PERSONAL SATELLITE COMMUNICATION: TECHNOLOGIES AND CHALLENGES

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ABSTRACT

Communication regulatory bodies in many parts of the world have recently granted satellite operators the right to extend their networks by adding ground segments. This has opened the door, for the first time, to truly ubiquitous satellite coverage, thus revolutionizing the use of satellites in personal communications. In this article, we review personal satellite communication systems. Background on the evolution of satellite communications is given along with the basics of satellite systems. This is followed by a comprehensive discussion of the current challenges facing the future of personal satellite communication systems and some of the proposed solutions.

INTRODUCTION

The use of satellites in communication goes back a few decades. The role of satellite systems was always complementary to ground-based fixed, wireless, or mobile communication systems. For instance, the early satellite communication networks targeted the maritime community, which is not served by any ground-based network for geographical as well as technical reasons. With the evolving need of ubiquitous personal communications, satellites have served as gap fillers, covering the remote areas not serviced by either landline or cellular networks. Moreover, satellite communication has proved to be priceless in the time of natural disasters when and where all other forms of communication fail due to damage to the infrastructure.

Satellite communication networks have to overcome several challenges in order to become mainstream among users. From a network perspective, satellite communication suffers from problems related to upper network layers as well as the physical layer. Upper-layer problems include long delays, packet losses, and sometimes intermittent connectivity and link disruptions where well-known network protocol stacks, such as TCP/IP are ineffective solutions. New network architectures, such as the delay- and disruption-tolerant networking (DTN) architecture can present an alternative solution [1]. The use of satellites for personal communication and other applications, such as space (interplanetary) Internet requires newly developed algorithms and protocols for each of the network layers. A comprehensive survey in this context can be found in [2].

Physical layer challenges include the necessity of establishing line-of-sight (LOS) communication with the satellite, which limits the accessibility of users to the satellite network, especially in dense urban areas where LOS conditions are not satisfied. Moreover, satellite network capacity is limited by the relatively small bandwidth assigned to satellite communication and the high power required for transmission. Table 1 shows subscriber numbers of three major players in the satellite phone market (as of the end of the third quarter of 2010) [3]. The numbers reflect how far satellite-based phone services are from competing with cellular networks.

In its technical and economic forecast of mobile broadband [4], the Federal Communications Commission (FCC) expects that mobile data demand will grow between 25 and 50 times current levels within five years, and that while technology will continue to improve, spectral efficiency of current orthogonal frequency-division multplexing (OFDM)-based 4G solutions is approaching maximum expected limits.

For the above reasons, telecommunications regulatory bodies in North America (FCC) and in Europe (the European Commission, EC) have granted licenses to some of the satellite network operators to add an ancillary terrestrial component (ATC) — also known as complementary ground component (CGC) — to their satellite networks. This integrated satellite-ground network can benefit from the advantages of ground cellular systems such as frequency reuse and non-light-of-sight (NLOS) communication in addition to the satellite advantages such as wide coverage. These integrated networks are called mobile satellite systems (MSS) with ancillary terrestrial component (ATC) or MSS/ATC networks. As promising as these new systems are, there is still a technical and financial gap between conception and realization of such systems.

This work was supported in part by King Abdullah University of Science and Technology (KAUST) and by the Natural Sciences and Engineering Research Council (NSERC).

 1536-1284/12/$25.00 © 2012 IEEE

In this article, we discuss the main challenges facing satellite communications and the state of the art in this field. We also discuss the addition of an ATC component to the network and the resulting integration problems.

The rest of the article is organized as follows: MSS is discussed. This is followed by the introduction of the ground component. Finally, we discuss the current challenges facing the integration of MSS and ATC and some of the possible proposed solutions.

Service provider	No. of subscribers
Thuraya	360,000 (est.)
Globalstar	105,000
Iridium	413,000

Table 1. *Olympic Summer Games statistics.*

Mobile Satellite Systems (MSS)

Satellite communication services can be classified as fixed satellite services (FSS) and mobile satellite services (MSS). In this article, we focus on MSS, which represents the future of global satellite communication. The implementation of mobile satellite-based phone services goes back to the late 1970s. However, from a penetration point of view, satellite-based phone service has greatly suffered due to competition from cellular technology, which offers a reliable and affordable alternative that achieves near global coverage. Moreover, satellite services require the existence of LOS, which is hard to guarantee in urban areas and almost impossible to achieve indoors.

