Global Tracking and Inventory of Military Hardware via LEO Satellite: A System Approach and Likely Scenario

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Abstract - **A system for global inventory control of electronically tagged military hardware is achievable using a LEO satellite constellation. An equipment Tag can communicate directly to the satellite with a power of 5 watts or less at a data rate of 2400 to 50,000 bps. As examples, two proposed commercial LEO systems, IRIDIUM and ORBCOMM, are both capable of providing global coverage but with dramatically different telecom capacities. Investigation of these two LEO systems as applied to the Tag scenario provides insight into satellite design trade-offs, constellation trade-offs and signal dynamics that effect the performance of a satellite-based global inventory control system.**

1.0 Introduction

1.1 Study Goals

The goal of this study was to verify the feasibility and performance of direct Tag-satellite communication as applied to global inventory control of military hardware. Two commercial LEO systems were used as example satellite support scenarios. The investigation culminated with the estimation of temporal coverage and telecom capacity provided to potential military hot spots.

1.2 Satellite-Tag System Goals

The military employs Tags on equipment to help automate inventory control, speed access to inventory and provide automated tracking of valuable or sensitive material. Initial systems used bar codes and readers. Current systems now under development include an RF Tag with 2-way capability and a capacity of 128,000 bytes of information. A single interrogation unit can cover an area up to two acres, access any single unit or multiple units, read current information, update information and locate the device within a radius of 15 to 20 feet. While these new systems are limited to a range of several hundred feet, the desire is to be able track equipment in a theater of operation that may be scattered over hundreds of miles and equipment in transit to the theater of operations. The idea proposed is to augment existing remote inventory control with direct Tag-to-Satellite communications. A constellation of Low Earth Orbit, LEO, satellites would pass sufficiently low over equipment to allow two way communications to a Tag equipped with an omni-directional antenna and limited to 5 watts RF transmit power. There are several applicable commercial LEO satellite networks currently under development that could accomplish the task of providing true global connectivity to tagged military equipment.

This operational scenario is depicted in Figure 1 where a logistics support person is shown as using a computer to send (and receive) messages to (and from) a Tag. Tags will be placed on equipment containers that are shipped and stored around the world. The computer messages envisaged as utilizing the Internet or private line to link the user with a satellite hub station. Messages are reformatted at the hub station to conform to the satellite and Tag system protocols. These messages are then transmitted to the Tag via the appropriate satellite in a constellation of satellites providing global coverage.

1.3 LEO System Models

In this study two types of Low Earth Orbiting (LEO satellites are examined for use in closing the link to the Tag: an IRIDIUM satellite' and an ORBCOMM satellite. IRIDIUM and ORBCOMM satellites were chosen for two reasons; (1) to represent operation with a satellite from the 'Big' LEO category (IRIDIUM) and from the 'Little' LEO category (ORBCOMM) and (2) to investigate Tag operation and performance with satellites systems likely to offer global coverage in the near future.

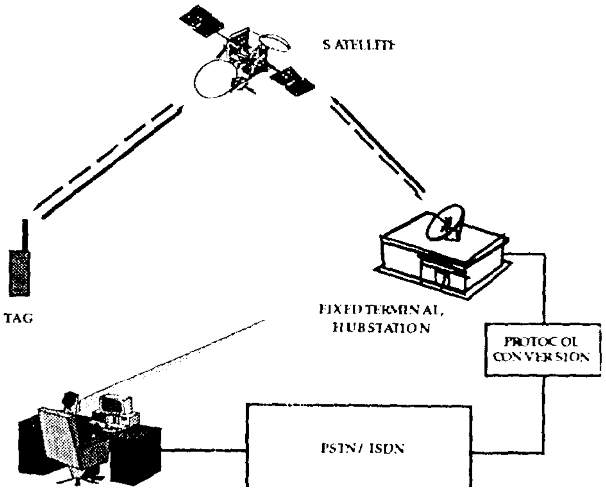

Figure 1. Operational scenario for remote inventory tracking using satellite communications to link materiel Tags with a logistics support personnel

Using these two candidate LEO systems, additional study goals were to investigate LEO satellite systems' coverage of the Earth and their applicability to global Tag operations and provide insight into satellite design trade-offs, constellation trade-offs, and signal dynamics that effect the performance of a satellite-based global inventory control system.

