ABSTRACT

Commercial Satellite Communications (SATCOM) provide a range of services to network centric military applications. In addition to fixed satellite systems, a wide range of mobile satellite systems are suitable to support mobile services to emergency applications and communications on the move. The unique capabilities such as robustness, wide area coverage and broadcast/multicast capabilities make SATCOM a preferred choice for worldwide war fighter communication services. In this paper we survey current mobile satellite networks and services, encompassing recent standardization efforts and currently available and planned systems characteristics. An efficiency comparison is also presented to emphasize the impact of different design parameters in selecting a GEO or LEO based system architecture.

1. INTRODUCTION

Network centric operations employ a significant percentage of commercial SATCOM services to the joint war fighter. These capabilities include satellite bandwidth, leased bandwidth terminals, global mobile satellite airtime, and commercial teleport services. Future network centric systems for military applications employ internet protocol (IP). The IP based satellite systems could be a part of hybrid network systems including terrestrial segments or be stand alone satellite systems depending on the operational requirements.

There is a wide range of applications such as (e.g., land-mobile, aeronautical, maritime, transport, rescue and disaster relief, require mobile communication services where the satellite is the only viable option [1, 2]. Moreover, mobile satellite operators have already started a new investment cycle for the replacement of current satellite constellations with second-generation ones. Some of the GEO-based systems can be supported with a terrestrial segment according to the hybrid or integrated architecture. In order to define the terrestrial segment, the EU Commission has introduced the concept of Complementary Ground Component (CGC); while FCC in U.S. has used the term Ancillary Terrestrial Component (ATC). CGC and ATC are quite interchangeable concepts. Terrestrial systems could be based on 3rd generation (3G), Wireless Fidelity (WiFi, IEEE 802.11 a/b/g), or Worldwide Interoperability for Wireless Microwave Access (WiMAX) and or long term evolution (LTE) technologies.

The main focus of this paper is to provide a brief description of some of the mobile satellite systems (MSSs) and compare their system characteristics as well as system efficiency. In addition we study the current standards development as appropriate to hybrid architectures with terrestrial segments or stand alone satellite systems.

The paper is organized as follows. Section 2 provides a brief overview of the MSSs standards development. Section 3 provides MSSs systems description and a characteristic comparison in terms of orbits, frequency, multiple access and applications. In section 4 we provide a system efficiency expression comparing GEO and LEO based systems. Finally conclusions are drawn in section 5.

2. MOBILE SATELLITE SYSTEMS STANDARDS

The following section provides an overview of the following five standards applicable to the mobile satellite systems (MSSs). These include: a) Global System for Mobile Communications (GSM) via satellite b) Satellite - Universal Mobile Telecommunications System (UMTS) System (SUMTS) c) Digital Video Broadcasting - Satellite Version 2 (DVB-S2) and related return-link standard (DVB-RCS) d) Satellite – Digital Multimedia Broadcasting (S-DMB) e) DVB - Satellite to Handheld (DVB-SH).
2.1 GSM
At present, GSM [3] is the most popular standard for cellular communications supporting packet-switched data with the General Packet Radio Service (GPRS). GSM is a terrestrial system, but extensions are commercially available that permit a “form” of GSM via satellite. Mobile terminals can be dual-mode, thus allowing the use of either the terrestrial GSM interface or the GEO satellite. In particular, the GEO Mobile Radio (GMR) air interface is used for mobile services via GEO satellite. ETSI has produced two sets of specifications for GMR derived from GSM called GMR-1 (used by Thuraya sec.3.5) and GMR-2 (used by ACeS sec.3.6) and contain adaptations for the GSM standard to cope with the characteristics of GEO systems (see section III). GMR allows access via satellite to the GSM core network. Besides a cellular coverage and the frequency reuse concept, other similarities between GSM and GMR exist for protocol layers above the physical layer.