In the early 2000s, in order to overcome some of the above problems and help satellite-based communications be more appealing to the mainstream market, satellite network operators succeeded in getting the telecommunication regulatory bodies in many parts of the world, like North America, the European Union, and Japan, to grant them permission to integrate ground components to the satellite networks. More details about the addition of the ground component are given.

Using terminology similar to that of cellular networks, a satellite spot beam can be considered a *satellite cell*. Spot beam sizes range from *global* (covering about one third of the Earth's surface) to *regional* (which is smaller in size than global) to *narrow* with a coverage of about a few hundred kilometers. Figure 1 shows an example of regional spot beams coverage of North America, while Fig. 2 illustrates an example of narrow spot beams coverage of the same region. These figures represent the actual coverage of two MSS operators, namely Skyterra and Terrestar, respectively.

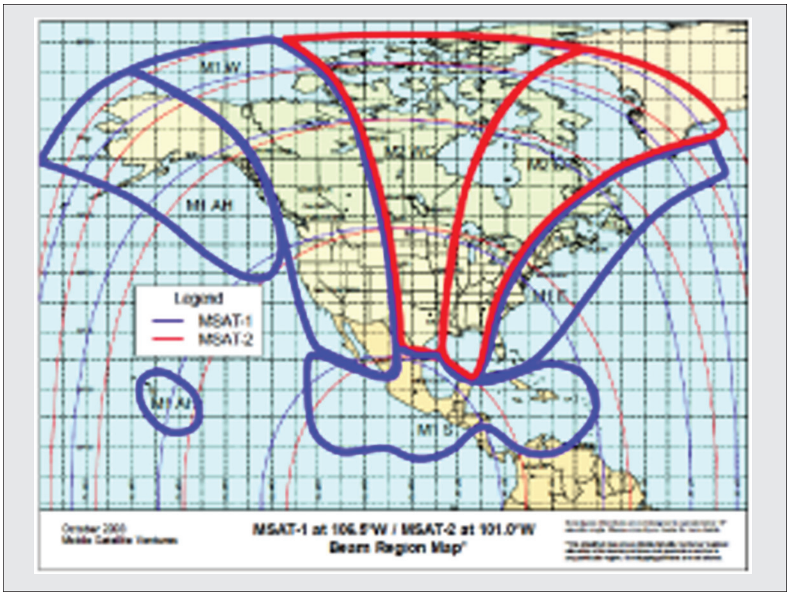

Figure 1. *Regional spot beams coverage of North America by Skyterra.*

Exactly as in the case of cellular cells, *frequency reuse* can be implemented in non-adjacent satellite cells. However, in the case of satellite systems, frequency reuse is limited due to the impracticality of forming a very large number of spot beams.

Figure 2 illustrates the concept of satellite cells formed by different spot beams. There are two main differences between satellite and cellular cells.

Size: Cellular cells range from a few meters (in case of a home cell) to around 30 km (macrocell), whereas satellite cells range from 100 to 1000 km depending on the satellite altitude.

Mobility: Mobility of the user across cellular cells necessitates handover from one base station to another. On the other hand, in the case of non-geostationary satellites, cells are not geographically fixed since they follow the satellites moving with respect to a fixed point on the ground. Thus, even for fixed users, handover is necessary from one satellite to another [5].

In current MSSs, the satellite uses low-power transmission with relatively small antennas, while on the other side, the user uses a high-power device with a relatively large antenna. Future MSS satellites are designed with huge antennas and are intended to use high transmission power in order to allow for user terminals to be small in size and reasonable in power consumption. The relatively high *link margin* required in MSS to allow for small-sized practical handheld devices results in limiting the capacity of MSS as opposed to FSS from about 10,000 calls in FSS to about 3000 to 4000 simultaneous calls in MSS.

The MSS system performance also depends on the amount of onboard processing (OBP) (or the lack thereof) done by the satellite. Traditional satellites, especially GEOs, serve as *bent pipes*. This means they simply act as relays between two ground points. However, other satellites allow OBP for more efficient channel usage and higher capacity. OBP also allows direct communication between satellites of the same constellation, thus enabling intersatellite links (ISL) to perform faster call routing directly through ISL. This significantly decreases the delay typically experienced in satellite-based voice communications.