Analytical and trade-off analysis performed in this section were based on LEO satellite system parameters found in references 1,2, 3, and 4.

1.4 Tag Operating Environment and Constraints

Tags will be placed on equipment containers that are shipped and stored around the world. Shipping times may be on the order of several months and storage times may exceed several years. Tags must be able to operate for years off battery power possibly augmented by solar cells. RF power output will be limited to about 5 watts peak and the antenna must be omni-directional to accommodate random orientations. The link must have sufficient margin to accommodate some shadowing and multipath as the Tag may at times be obscured from a line-of-sight link to the satellite. Link budgets in appendix A of this paper show that both the IRIDIUM and ORBCOMM systems can close the link while providing 15 dB of signal shadowing margin.

Tags will be in motion at times, but this motion will be dwarfed by the relative motion of the LEO satellites that communicate with the Tags. Hence both Tags and satellites must accommodate Doppler shifts of the transmit and receive frequencies due to the physical dynamics of the link.

No specific requirements exists for unintentional or intentional interference. Error correction coding and link margin must be sufficient to combat unintentional interference and special techniques, not covered in this analysis, would be necessary to combat intentional interferers. Security may be achieved by currently available digital encryption techniques.

2.o LEO Satellite System Characteristics

2.1 IRIDIUM

IRIDIUM was originally developed and marketed by the Motorola Corporation. Under current organization, the IRIDIUM system will be funded and managed by the private international corporation, Iridium, Inc. which includes investors from the U. S., Canada, South America, Asia, India, Russia, Europe and the Middle East. The system is being marketed as a global satellite based personal communications system, providing near toll quality two-way voice, paging, data, geo-location and FAX services.

Global coverage is provided by 66 satellites placed in polar LEO orbits. Communications is Time Division Multiple Access, TDMA. Uplink and downlink frequencies are identical and channels are allocated in the 1610-1626.5 MHz L-band range. 50 kbps uplink and downlink data bursts are time-interleaved and thus with appropriate data buffering the users have the option of lower rate, 4800 bps voice or 2400 bps data, full duplex communications.

subscriber units will include hand-held, portable and mobile versions that will be offered in a dual-mode configuration that will work with terrestrial cellular networks and the new IRIDIUM satellite network.

2.2 ORBCOMM

ORBCOMM is a LEO satellite communication system proposed by Orbital Communications Corporation a wholly owned subsidiary of Orbital Sciences Corporation. ORBCOMM has secured license agreements with service providers in Argentina, Brazil, Canada, Columbia, Ecuador, Guatemala, Honduras, Mexico, Panama and Uruguay.

The developers have proposed a tier set of communication and position location services. Two way communications services are emphasized for accidents, search and rescue, and emergency medical units. Data acquisition services are emphasized for monitoring of remote environmental test sites and utilities vehicles. The monitoring service provides a one-way data retrieval and position monitoring with the option of occasional transmission to the remote unit.

Based on ORBCOMM'S 1990 FCC filing their satellite constellation is comprised of '20 satellites in circular LEO orbits at an altitude of 970 km. *(More Recent FCC Filings propose a different satellite constellation of 36 satellites orbiting at an altitude of 775 km. This analysis is based on the earlier filings).* Uplink from the user is a 2400 bps QPSK signal at 148 MHz. Downlink to the user is a 4800 bps BPSK signal at 137 MHz.

ORBCOMM has proposed different classes of user terminals, including portable, mobile and hand held units. The simplest units will have fixed transmit and receive channels which will restrict access to satellites in a single orbit plane and thus reduce coverage by 1 3. More advanced terminals add frequency agility to” the transmitter and to the receiver. Position determination service and hardware is optional.

3.0 Satellite Network and Satellite Dynamics

The IRIDIUM Satellite constellation consists of 66 satellites divided into 6 polar orbit planes spaced 31.6° apart. Each plane has 11 satellites equally spaced around the orbit with the orbit positions in adjacent orbit planes staggered. The satellites have an orbital altitude of 785 km with an inclination of 86.4° and a nearly circular path. The resulting orbital period is approximately 101 minutes.