2.2 S-UMTS
ETSI has been involved in extension of the UMTS standard for satellite, S-UMTS [4]. UMTS is one of the 3G terrestrial cellular technologies [5]. We refer to the UMTS version based on the Wideband - Code Division Multiple Access (WCDMA) air interface with Frequency Division Duplexing (FDD). The ETSI TC SES group has defined the S-UMTS family G specification set, aiming at the satellite air interface fully compatible with the terrestrial WCDMA-based UMTS system. S-UMTS is not only intended to complement the terrestrial UMTS coverage, but it is also conceived to extend UMTS services to areas where the terrestrial coverage would be either technically or economically unfeasible. S-UMTS uses frequency bands around 2 GHz that are close to those used by terrestrial 3G systems. S-UMTS supports multimedia services with bit-rates up to 144 Kbit/s. [6] proposes a possible S-UMTS system architecture with interworking of the satellite segment and an IP-based core network.

At present, we refer to S-UMTS “phase-1” as to a system implementing a forward path via satellite to support broadcast and multicast services, with the possibility to exploit a return path through a terrestrial 3G segment for interactive services. Then, the future S-UMTS “phase-2” will also allow a return path via satellite with optimized link budget for mobile handsets and possibly considering an Orthogonal Frequency Division Multiple Access (OFDMA) – based air interface operating at 5 GHz. This activity is in accordance with the effort recently started by the ITU-R working party 4C focusing on multi-carrier air interface for the satellite component aiming at the compatibility with terrestrial systems evolving towards 4th generation (4G) mobile networks, such as LTE and WiMAX.

2.3 DVB-S2 - Mobile Extension
DVB-S2 is the 2nd-generation standard for digital video broadcast transmission by satellite [7]. Besides broadcasting services, DVB-S2 can also be employed for interactive point-to-point applications (e.g., Internet access) by using new operation modes that permit dynamic adaptation of the Modulation and Coding (ModCod) levels depending on channel conditions at the receiver. DVB-S2 has been conceived for fixed users, but it is being evolved to support mobile users on aircrafts, trains and landmasses operating in Ku and Ka bands [8]. This extension needs to address many challenging issues, such as: stringent frequency regulations, Doppler Effect, frequent handovers, and impairments in synchronization acquisition and maintenance. For the return link the DVB-RCS+M specification has been completed to support mobile users.

2.4 S-DMB
3G mobile networks providing multicast/broadcast services support many mobile entertainment services. The S-DMB standard envisages a satellite-based broadcast component for 3G mobile networks. It permits to distribute the Multimedia Broadcast Multicast Service (MBMS) that can be offered via GSM or UMTS cellular networks [9].

The S-DMB architecture is composed of a GEO satellite and terrestrial repeaters named Intermediate Module Repeaters (IMR) co-located with 3G base stations using WCDMA. The operating technology copes with heavy shadowing in urban areas using hybrid network architecture at VHF and L bands. From the joint S-DMB and DVB-Handheld (DVB-H) experiments, a new technology, i.e., DVB-SH has been conceived operating in S band around 2.2 GHz.

2.5 DVB-SH
DVB-SH is an ETSI mobile broadcast standard based on an Orthogonal Frequency Division Multiplexing (OFDM) air interface provisioning data, audio and video services to small handheld terminals and some vehicular devices [10]. DVB-SH achieves a large coverage by combining a
satellite component and a CGC system. Terrestrial Repeaters are employed to increase the DVB-SH service availability in zones where it is impossible to have LoS conditions with the satellite (e.g., urban areas and indoor reception). DVB-SH will also complement the coverage of DVB-H terrestrial systems. Dual-mode terminals are considered, with the DVB-SH reception in S-band around 2.2 GHz, (near the 3G terrestrial frequencies) and DVB-H reception in the UHF-band. DVB-SH will provide IP-based multimedia services to mobile users. Users can access the services when traveling on ships, cars, trains or while walking. The main interest is not only in supporting broadcast services, but also data push delivery and interactive services via an external return channel, e.g., UMTS. The, ICO global communications has selected DVB-SH for the mobile video service platform supported by the recently-launched ICO-G1 GEO satellite for the coverage of the CONUS area (11).

3. MOBILE SATELLITE SYSTEMS

In this Section, we provide a brief description of operational and planned mobile satellite system. Each satellite operates similar to a base station of terrestrial cellular network.