Another application of OBP is required in

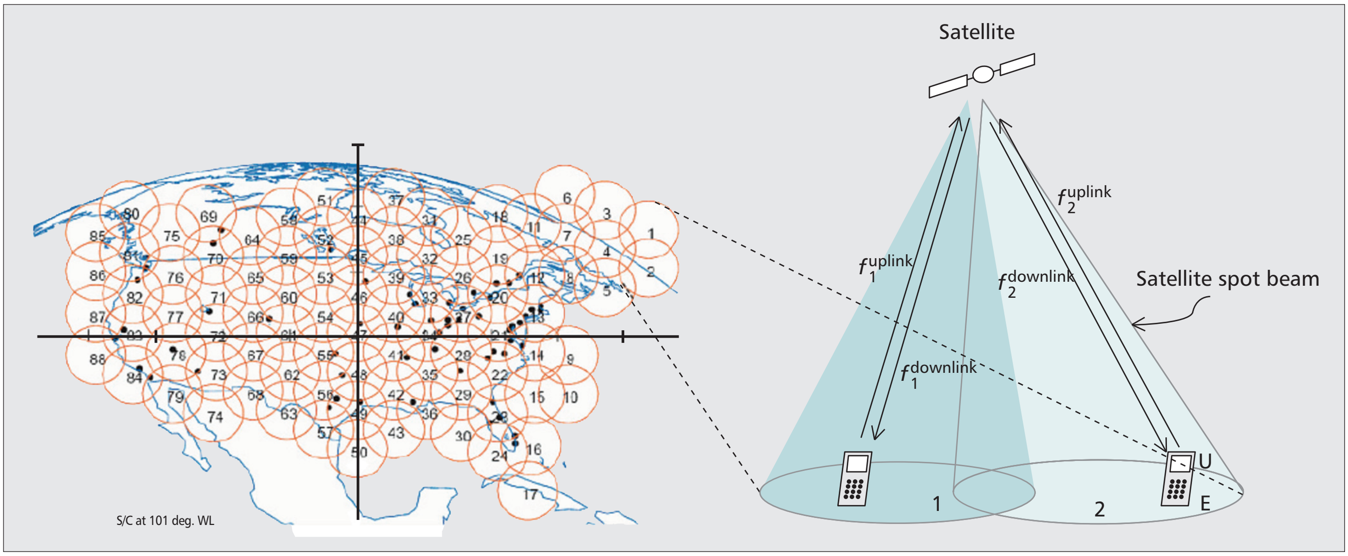

Figure 2. *Narrow spot beams coverage of North America of Terrestar and an illustration of the spot beam concept.*

return-link space diversity. In this case, more than one satellite (usually two) communicate with the user equipment to enhance satellite visibility [5]. Return-link diversity requires OBP to combine signals received by both satellites. Forward-link space diversity can also be used. However, in this case, the simpler switched satellite diversity may be enough [6].

Table 2 contains technical as well as commercial information about current MSS network satellites [7, 8].

Ground Component

Ground-based communication systems provide wide global coverage for the largest part of the communication market. These systems include public switched telephone networks (PSTNs) for fixed communications and cellular networks for mobile communications in addition to other systems. However, true ubiquity cannot be achieved using ground-based systems alone. Rural areas with low population density are usually not covered adequately by cellular networks, and true mobility is not provided. Aeronautical and maritime communications are also examples where ground-based systems do not provide coverage. This is where satellite communication proves to be valuable for comprehensive coverage for both fixed and mobile communications; FSS and MSS, respectively.

Comparing MSS with cellular systems, MSS has the following advantages.

Wider coverage: This is because satellite spot beams cover almost the whole surface of the planet.

Disaster tolerance: This means that in case of natural disasters like earthquakes and hurricanes, satellites can provide communication when other ground-based communications fail due to damage to the infrastructure.

On the other hand, cellular networks have the following advantages over MSS.

Low cost: Cellular networks provide low-cost coverage for high-density populations in urban areas. Typically, voice calls from a satellite phone to a landline or a mobile phone varies from around 0.15 to 2 per minute.

Spectral efficiency: This is a result of efficient frequency reuse in cellular networks. In case of satellites, frequency reuse is performed through the use of spot beams.

Better coverage in urban areas: Contrary to MSS, ground-based communication does not require LOS conditions for establishing communication. Thus, it provides better coverage in urban and dense urban areas.

It can thus be seen that a *hybrid* network comprising a satellite component and a ground component that complement each other can benefit from the advantages of both systems. This ground component is given the name ancillary terrestrial component (ATC) in North America and the name complementary ground component (CGC) in Europe. In this article we shall refer to this hybrid network for mobile communication as MSS/ATC.