IRIDIUM assumes that the ground user will be able to communicate with the spacecraft if it appears at least 7°-10° above the horizon. Given this minimum elevation angle of 7°-100 and the low 785 km altitude of the spacecraft we find that at any instant the spacecraft can communicate to any user within an area below it on the earth roughly 4170-4650 km in diameter. Figure 2 depicts the scenario.

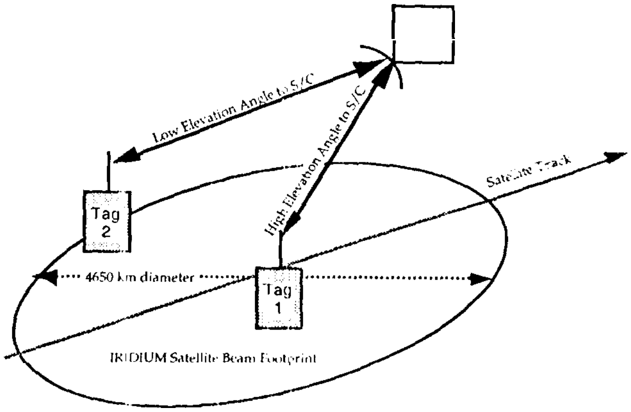

Figure 2: Users on outskirts of coverage see spacecraft only briefly at low elevation angles.

Users on the outskirts of this footprint only see the spacecraft for a brief instant as it rises above 10° elevation angle. Users directly under the path of IRIDIUM see the spacecraft above 10° elevation for about IO minutes, which corresponds to the maximum pass time for any user.

The ORBCOMM full constellation consists of 20 satellites in circular LEO orbits at an altitude of 970 km. The resulting orbital period is about 104 minutes. Eighteen of the satellites form the primary constellation and are partitioned into 3 orbit planes equally spaced 120° apart in longitude and inclined between 40 and 60 degrees. Exact orbit inclination will be determined after further technical and market research. Within a plane, the 6 satellites are equally spaced around the orbit path. This primary constellation is designed to favor coverage to the equatorial and temperate latitudes, Two additional satellites in orthogonal polar orbits and 180° out of phase provide coverage to latitudes above 70° north or south. Coverage gaps of one to two minute; will occur in the lower latitudes and coverage to the northern latitudes is in 14 minute intervals separated by 30 minute gaps.

ORBCOMM assumes a minimum elevation angle of 50 which results in a maximum slant range of 3135 km and a beam coverage circle 5600 km in diameter. Maximum pass time is about 15 minutes and decreases as the satellites ground track diverges from the user's location.

3.0 **Global Coverage**

The rotation period of the Earth is much slower than the orbit time of the IRIDIUM spacecraft. This results in a single spacecraft covering a different ground swath on every orbit. In one day an IRIDIUM spacecraft completes 14.3 orbits. If we integrate the full 66 satellite constellation coverage over 1 day we get the coverage vs. user latitude plot shown in figure 3. In general, coverage increases for increasing latitude. This is a feature of any near polar low earth orbit. On every orbit each IRIDIUM satellite visits the poles but on each orbit only a fraction of the lower latitudes can be covered. Coverage values at a 11 latitudes exceed 24 hours per day. This means that at times, there is more than one satellite visible. A coverage time of more than 48 hours per day says that there are on average, 2 or more satellites visible to the ground user during the entire day. This is true for users above 55" north or south latitude.

Similar results for the 20 satellite ORBCOMM constellation are also shown in figure 3. (Note the different minimum elevation angle assumption). The main constellation, with orbits inclined at 50°, enhances coverage in the lower to middle latitudes. Coverage falls off at higher latitudes and would in fact be zero above 75° if the two polar orbiters were eliminated. It is important to note that for latitudes below 40°, the ORBCOMM constellation provides nearly the same temporal coverage as does IRIDIUM but with only 1/3 the number of satellites. This is because the orbit inclination of 50° in general is better than a near polar orbit for providing coverage to lower latitudes. Above 40° latitude the IRIDIUM constellation is a better performer in part because of the better high latitude coverage afforded by polar orbiting satellites. Reasons for using a larger number of satellites in near polar orbit include IRIDIUM's desires, (1) to provide> 99% temporal coverage to virtually 100% of the globe, (2) to provide traffic capacity high enough to meet expected user demands.