3.1 Iridium and Globalstar systems

Iridium [12] and Globalstar [13] systems must be considered as the ancestors of all the MSSs existing today. Iridium is the only satellite system to provide complete earth coverage, including Polar Regions, air routes and ocean zones as shown in Figure 1 employing a LEO-constellation supporting voice and data. Satellites have On Board Processing (OBP) capabilities and Inter Satellite Links (ISLs) for data routing among satellites of the constellation. Iridium provides communication services to the U.S. Department of Defense. Recently, the Iridium Company has announced the second-generation system with IP-based satellites to be able to monitor continuously the environment, allowing transmission rates up to 10 Mbit/s.

Globalstar provides communication services covering an area within ± 70° latitudes. Globalstar uses bent-pipe LEO satellites as shown in Figure 2. Each mobile terminal communicates via satellite directly to the nearest gateway which covers a radius of approximately 2,000 km. The Globalstar system offers real-time voice, data and fax. Voice is encoded at a variable bit-rate; 2.4, 4.8 or 9.6 kbit/s, depending on the background noise level. The maximum supported data rate is 9.6 kbit/s. Also Globalstar is now planning second-generation satellites for its constellation.

3.2 ICO system

Intermediate Circular Orbit (ICO) Global Communications was founded in 1995 as a private Company to provide global mobile personal communication services via satellite [11]. Following a filing for bankruptcy code in 1999, it emerged with the name of New ICO in 2000. The plan was for a MEO constellation with 12 satellites at an altitude of 10,390 km according to the architecture in Figure 3. These satellites employ a Frequency Division / Time Division Multiple Access (FDMA/TDMA) air interface in the C/S-bands. The services supported include voice at 4.8 kbit/s, data at 2.4 kbit/s, fax, wireless Internet, messaging and positioning. However, at present, only one MEO satellite is operational, providing data gathering services for the U.S. government.
ICO is also planning to offer S-band MSS services via a new GEO (ICO-G1) satellite that has been recently launched and put at 91° West longitude for North America coverage (CONUS area). This ICO GEO-based system uses a new generation of pocket-size dual-mode handsets. Customers will be able to roam among ICO-G1 and other mobile terrestrial networks around the world.

3.3 Inmarsat system

Established in 1979 to serve the maritime community, Inmarsat delivers broadband communication services to enterprise, maritime and aeronautical users [14]. Inmarsat operates a constellation of GEO satellites that provide mobile phone, fax and data communications to the entire world, except Polar Regions (see Figure 4). In particular, Inmarsat uses 11 GEO satellites (only 10 of them are active): 4 Inmarsat-2, 5 Inmarsat-3, and 2 Inmarsat-4 satellites.

**BGAN system of Inmarsat**

Recently, the Inmarsat Broadband Global Area Network (BGAN) [14] system has acquired momentum to provide several services (e.g., telephony, Internet, messaging) to both fixed and mobile users by using Inmarsat-4 satellites. BGAN satellites are bent-pipe, and uses two Inmarsat-4 satellites (the third Inmarsat-4 satellite will be available in the future). BGAN is intended to be integrated with a terrestrial 3G component (3GPP release 4 network). The feeder link uses the C band and has a global coverage beam; while the user link (transmissions to users via satellite) is in the L band and employs a deployable antenna using up to 256 beams. In a typical configuration, there are 19 wide beams (large coverage), 228 narrow beams (focused coverage), and one global beam. Only the narrow beams are used for land-mobile communications. BGAN replaces the WCDMA air interface typical of 3G systems with a proprietary air interface (namely, Inmarsat Air Interface-2, IAI2). Different modulation options are available (i.e., QPSK, 16QAM, and π/4-QPSK with different turbo code steps and variable coding rates obtained by means of puncturing) [15]. It is possible to adapt the transmission power, bandwidth, coding rate modulation scheme to channel conditions achieving high transmission efficiency. This system allows communications from 4.5 kbit/s to about 512 kbit/s (Maximum effective user throughout being 492 kbit/s) to 3 classes of portable user terminals[15].

Figure 4: Inmarsat system components.

The BGAN Extension (BGAN-X) project has been developed extending the terminal classes to 11 (including 3 classes for aeronautical, 3 classes for maritime and 2 classes for land-vehicular categories) with omnidirectional and directional antennas. In [16], the authors provide performance of BGAN air interface for maritime, land-vehicular and aeronautical user terminals, considering dynamic channel conditions due to multi-path, fading, shadowing. The BGAN system can guarantee a broadband Internet access service up to 492 kbit/s.