The idea of using a ground component to complement the satellite segment is not new and is not restricted to communication networks. CGC has been used in broadcasting satellite networks for a long time. However, in broadcasting, the CGC is a simple repeater (also called gap filler) that fills the *holes* in the coverage of the satellite. In this case, the CGC can either use the same frequency as the satellite segment or receive the signal at a certain frequency from the satellite and retransmit it at a different frequency to end users.

Examples of satellite broadcast networks that use a ground component are S-DMB, XM Satellite Radio, Sirius Satellite Radio, DVB-SH, and European Telecommunications Standards Institute (ETSI) Satellite Digital Radio (SDR). In such systems, the ground component is mainly employed in dense urban areas not reachable by satellites.

In MSS, the addition of ATC targets more than repeating the satellite signal; thus, ATC is not a simple repeater since it must have a return channel. In fact, the integration of an ATC into MSS should have several benefits. These bene-

Service provider	Launching	Satellites	Orbit	Coverage area	Freq. band	Modulation	Multiple access	ISL	OBP
Inmarsat	1976	11	GEO	Global except polar regions	L	QPSK, π/4-QPSK, 16-QAM	TDMA	No	No
Iridium	1997	66	LEO	Global except N. Korea, Poland, Hungary	L	QPSK	FDMA, TDMA, TDD	Yes	Yes
HISPASAT	1992	6	GEO	N. and S. America, and W. Europe	Ku, Ka, X, C	QPSK	FM, TDMA	No	Yes
Light-squared	1995	2	GEO	N. and Central America	L, Ku	—	—	Yes	Yes
Globalstar	1998		LEO	N. and S. America, Europe, Australia, N. Africa and parts of Asia	S	FM, SS, QPSK	FDMA/CDMA	No	No
Thuraya	2000		GEO	Europe, N. and Central Africa, large parts of Asia, Australia and part of the Pacific	L	π/4-QPSK	FDMA	No	Yes
ICO	2000	1	MEO/GEO	N. America	C, S	—	FDMA, TDMA	No	No
ACeS	2000	1	GEO	Parts of Asia	L	GMSK	FDMA, TDMA	No	Yes
Terrestar	2009		GEO	Continental U.S., Canada, Puerto Rico, U.S. Virgin Islands, Hawaii and Alaska	L	—	—	No	Yes

Table 2. *Mobile satellite systems facts and figures.*

fits include filling the gaps in MSS coverage, increasing MSS network capacity, and the development of ubiquitous digital communications.

The ATC can follow any of the known cellular terrestrial standards, like LTE, GSM, CDMA2000, etc. However, the operating frequency band of the ATC should be the same as the satellite component frequency band (usually L-band or S-band). Both components (MSS and ATC) are operated by the same satellite operator. Figure 3 shows a diagram of the integrated MSS/ATC network.

The first ATC license was awarded by FCC in 2004. Since then, other licenses were granted to other MSS operators to add ATC to their existing networks. FCC rulemaking permits MSS licensees in the 2 GHz band, the L-band, and the Big LEO band. The European Commission (EC) also granted two CGC licenses in 2009. Table 3 gives details about the operators licensed to add ground components to their satellite networks.

Regarding the user's equipment, *dual-mode* handheld terminals are available today on the market. These terminals operate in both satellite and cellular modes. However, they should not be confused with MSS/ATC devices that are yet to be developed. The state-of-the-art terminals operate in two different frequency bands (MSS and cellular) with two different networks (a satellite network operator and a cellular network operator that have a combined service agreement). Moreover, the switching between the two modes is done manually by the user upon a personal decision that one network will deliver better quality of service (QoS) than the other in a specific location at a given time. This is very different from the ATC purpose (and technical specifications) provided by the FCC since the MSS/ATC system should be an integrated system with automated switching among the two segments of the network. Also, MSS/ATC uses one network with one frequency band.

In what follows, we discuss some of the challenges facing the integration of the MSS and ATC for use in personal satellite communication.

Integration Challenges

Although the early licenses for adding ATC to MSS have been granted for a few years now, it is logical to assume that fully operational MSS/ATC networks will not be available anytime soon. Indeed, there are several challenges that have to be overcome by the MSS industry before this integration becomes a reality. These challenges are mainly financial or technical in nature.