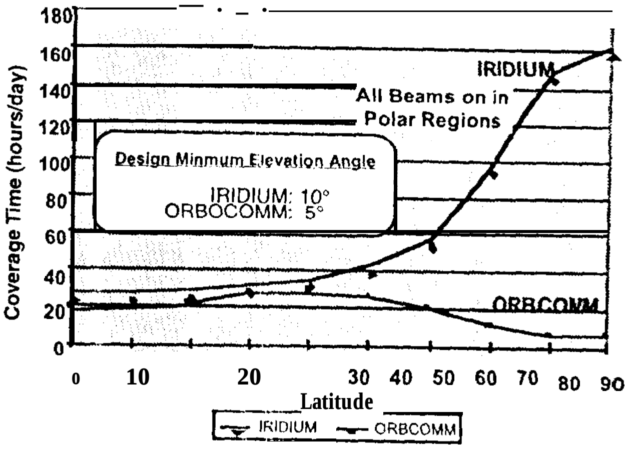

Figure 3: IRIDIUM vs. ORBCOMM: full constellation coverage vs. user latitude,

Normally, the IRIDIUM system turns off overlapping beams in the polar regions so actual polar coverage is lower than the maximum value shown.

4,0 Global Telecom Capacity

A single IRIDIUM satellite sees a ground swath up to 4650 km wide on the earth below. For IRIDIUM the roughly circular coverage is divided into 48 spot beams as depicted in figure 5. The diameter of each spot beam is about 600 ire-L As the spacecraft moves the user is passed to adjacent beams approximately once a minute. Adjacent spots use different frequencies, but non-adjacent spots can re-use the frequency already used by another spot. In fact the allocated frequency is divided into 12 sub-bands and each sub-band is reused 4 times on a single satellite.

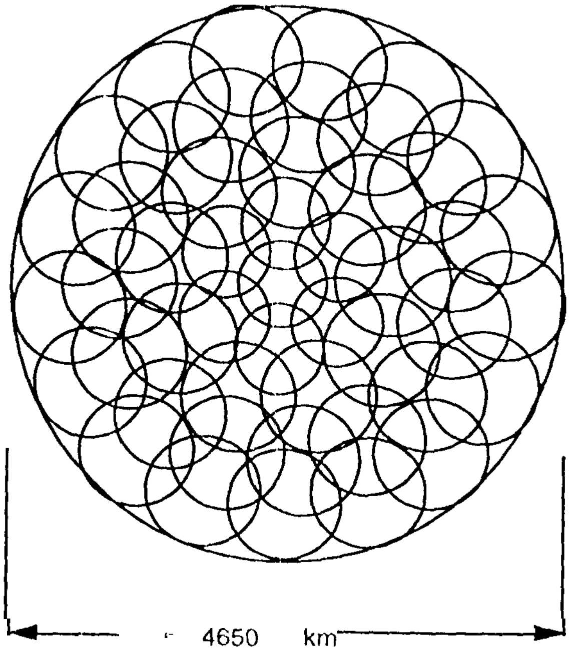

Figure 5. IRIDIUM 48 spot beam antenna pattern.

With 48 spot beams per satellite and 66 satellites, a total of 3168 beams are available to cover the globe. At high latitudes, spacecraft orbits cross and coverage overlap between satellites increases. Some of the outer beams on each satellite are not used at high northern or southern latitudes. The result is that 2150 spot beams are active at any instance to cover the globe and a global frequency reuse factor of 2150/12 ≈ 180 is achieved. Motorola states that 59 beams will cover the lower 48 states, CONUS, for a frequency reuse of 59/12 ≈ 5. The system is designed for each spot beam to support 80 channels; 80%9 = 4720 channel for CONUS and 80'2150 ≈ 172000 channels worldwide. Each Channel will support 4 TDMA Full Duplex Users. Two user modes are available, 4800 bps compressed voice or 2400 bps data. If data links are used, it may be possible to split the channel usage into 4 uplinks and downlinks for a total of 8 users **per channel.**

Table 1 summarizes the global telecom capacity for the two systems. Calculations are based on system descriptions given in [1], [2] and [3]. In the case of IRIDIUM it is not completely clear from the documentation available how the data and voice services differ in format and quality.