3.4 Hispasat system

Hispasat was set up in 1989 with the objective of becoming a leading satellite operator for the Spanish and Portuguese markets[17]. Hispasat has become a global satellite operator covering Europe, America, Canada and North Africa. Hispasat offers IP-based broadband services, such as mobile services, Internet and content distribution tele-medicine and tele-education, voice over
IP, video streaming, and IPTV. The Hispasat satellite communication system includes GEO satellites located at the following orbital positions:
a) A transatlantic position at 30º W, where four GEO satellites are located with transponders in Ku, Ka and X bands.
b) An American position at 61º E, where the GEO Amazonas satellite is located (32 transponders in Ku band and 19 in C band).
c) An oriental position at 29º E, where the GEO Xtar-Eur satellite is located (12 transponders in X band).

3.5 Thuraya system

Thuraya was founded in the UAE in 1997 by a consortium of leading national telecommunication operators and international investment houses [18]. Using GEO satellites, Thuraya covers more than 110 countries, spanning Europe, North and Central Africa, Middle East, Central Asia and the Indian Subcontinent. Thuraya-3 satellite has been recently launched to substitute Thuraya-1 satellite, expanding coverage in Asian zones (e.g., China and Japan) as well as in Australia. At present, the Thuraya fleet comprises 2 operational GEO satellites (i.e., Thuraya-2 and Thuraya-3), using GMR-1 air interface in L band. Thuraya satellites are equipped with a 12.25 m L-band transmit-receive reflector antenna and 200-300 spot-beams can be created. On-board processing is used to support mobile-to-mobile links between any spot-beams within a satellite. Dual-mode handsets integrate the access to either a terrestrial GSM network or the Thuraya system for underserved and impervious areas, allowing customers to roam vast areas without service interruptions. The satellite communication services offered by Thuraya mobile handsets include: GSM-like voice, fax/data at 2.4, 4.8 and 9.6 kbit/s, and messaging. Thuraya also allows Internet connectivity through a small portable (notebook size) terminal at high-speed up to 144 kbit/s and high-speed IP-based service at 444 kbit/s.

3.6 ACeS system

The Asia Cellular System (ACeS) is a satellite-based communication network providing digital voice and optional data services for handheld terminals in Asia [19]. ACeS uses the GMR-2 air interface. ACeS aims to provide interoperability with GSM terrestrial cellular access networks. GSM subscribers can continue to use their existing GSM SIM cards with the dual-mode (GSM/satellite) handsets. The ACeS system architecture is composed of a GEO satellite (named Garuda 1), 3 gateways located in Indonesia, Philippines, and Thailand. ACeS provides an interface with terrestrial fixed and mobile telephone networks and (either fixed or mobile) ACeS terminals. Garuda 1 satellite has two 12.25 m L-band antennas with each antenna consisting of 140 beams. The ACeS services are: voice (3.6 kbit/s), duplex data transmission (2.4 kbit/s), standard GSM supplementary services. Optional services include: messaging, voice mail, email, fax and high power paging.

3.7 MSV system

The Mobile Satellite Ventures (MSV) Company has built an integrated satellite-terrestrial all-IP network, which provides ubiquitous wireless broadband services, including Internet access and voice services [20]. The ATC segment is composed of some terrestrial base stations that support the satellite system, providing complementary and combined terrestrial/satellite services. The MSV satellite fleet has two GEO satellites (i.e., MSAT-1 and MSAT-2) that deliver voice and data services for public safety, security, and fleet management. MSV has engaged the Boeing Company to develop two new GEO satellites (i.e., MSV1 and MSV 2) for replacing the current satellites and providing new services. The new satellites will have a 22 m L-band reflector antenna providing 250 spot-beams.

3.8 TerreStar system

TerreStar is an emerging first North America’s 4G integrated mobile satellite and terrestrial communication network providers universal access to conventional wireless devices [21]. TerreStar is building an all-IP, next-generation mobile communication network. TerreStar will operate in two 10 MHz blocks of contiguous spectrum in the 2 GHz band throughout the United States and Canada. TerreStar-I, the first satellite, is currently under construction by Space Systems/Loral. This satellite is equipped with an 18 m antenna providing up to 500 dynamically-configurable spot-beams. TerreStar is expected to provide new services and control systems for homeland security agencies, public safety agencies, and rural communities.

