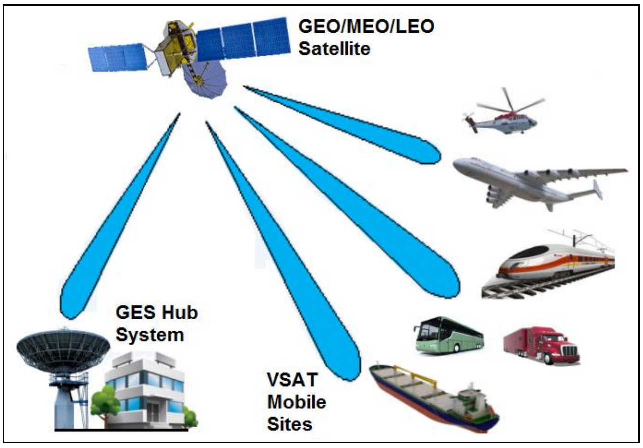

Figure 6. Mobile VSAT Multibeam Satellite Network

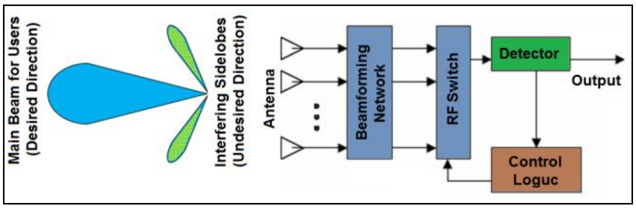

Figure 7. Switched Beamforming Lobes Radiation Pattern and Switched Beam Antenna

6.1 *Switched Beamforming Pattern and Switch Beam Antenna Array*

The switched multi-beam antennas are designed to track each user of a given cell for cellular and spot for satellite systems with an individual beam pattern as the target subscriber moves within the cell or spot coverages. Therefore, it is possible to use array antennas and to create a group of overlapping beams that together result in omnidirectional coverage. This is the simplest technique comprising only a basic switching function between separate directive antennas or predefined beams of an array. In fact, switched beam antenna system has a fixed number of beams, which one or more beams can be selected from the array for transmission or reception. The main motivation of the switched beam antenna is to increase the antenna gain. For example, a four-switched beam antenna system that used in 120° sector antenna, the resultant increased gain (G) can be calculated using the formula as follows:

$$G = 10 \log (M) \tag{1}$$

where M is the number of beams per sector. Thus for a sector containing 4 beams (M=4), the gain increase is 6dB over the original sector antenna.

Beam-switching algorithms and RF signal-processing software are incorporated into smart antenna designs. For each call, software algorithms determine the beams that maintain the highest quality signal and the system continuously updates beam selection, ensuring that customers get optimal quality for the duration of their call. One might design overlapping beam patterns pointing in slightly different directions, similar to the ones shown in Figure 5. (Left). Every so often, the system scans the outputs of each beam and selects the beam with the largest output power. The blue spots reuse the frequencies currently assigned to the mobile terminals, so they are potential sources of interference. In fact, the use of a narrow beam reduces the number of interfering sources seen at the base station. Namely, as the mobile moves, the smart antenna system continuously monitors the signal quality to determine when a particular beam should be selected.

Therefore, a switched spot beam antenna provides many narrow predefined beams and activates one or more beam in instant way, which scenario is shown in Figure 7 (Left). In terms of radiation patterns, the switched beam is an extension of the current micro cellular or cellular sectorization method of splitting a typical cell. The switched beam approach further subdivides macro-sectors into several microsectors as a means of improving range and capacity. Each micro-sector contains a predetermined fixed beam pattern with the greatest sensitivity located in the center of the beam and less sensitivity elsewhere. The design of such systems involves high-gain, narrow azimuthal beamwidth antenna elements. Smart antenna systems communicate directionally by forming specific antenna beam patterns. When a smart antenna directs its main lobe with enhanced gain in the direction of the user, it naturally forms side lobes and nulls or areas of medium and minimal gain respectively in directions away from the main lobe. Different switched beam and adaptive smart antenna systems control the lobes and the nulls with varying degrees of accuracy and flexibility.

By referring to Figure 7 (Right), a switched beam antenna system can be realized by breaking the whole system down into four major building blocks for ease of analysis. And shows how the system can be broken down into a beamforming network to form independent beams, an RF switch for switching between input ports, a power detector to monitor signal strength and a control logic running an algorithm that controls the whole system. The basic operation of the switched beam can be explained as follows. The input of the RF switch is connected to the beamforming network and its outputs connected to the power detector. At instant, only one switch will be turned on while others will be turned off. The power detector will measure the signal strengths for that incoming beam, which then will be connected to control logic. The main function of this control logic is to samples all the power and then make a comparison between them. After that, logic control will feedback to the RF switch and select the beam which received the highest signal to noise ratio, Signal-to-Noise Ratio (SNR) by sending a certain amount of voltage to thw RF switch. Thus, since the power detector operated in analog form while the microcontroller in digital form, an analog-to-digital converter may be needed for the interfacing part. However, this is just a general idea about how a switched beam antenna can be implemented as a system but the complete implementation of this switched beam system of way is not as simple as what was mentioned above.