System	**IRIDIUM**		**ORBCOMM**	
	Uplink	**Down-link**	**Uplink**	**Down-link**
Single Sat				
# Spot Beams/Sat.	48	48	1	1
Freq. Reuse/Sat.	x4	x4	‘xl	xl
# Chan/ Sat,	48*80=3840	**48’80=3840**	’21	18
Data Rate/Chan	**19200** kbps voice or 9600 kbps data i.e. 4 users	**19200** kbps voice or 9600 kbps data i.e. 4 users	2.4 kbps	4.8 kbps
bps/Sat.	73,7 Mbps voice or 36.9 Mbps data	73,7 Mbps voice or 36.9 Mbps data	48 kbps	86.4 kbps
Global				
# spot **Beams**	2150	2150	20	**20**
# **Channels**	172000	172000	**420**	**360**
bps Global Max	3.3 Gbps data or 1.7 Gbps voice	3.3 Gbps data or 1.7 Gbps voice	1.0 Mbps	**1.7 Mbps**

Table 1: Global Telecom Capacity Comparison

A compact high gain spacecraft antenna operating in the ORBCOMM UHF band is not feasible and thus a much simpler single beam antenna is proposed. The result is lower antenna gain and no possibility of frequency reuse per spacecraft. Although not completely clear from the reference material, it appears that each satellite is capable of handling 21 uplinks at 2400 bps and 18 downlinks at 4800 bps. (Note that the individual satellite uplink capacity is well below the uplink frequency allocation which allows **74** channels total (see table 4 and page 4-10 of reference 2. That is, a single satellite is not capable of using the entire uplink allocation). Focusing on the uplink channels as they apply most to the data retrieval scenarios envisioned by ORBCOMM, at any one time there are a maximum of 20 satellites x 21 channels/sat. = 420 channels worldwide. This is a factor of 400 less than IRIDIUM. The last row of Table 1 shows that after scaling for data rate differences, the ratio of IRIDIUM to ORBCOMM global telecom capacity is between 1000:1 and 3000:1.

5.0 Single User Coverage Dynamics

5.1 Pass Duration and Elevation Angle vs. Time

This section considers the single satellite, single pass coverage provided to a user located in Goldstone California, 35.43° North Latitude, 116.89° West Longitude, the U.S. site for JPL's deep space antennas. This location is used as an example only to give the reader a feeling for the link geometry and dynamics. In general for a polar orbit satellite, coverage increases with increasing latitude

Figures 4 show IRIDIUM Elevation Angle to the spacecraft vs. time for a near overhead pass. Recalling that the minimum elevation angle for IRIDIUM is 10°, the useful pass time is seen to be 10 minutes.

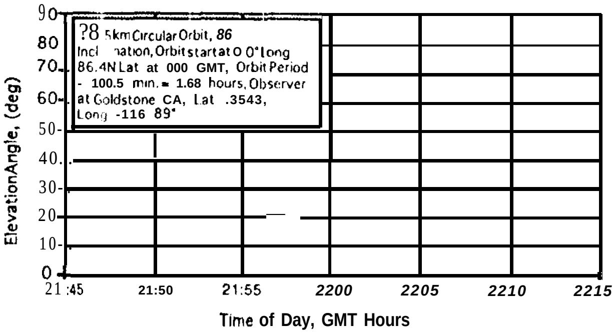

Figure 4: Goldstone, Ca. pass elevation angle to IRIDIUM vs. time.

Figure 5 shows a similar plot for an ORBCOMM satellite, ORBCOMM minimal elevation angle is 5° and thus the useful pass time is 15 minutes. The longer time is the combined result of ORBCOMM's higher orbit altitude and lower minimum elevation angle.

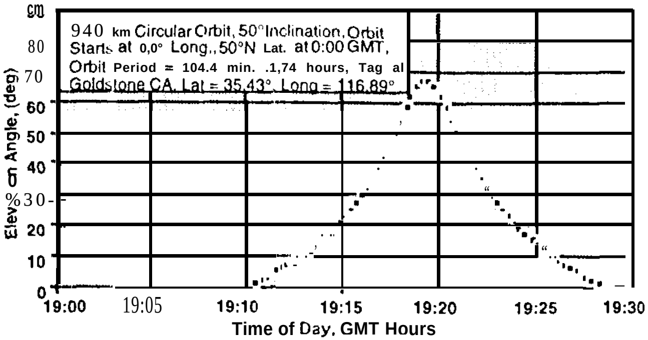

Figure 5: Goldstone, Ca. pass elevation angle to ORBCOMM vs. time.