4. SYSTEMS COMPARISON

4.1 System Characteristics

Table 1 provides a brief comparison of MSSs discussed in sec 3. These systems are compared in terms of the system are compared in
<table>
<thead>
<tr>
<th>System</th>
<th>Satellite orbit</th>
<th>Frequency bands</th>
<th>Physical Layer (PHY)</th>
<th>Multiple access (satellite)</th>
<th>Satellite features</th>
<th>ISL</th>
<th>Standard</th>
<th>Supported applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRIIDIUM</td>
<td>LEO</td>
<td>L</td>
<td>QPSK</td>
<td>FDMA / TDMA - TDD (uplink and downlink)</td>
<td>OBP, switching, routing</td>
<td>Yes</td>
<td>Dual-mode (satellite - GSM)</td>
<td>p2p file exchange, real-time voice</td>
</tr>
<tr>
<td>GLOBALSTAR</td>
<td>LEO</td>
<td>S</td>
<td>FM / spread-spectrum modulation - QPSK</td>
<td>Combined FDMA / CDMA (uplink and downlink)</td>
<td>Bent-pipe</td>
<td>No</td>
<td>Dual-mode (satellite - GSM)</td>
<td>p2p file exchange, real-time voice</td>
</tr>
<tr>
<td>BGAN</td>
<td>GEO</td>
<td>L</td>
<td>QPSK, π/4-QPSK, 16QAM</td>
<td>TDMA</td>
<td>Bent-pipe</td>
<td>No</td>
<td>Dual-mode (satellite - GSM); proprietary air interface</td>
<td>Broadband Internet access, VoIP, p2p file exchange, live video, videoconferencing, real-time voice</td>
</tr>
<tr>
<td>HISPASAT Operator (AmerHis transponders of the Amazonas satellite)</td>
<td>GEO</td>
<td>Ku</td>
<td>QPSK</td>
<td>MF-TDMA</td>
<td>Regenerative, OBP, beam switching</td>
<td>No</td>
<td>DVB-S/-RCS</td>
<td>VoIP, p2p file exchange, live video, videoconferencing, real-time voice</td>
</tr>
<tr>
<td>THURAYA</td>
<td>GEO</td>
<td>L</td>
<td>π/4 QPSK</td>
<td>FDMA</td>
<td>OBP, beam switching</td>
<td>No</td>
<td>Dual-mode (satellite – GSM); GMR-1 air interface</td>
<td>p2p file exchange, real-time voice</td>
</tr>
<tr>
<td>ACeS</td>
<td>GEO</td>
<td>L</td>
<td>GMSK</td>
<td>FDMA / TDMA</td>
<td>OBP, beam switching</td>
<td>No</td>
<td>Dual-mode (satellite – GSM); GMR-2 air interface</td>
<td>p2p file exchange, real-time voice, GSM supplementary services, messaging, high power paging</td>
</tr>
<tr>
<td>MSV</td>
<td>GEO</td>
<td>L</td>
<td>-</td>
<td>-</td>
<td>OBP, beam switching</td>
<td>Yes</td>
<td>Dual-mode (satellite - GSM)</td>
<td>p2p file exchange, real-time voice, broadband Internet access, services for public safety</td>
</tr>
<tr>
<td>TERRESTAR</td>
<td>GEO</td>
<td>L</td>
<td>-</td>
<td>-</td>
<td>OBP, beam switching</td>
<td>No</td>
<td>Dual-mode (satellite - GSM)</td>
<td>p2p file exchange, real-time voice, live video, broadband Internet access</td>
</tr>
</tbody>
</table>

Table 1: Characteristics of Mobile Satellite Systems
Terms of the system Characteristics of Mobile Satellite system characters such as satellite orbits, frequency band, modulation, multiple access, standard and the applications supported. As we see, the first generation MSSs e.g. iridium, globalstar support mainly voice applications whereas the recent systems BGAN, MSV and terre star are designed to support broadband internet access and video applications. Also, it can be observed that majority of the MSSs employ GEOS. Many net centric applications can be supported by these GEO based systems requiring broadband usage.