Financially, there is a huge overhead to building an MSS/ATC network. First, there is the cost of building satellites that are more powerful than existing ones (in order to deliver more link margin). Then come satellite launching, ATC network infrastructure (including building thousands of base stations), and new handset development. Investment in the MSS/ATC field is long-term, and some operators face difficulties committing to this caliber of investment and have to downsize or postpone their initial planned services.

From a technical point of view, challenges facing the MSS/ATC system inherently include problems facing MSS networks and problems facing cellular networks in addition to problems resulting from the integration of the two networks. MSS problems include developing reliable handover techniques (for non-geostationary satellite systems), optimization of call routing, and efficient frequency planning. Among the problems of cellular network design comes construction of green cellular networks using energy-efficient base stations, dynamic frequency planning, and many others.

Now, we focus on the technical challenges facing the integration of MSS and ATC (or CGC). These can be classified in two broad categories: *transparency* and *interference*. In what follows, we discuss each in more details.

Transparency

One of the main features of a truly integrated hybrid network is transparency. It is also one of the main requirements of the FCC for an MSS/ATC network. This means that moving from the satellite component to the ground component or vice versa should be transparent to the user (i.e., there should be no interruption in the service or any sudden change of any sort, including change in the level of power consumption of the user equipment). Although the definition of transparency is quite simple and clear, achieving it is a challenging task. In order to achieve transparency, the following solutions have been proposed and implemented in some cases.

Service provider	Date	Issued by	Licensed spectrum	Orbit
Lightsquared (formerly Skyterra)	2004	FCC	L-band	GEO
Globalstar	2006*	FCC	L-band	LEO
Inmarsat	2009	EC	S-band	GEO
ICO	2009	FCC	S-band	GEO
Eutelsat (Solaris)	2009	EC	S-band	GEO
Terrestar	2010	FCC	S-band	GEO

Table 3. *Globalstar license was suspended in 2010 because of failure to meet ATC gating requirements at preset deadlines.*

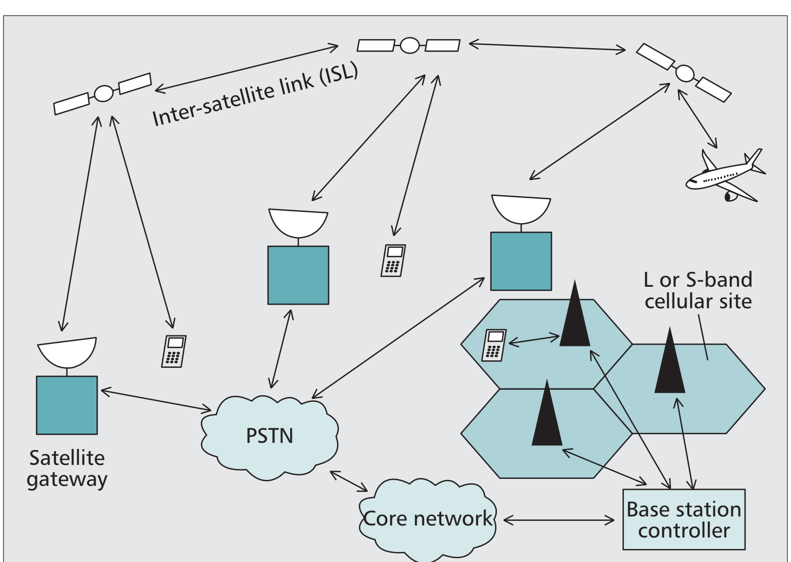

Figure 3. *The integrated MSS/ATC system.*

Power requirement: The user equipment should be able to communicate with the MSS and ATC with the same power. This dictates for satellites with larger antennas and higher transmission power to achieve a link margin capable of communicating with a low-power user equipment.

Communication compatibility: The same device is used with both MSS and ATC. Thus, in order to keep the user equipment small in size, hardware duplication should be avoided. This can be achieved through designing the air interface as well as the physical layer of both the MSS and ATC to be very similar or even identical. This guarantees the same radio frequency (RF) and baseband chipset for both components in the user equipment [6]. However, in case of MSS, the user equipment almost always deploys an external antenna (omnidirectional) in order to be able to communicate with the satellite. Furthermore, the orientation of the antenna should be adjusted to receive maximum signal power.