Figure 6 shows how constellation coverage time to our Goldstone user varies with minimum elevation angle. In general, if lower elevation angles are allowed, the user's view period of any satellite increases and in particular is extended around the times of satellite rise and set. In addition, the ground swath covered is larger allowing a single satellite to cover more area per pass.

On the other hand, allowing lower elevation angles has some negative impacts. For lower elevation angles, slant range to the spacecraft increases in turn increasing the required signal power needed to communicate. At lower angles the possibility of signal blockage increases and interference from signal reflections, i.e. multipath, also increases. Link power again must be pushed up to cover these additional link impairments.

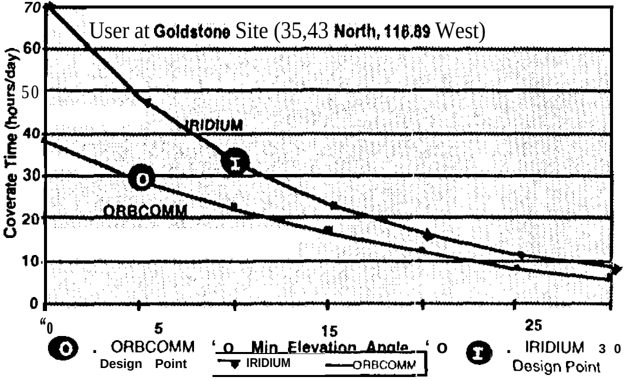

Figure 6: IRIDIUM vs. ORBCOMM: single satellite average coverage per day vs. minimum elevation angle.

System designers must trade off, number of satellites, orbit parameters, coverage times, link power requirements and link continuity requirements when choosing a minimum elevation angle. In addition the type of user must be considered. For example, if we designed a LEO satellite system to communicate with aircraft we would not have to worry about blockage. Multipath would vary as the reflection coefficient of the earth below varied. For small elevation angles and aircraft heights above about 10 km, the reflection from the Earth is reduced by its curvature and thus we could specify a very low elevation angle. For a system primarily used for maritime communications, blockage would be almost nil, but multipath reflection from the sea could impair communications somewhat at all elevation angles. For a land mobile system, signal blockage in heavy foliage or urban terrains will be significant at low elevation angles. In these situations even 10-15 dB fade margins will not eliminate frequent signal interruptions, There is no simple formula to solve these complex trade offs. System designers use models of the satellite constellations and links to investigate different options and to optimize performance based on the desired set of services and coverage. The ORBCOMM and IRIDIUM examples show us that these, "optimized," designs can result in very different satellite systems.

5.2 S/C to Tag Range Variations

Figures 7 shows Range to the IRIDIUM spacecraft vs. time from the same near overhead pass used in figure 5. Range varies from a maximum of about 2574 km for 7° elevation angle down to 785 km for the IRIDIUM spacecraft directly overhead. Since link capacity varies inversely as the square of the distance we can say that the link capacity at minimum range is about 10dB more than at maximum range. To compensate for this variable space loss, the gain of the IRIDIUM antenna is tapered so that the gain for spot beams at the perimeter is 7.5dB higher than the gain for the center spot beam. The result is a signal power between user and Spacecraft that is much less dependent on the range and elevation angle.

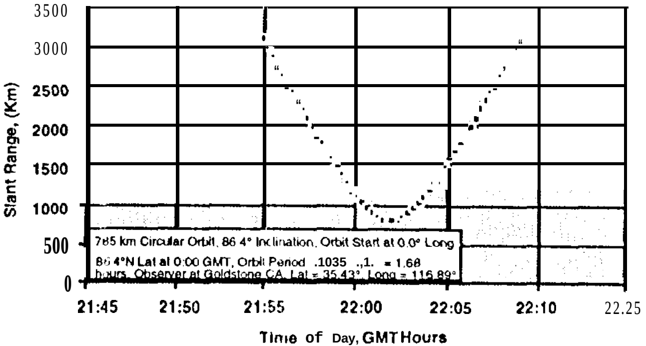

Figure 7: IRIDIUM single spacecraft: typical pass, range vs. time.