4.2 System Efficiency Comparison

In this section, we compare the system efficiency in terms of traffic engineering parameters. Table 2 shows some of the system parameters such as bandwidth, number of beams per satellite, system frequency reuse and system efficiency for GEO based and LEO based MSSs examples. We are interested to define an MSS efficiency parameter $\eta_{SI-SAP}$ which is related to the efficiency at the Satellite Independent-Service Access Point (SI-SAP) level [22]. In particular, this parameter is computed as the bit-rate capacity of a beam multiplied by the number of active beams in the system and divided by the total one-way bandwidth.

Table 2: Traffic Engineering parameters for MSSs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GEO BGAN-like</th>
<th>GEO Thuraya-like</th>
<th>LEO Iridium-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B$ [MHz/downlink]</td>
<td>34</td>
<td>34</td>
<td>16.5</td>
</tr>
<tr>
<td>$N$ [# beams/system]</td>
<td>~456</td>
<td>~600</td>
<td>~2150</td>
</tr>
<tr>
<td>$F$, reuse degree</td>
<td>20</td>
<td>30</td>
<td>~180</td>
</tr>
<tr>
<td>$K$ [#beams/cluster]</td>
<td>~27</td>
<td>~21</td>
<td>~12</td>
</tr>
<tr>
<td>[bit/s/Hz]</td>
<td>1.22</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>Altitude [km]</td>
<td>35,800</td>
<td>35,800</td>
<td>780</td>
</tr>
<tr>
<td>Beams/satellite</td>
<td>228</td>
<td>300</td>
<td>48</td>
</tr>
</tbody>
</table>

This formula has been proposed by mobile satellite service providers (e.g., EUTELSAT, SES-ASTRA)

$$\eta_{SI-SAP} = \frac{\text{beam capacity} \times \text{(# of active beam in the system)}}{\text{one way total bandwidth}} = \frac{\eta \times N}{K} = \eta \times F \left(\frac{\text{bit/s}}{\text{Hz}}\right)$$

where $N =$ number of beams simultaneously active in the MSS, $K =$ size of the frequency reuse cluster of the MSS, depending on the antenna technology, air interface type and tolerance to interference of the multiple access system; $F =$ reuse factor of the MSS (i.e., the number of times that a frequency is reused among active beams); $\eta =$ total efficiency of physical and MAC layers. For details of the equation please refer to [24].

Figure 5, shows the efficiency $\eta_{SI-SAP}$ calculated according to the previous equation and the data in Table 2. These results show that LEO systems are characterized by a higher efficiency than GEO-based ones. The antenna technology plays a crucial role to determine the efficiency in MSSs: the antenna directivity (high insulation among adjacent beams in a multi-beam antenna) allows much lower inter-cell interference in LEO systems than in GEO satellite. Also results in much larger overlaps in the coverage of adjacent beams and consequent side-lobe effects. Hence, smaller cluster sizes can be adopted in LEO systems than in GEO ones. This aspect, coupled with the fact that a LEO constellation can have many active beams, allows that LEO satellites (e.g., Iridium) attain a much higher degree of resource reuse than GEO systems. It is interesting to note that if we evaluate the $\eta_{SI-SAP}$ value for an advanced Fixed Satellite System (FSS), like the Hot Bird 6 GEO satellite referring to its payload of 4 Ka-band Skyplex DVB-RCS transponders (each of them with a bandwidth of 33 MHz), we obtain an efficiency value of 2.8 bit/s/Hz. This is a much lower efficiency value than those obtained in Figure 5 for MSSs. The difference between FSSs and MSSs lies in the fact that MSSs need many beams to focus the power transmission due to the criticalities of the link budget with mobile users. These stringent requirements are not needed by FSSs which consequently results in a lower efficiency.
5. CONCLUSIONS

In this paper we have surveyed briefly some of the mobile satellite systems (MSSs) in terms of their system characteristics e.g. orbits, frequency band, modulation, multiple access, standard and applications. An overview of the current status of the appropriate standards development for mobile satellite systems is included. We have provided an expression for system efficiency and compared it for GEO based and LEO based systems. It has been observed, that the LEO systems can provide higher system efficiency than GEO based one. However, the traffic load handled, the broadband data rate supported and the mobility are the other design requirements which must be compared to fully recommend systems for specific net centric applications. The future studies will consider an extensive analysis for recommending the commercial SATCOM for network centric war fighter applications.

REFERENCES