Seamless handover: One of the integration requirements is to ensure seamless handover between the MSS and the ATC. Designing a reliable handover mechanism in this case should take into consideration the difference in power and delay between both the MSS and the ATC. In [9], the authors suggest using two different algorithms for handover within each of the two components (*intrasystem* handover) and a combination of two algorithms for handover between the two components (*intersystem* handover, also known as *intersegment* handover, ISHO). In [10], a new handover algorithm that relies on the GPS receiver in the user equipment is proposed. In this algorithm, the user terminal reports its position to the nearest satellite, which communicates this information to the neighboring satellites through intersatellite links (ISLs). The information finally reaches nearby Earth stations, which update a location register in the local exchange. In [11], an adaptive handover algorithm is presented which estimates the probability that the received signal strengths from both the MSS and ATC links fall below a predetermined threshold.

As mentioned earlier, current dual-mode user handsets available require manual handover (switching) between the satellite and cellular networks. In general, handover in the MSS/ATC systems employing low Earth orbit (LEO) satellites is doubly complicated. This is because LEO satellites are non-geostationary. Thus, these satellites result in *satellite-fixed cells* as opposed to *Earth-fixed cells*. This implicates continuous handover among satellites even for fixed users. On top of that continuous intersystem satellite handover, there is the intrasystem handover between satellite and terrestrial cells for mobile users.

It is worth mentioning that at the deployment of the MSS/ATC networks, it is expected that there will be discrepancies in the QoS and transparency among different operators. Some satellite operators will use new satellites that can deliver significantly higher transmission power that will guarantee good satellite reception (high signal-to-noise ratio [SNR]) even with shadowing. Other service providers will use already existing MSS satellites and can guarantee good reception only in open areas that have a clear view of the sky. Thus, users of certain services might experience a degradation in QoS when intercomponent handover occurs.

Interference

Among the major challenges facing the use of an ATC with MSS is the problem of interference. Satellite operators are licensed to use an ATC that operates in the same frequency band as the satellite segment. Inherently, this means the existence of interference between the satellite and the ground components within the same network (operator) or with other networks. In an effort to limit interference, the first FCC ATC license ruling which is Mobile Satellite Ventures (MSV) — currently *Lightsquared* — states that "no more than 1725 ATC base stations may operate in the U.S. on any one 200 kHz L-band channel" [12]. As per the FCC, this limitation in the number of ATC base stations is decided for two reasons: to limit self-interference with the operation of MSV's own satellite system and to prevent harmful interference with the operation of other L-band MSS systems. The commission said, however, that it would entertain requests to deploy more than 1725 base stations in the United States based on a showing that there would be no consequent increase in interference to either MSV's own MSS or other MSSs. The commission determined that limiting the number of active U.S. base stations to 1725 per channel would ensure that MSV'sATC operation would raise the noise floor of other satellite operators, (i.e., Inmarsat) by no more than 1.4 percent, which the commission deemed to be acceptable [12].

There are basically two main types of interference, *intercomponent interference* and *intracomponent interference*. The latter is dealt with within each component (satellite or terrestrial) in the same way as regular MSS or cellular networks do. It is the intercomponent interference that we consider here since it results from the integration of MSS and ATC. Figure 4 illustrates the interference between the uplink and downlink of MSS with those of the closest ATC cell that reuses the same frequency.

According to [13], the most significant interference is the uplink signal from a terrestrial user reaching a satellite within its LOS and using the same uplink frequency. This can occur even when the terrestrial user is outside the *exclusion region* (defined below) of the satellite. The signal received by the satellite, $y(t)$ at time t, can be expressed as

$$y(t) = x_i(t) + \sum_{j \neq i} x_j(t) + v(t),$$

where x_i is the signal received from user terminal i at frequency f, $x_j \neq i$ is an interference signal received from user j at the same frequency, and $v(t)$ is thermal noise.