Switched-beam antennas are normally used only for the reception of signals since there can be ambiguity in the system's perception of the location of the received signal. In fact, these antennas give the best performance, usually in terms of received power but they also suppress interference arriving from directions away from the active antenna beam's centre, because of the higher directivity, compared to a conventional antenna, some gain is achieved. In high-interference areas, switched-beam antennas are further limited since their pattern is fixed and they lack the ability to adaptively reject interference. Such an antenna will be easier to implement in existing cell structures than the more sophisticated adaptive arrays but it gives only limited improvement.

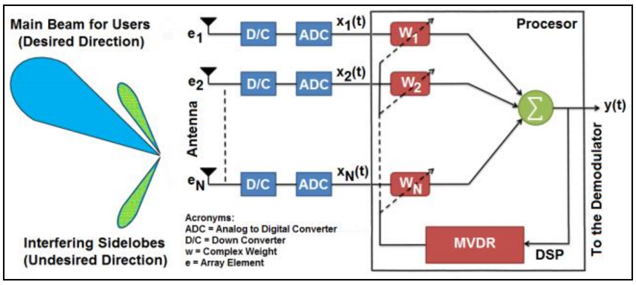

Figure 8. Adaptive Beamforming Lobes Radiation Pattern and Adaptive Beam Antenna

6.2 *Adaptive Beamforming Pattern and Adaptive Beam Antenna Array*

Adaptive Array systems provide more intelligent operation where it has the ability to adapt in real-time radiation patterns to the RF environment. It arranges beamforming lobes radiation pattern according to the target and interferes with user locations, which is shown in Figure 8 (Left). The adaptive system chooses a more accurate placement, thus providing greater signal enhancement. Similarly, the interfering signals arrive at places of lower intensity outside the main lobe, but again the adaptive system places these signals at the lowest possible gain points. The adaptive array concept ideally ensures that the main signal receives maximum enhancement while the interfering signals receive maximum suppression.

The adaptive antenna array systems select one beam pattern for each user out of a number of preset fixed beam patterns, depending on the location of the subscribers. At all events, these systems continually monitor their coverage areas, attempting to adapt to their changing radio environment, which consists of (often mobile) users and interferers. Thus, in the simplest scenario, that of a single user and no interferers, the system adapts to the user's motion by providing an effective antenna system pattern that follows the mobile user, always providing maximum gain in the user's direction. The principle of SDMA with adaptive antenna system application is quite different from the beam-forming approaches described in Figure 5 (Right) and in Figure 6 Figure 2. (B).

The adaptive antenna systems approach communication between MES and GES terminals in different ways by adding the dimension of space. By adjusting to the RF environment as it changes (or the spatial origin of signals), adaptive antenna technology can dynamically alter the signal patterns to optimize the performance of the satellite system. Adaptive array systems provide more degrees of freedom since they have the ability to adapt in real-time the radiation pattern to the RF signal environment; in other words, they can direct the main beam toward the pilot signal or Signal of Interest (SOI) while suppressing the antenna pattern in the direction of the interferers or Signals Not of Interest (SNOI). To put it simply, adaptive array systems can customize an appropriate radiation pattern for each individual user. Fig. below illustrates the general idea of an adaptive antenna system. Adaptive array systems can locate and track signals (users and interferers) and dynamically adjust the antenna pattern to enhance reception while minimizing interference using signal processing algorithms. A functional block diagram of the digital signal processing part of an adaptive array antenna system is shown in Figure 8 (Righ). Thus, one of the most famous adaptive processors in array signal processing is the Minimum Variance Distortionless Response (MVDR). The MVDR algorithm has been adopted by many researchers for Angle of Arrival (AoA) estimation, which is a process that determines the direction of arrival of a received signal by processing the signal impinging on an antenna array.

With reference to Figure 8 (Righ), it can be observed that the RF signal received by each of the N antennas comprising the array is at first brought down to baseband and then converted into digital form. The N complex signals obtained are then sent as inputs to the Direction of Arrival (DSP), which multiplies the signal of each antenna by a suitable factor (wi), and finally adds the various terms. The output signal is therefore given by:

$$y(t)=\sum_{i=1}^{N} w_i x_i(t) \qquad (2)$$

An appropriate choice of the weights vector values w = [w1, w2, ...wN] allows giving the radiation pattern the desired characteristics. In particular, vector w is determined using an adaptive strategy. Coefficients are therefore updated periodically, based on the observation of data received. To assure correct operation of the system, it is necessary that the adaption rate could compensate for the environmental variations, due to the mobility of the sources and accentuated by the presence of multiple paths. The use of an adaptive antenna array system at the base station thus allows introducing the SDMA technique, whose main advantage is the capability to increase system capacity, i.e. the number of users it can handle. Thus, this increase can be obtained in two different ways, and therefore the following applications are possible: (1) Reduction in co-channel interference between the different cells using the same group of radio channels is obtained, as above seen, by minimizing the gain in the direction of interfering mobile units. This technique, indicated with the acronym Spatial Filtering for Interference Reduction (SFIR) allows reducing frequency re-use distance and cluster size. In this way, each cell can be assigned a higher number of channels.and (2) Spatial orthogonality between signals associated with different users is obtained by transmitting them in different frequency bands of FDMA, in different time slots of TDMA, or using different code sequences of CDMA scheme.

The events processed in SDMA adaptive array antenna systems are as follows:

1 A "Snapshot", or sample, is taken of the transmission signals coming from all of the antenna elements, converted into digital form and stored in memory.
2 The SDMA digital processor analyzes the sample to estimate the radio environment at this point, identifying users and interfering their locations.
3 The processor calculates the combining strategy for the antenna signals that optimally recover the user's signals. With this strategy, each user's signal is received with as much gain as possible, and with the other users/interferers signals rejected as much as possible.
4 An analogous calculation is done to allow spatially selective transmission from the array. Each user's signal is now effectively delivered through a separate spatial channel.
5 The system now has the ability to both transmit and receive information on each of the spatial channels, making them two-way channels.

As a result, the SDMA adaptive array antenna system can create a number of two-way spatial channels on a single conventional channel, be it frequency, time, or code. Of course, each of these spatial channels enjoys the full gain and interference rejection capabilities of the antenna array. In theory, an antenna array with (n) elements can support (n) spatial channels per conventional channel. In practice, the number is somewhat less because the received multipath signals, which can be combined to direct received signals, takes place. In addition, by using special algorithms and space diversity techniques, the radiation pattern can be adapted to receive multipath signals, which can be combined. Hence, these techniques will maximize the SIR or Signal to Interference and Noise Ratio (SINR).

7 HYBRID SDMA NETWORK ARCHITECTURES

Further enhancement can be obtained when SDMA technique grouping is considered in combinations with FDMA, TDMA, and CDMA schemes in order to improve switching, transmission and frequesny bands conditions of baseband signals, and improve control of the satellite up and downlinks.

7.1 *SDMA/FDMA*

This modulation arrangement uses filters and fixed links within the satellite transceiver to route an incoming uplink frequency to a particular downlink transmission antenna. A basic arrangement of fixed links may be set up using a switch that is selected only occasionally. Thus, an alternative solution allows the filter to be switched using a switch matrix, which is controlled by a command link. Because of the term SS (Switching Satellite), this scheme would be classified as SDMA/SS/FDMA. The satellite switches are changed only rarely, only when it is desired to reconfigure the satellite, to take account of possible traffic changes. The main disadvantage of this solution is the need for filters, which increase the mass of the payload.

7.2 *SDMA/TDMA*

This solution is similar to the one previously explained in that a switch system allows a TDMA receiver to reconfigure the satellite. Under normal conditions, a link between beam pairs is maintained and operated under TDMA conditions. The utilization of time slots may be arranged on an organized or contention basis. Switching is achieved by using the RF signal. Thus, onboard processing is likely to be used in the future, allowing switching to take place by the utilization of baseband signals. The signal could be restored in quality and even stored to allow transmission in a new time slot in the outgoing TDMA frame. This scheme is providing up and downlinks for the later Intelsat VI spacecraft, known as SDMA/SS/TDMA.

7.3 *SDMA/CDMA*

This arrangement allows access to a common frequency band and may be used to provide the MAT technique to the satellite when each stream is decoded on the satellite in order to obtain the destination addresses. Thus, on-board circuitry must be capable of determining different destination addresses, which may arrive simultaneously, while also denying invalid users access to the downlink. However, on-board processors allow the CDMA bitstream to be retimed, regenerated and stored on the satellite. Because of this possibility. the downlink CDMA configurations need not be the same as for uplink and the Earth link may thus, be optimized.

8 CONCLUSION

The performances and capacities of MSC 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 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.

However, CDMA is wasteful in feeder link bandwidth, and the choice of a multiple access system must take all parameters into consideration, such as oscillator stability, interference rejection, system complexity, etc. as well as system cost before deciding on a particular multiple access systems.

The communication satellites for GMSC systems 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 inter-beam interference in L-band.

The CDMA scheme is better at absorbing Doppler and multipath effects, and it permits higher rate coding, but it suffers from self-jamming and from bandwidth constraints in the feede rlink. In general, all three multiple access systems show similar performance. However, at the chosen design point for aggregate EIRP values, the number of satellite beams, and allocated bandwidth, FDMA provides still the highest system channel capacity.

The narrowness of the frequency spectrum allocated to MSC 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.

Recently is developed SDMA as an advanced solution where all concerned MES terminals can share the same frequency at the same time within a separate space available for each link. On the other hand, the RDMA scheme is suitable for a large number of users in GMSC systems, where all MES terminals share asynchronously the same transponder by randomly transmitting short burst or packet divisions. In addition is developed several mobile Aloha methods, which successfully increase the system throughout.

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