Interference can be combatted through beam-

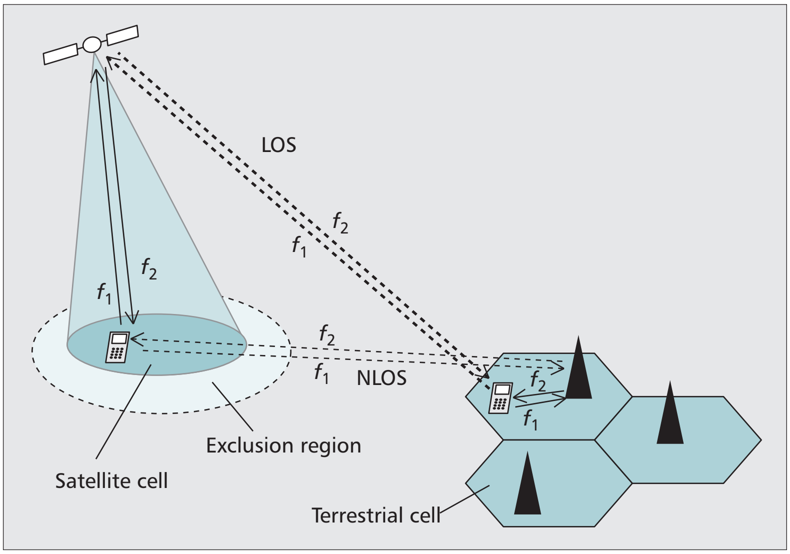

Figure 4. *Interference between satellite and terrestrial components.*

forming, interference suppression, and frequency planning as follows.

Beamforming: Beamforming is the choice of an antenna (shape, size, and aperture) that will result in a certain beam shape (antenna radiation pattern), whether for transmission or reception. In a satellite radio link, the received power P_r (excluding thermal noise) is given by [5]

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2,$$

where P_t is the transmit power, G_t is the transmit antenna gain, G_r is the receive antenna gain, and λ is the wavelength. The term $(\lambda/4\pi R)^2$ represents the free-space loss. The beam shape of the antenna radiation pattern determines the antenna gain G whether at the receiver or the transmitter. Thus, the received power can be maximized by controlling the beam shape in a certain direction.

Digital beamforming is a signal processing technique where the signals received by (or fed to) an array of non-directional antenna elements are linearly combined to simulate a highly directional antenna. This technique is used for *beam-shaping*.

In addition to beam-shaping, an array of antenna elements enable *beam steering*; that is, the direction of the resulting beam can be controlled. This is achieved through feeding the antenna elements signals that are identical in gain but have different phases. This can be done by controlling the length of the cable that feeds the antenna to result in different delays (phases) to different antenna elements. Digital beamforming has the advantage of flexibility. Indeed, the beam shape (antenna radiation pattern) and its direction can be adaptively changed without having to change the hardware. This allows dynamic area coverage by spot beams in order to adapt to the traffic demand in the network.

Beamforming is essential for minimizing the interference among different satellite spot beams (satellite cells) as well as the interference between the satellite cells and the terrestrial

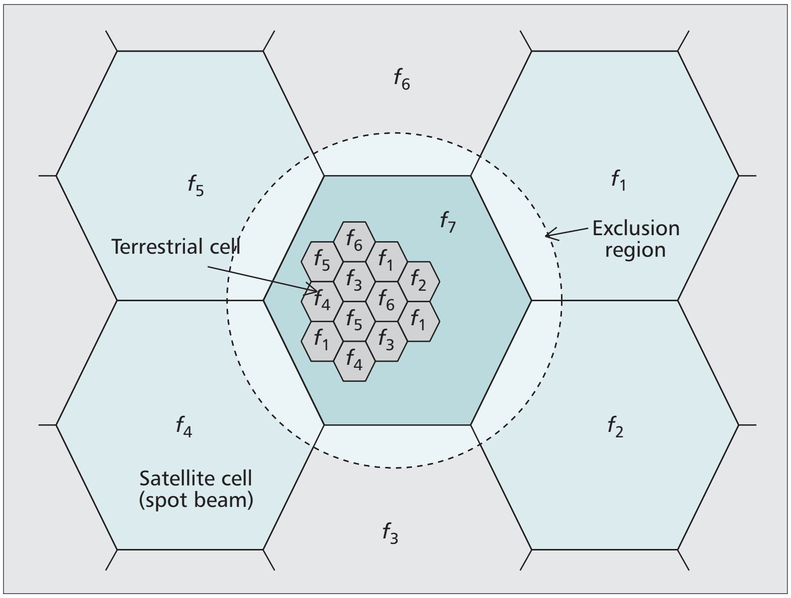

Figure 5. *Satellite and terrestrial frequency reuse.*

cells that reuse the same frequency. It is also worth mentioning that beamforming can be used at the receiver as well. This results in an increased sensitivity of the receiver towards beams received from certain directions. This also helps decrease interference. This is called *ground-based beamforming*, and is often used to simplify the OBP of the satellite.

Interference is one of the major problems that face the integration of MSS and ATC, and beamforming is one of the most effective solutions to this problem worth of further investigation.

Interference suppression: Signal processing techniques can be implemented for the purpose of interference suppression. For example, precoding can be used on different signals to maximize a certain performance metric, usually signal-to-interference-plus-noise-ratio (SINR). This technique is generally useful in multiuser systems in order to separate signals to or from different users. In case of MSS/ATC, signal processing can be used to minimize interference among different network components, for instance, between a satellite spot beam component and a terrestrial component that reuses the same frequency band.

In compliance with the above-mentioned FCC interference limits, MSS/ATC operators will have to employ signal processing interference cancellation techniques at their ATC base stations as well as at satellite gateways [14].

Sometimes the term beamforming is used in a mathematical sense to describe a signal processing technique where precoding is used to maximize some SNR. This is not to be confused with actual beamforming of antenna radiation patterns. In [15], the authors present a beamforming technique based on a minimum mean squared error (MMSE) performance index. The goal is to maximize the SINR of MSS links in an environment of significant terrestrial reuse of the satellite service link frequencies by ATCs.

Frequency planning: One factor that can contribute significantly to interference between the satellite and terrestrial components is frequency reuse. Thus, an optimum frequency planning strategy should be used for frequency reuse among the satellite and ground components. In addition to mitigating interference, a good frequency reuse plan can help maximize the system capacity through optimum allocation of the spectral resources.

Figure 5 illustrates a frequency reuse pattern among satellite cells as well as between satellite and terrestrial cells. In the figure, f_1 through f_7 designate seven different operating frequencies. Seven-cell frequency planning is used in this case for satellite cells (spot beams). Part of the central satellite cell (shaded in a darker color) represents a high-density population area. This requires an ATC in order to increase the capacity through frequency reuse, and for service accessibility inside buildings and confined areas. It can be seen in the figure that terrestrial cells are formed in this urban area where all the operating frequencies are reused except the one(s) from the same satellite cell.

It is worth mentioning that an additional safety margin can be added in the frequency planning: adding a *spatial guard band* [6]. This is an exclusion region around the original satellite cell (as shown by the dashed circle in Fig. 5) where the satellite cellular frequency cannot be used. This contributes to minimizing the interference between satellite and terrestrial cells.

The task of frequency planning in case of MSS/ATC is a challenging one since satellite coverage must be included in a cellular network planning tool. New satellite operators adopting the MSS/ATC approach have been actively developing frequency reuse schemes that optimize spectral efficiency and increase system capacity [14].

One important feature that should be taken into consideration while frequency planning for MSS/ATC is adaptivity. This means that the frequency reuse plan should be able to change dynamically in order to adapt to traffic demand in different coverage areas. In case of congestion, re-assigning frequencies between the satellite segment and the ground segment helps deal with temporary increase in traffic demand. This adaptive frequency allocation is also used between FSS and MSS and is called capacity offloading. This capacity sharing can also occur among MSS satellites.

Conclusion

Satellite networks have the potential to become the solution to ubiquitous communications. In this article, we have surveyed existing mobile satellite systems and discussed the addition of an ancillary terrestrial component. With the integration of the terrestrial component, system capacity, spectral efficiency, and coverage are all expected to be be significantly improved. We have summarized the different integration challenges that have yet to be addressed in order to arrive at a transparent network, and shed light on open research problems in that area and some proposed solutions.

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Biographies

MIRETTE SADEK [S'01, M'10] (mirettesadek@gmail.com) received B.Sc. and M.Sc. degrees in electrical engineering from Ain Shams University, Cairo, Egypt, in 1997 and 2001, respectively. She received M.Sc. and Ph.D. degrees in electrical engineering from the University of California, Los Angeles (UCLA) in 2006. Since 2007, she is an assistant professor at Ain Shams University, where she is doing research on signal processing in the field of wireless communications. She has also worked as a consultant for Newport Media Inc., Irvine, California, Varkon Semiconductors and Axxcelera Egypt in Cairo, Egypt, all in the field of physical layer design for wireless communication systems. From 2010 to 2011 she joined King Abdullah University of Science and Technology (KAUST), Thuwal, KSA, as a postdoctoral fellow, where she conducted research in the field of MIMO and satellite communication systems. She was the recipient of the Taha Hussein Medal of Honor for ranking first in the General Secondary School certificate, Egypt, 1992.

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One important feature that should be taken into consideration while frequency planning for MSS/ATC is adaptivity. This means that the frequency reuse plan should be able to change dynamically in order to adapt to traffic demand in different coverage areas.