Figure 8 shows Range to the spacecraft vs. time for the same ORBCOMM pass used in figure 6. Range varies from a maximum of about 3135 km for 5° elevation angle down to 1000 km for the spacecraft nearly overhead. The link margin at minimum range is about 10 dB more than at maximum range. ORBCOMM's filings with the FCC in 1990 did not propose a scheme to compensate for this variation.

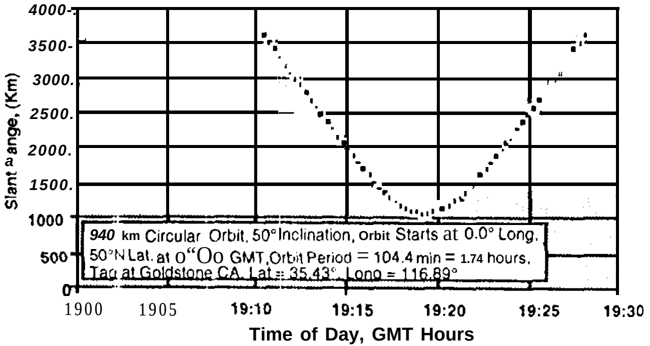

Figure 8: ORBCOMM single spacecraft: pass 6, range vs. time.

5.3 Doppler Dynamics

Figures 9 shows the Doppler Shift vs. time as seen by the IRIDIUM system user receiving a 1620 MHz transmission from the spacecraft for the same pass used in figures 5 and 7. When the Spacecraft comes over the horizon, the Doppler shift is at a positive maximum of 36 kHz. When the elevation angle reaches 10° the Doppler shift is still near maximum at 35 kHz. Over a full pass the user sees a Doppler shift ranging from +35 kHz to -35 kHz. Maximum Doppler Rate is over 300 Hz/see, Hence a user unit must handle these large Doppler Shifts and high Doppler rates. In their FCC filing, IRIDIUM has indicated that some form of Doppler compensation would be used but they were not specific.

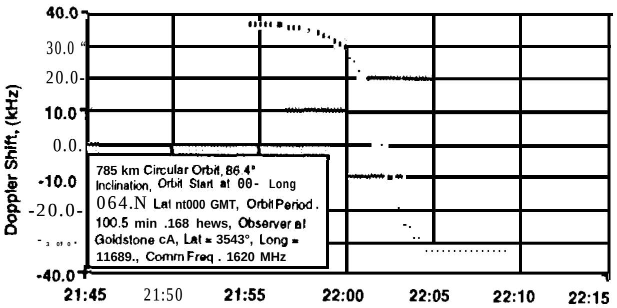

Figure 9: IRIDIUM: typical pass, Doppler shift vs. time.

Figures 10 shows Doppler shift vs. time as seen by an ORBCOMM system user receiving a 137.3 MHz transmission from the spacecraft for the same pass used in figures 8 and 10. Over a full pass the user sees a Doppler shift ranging from +2.8 kHz to -2.8 kHz. Maximum Doppler Rate is over 25 Hz/sec. No Doppler compensation techniques were described in the references.

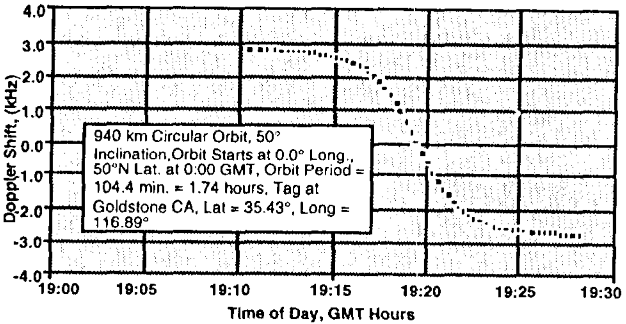

Figure 10: ORBCOMM: typical pass, Doppler shift vs. time.

6.0 Strategic Military Use

As stated previously, the military is particularly interested in tracking hardware in route to and in the theater of operations. Three example regions were considered, (1) North and South Korea, 124°-130° East Longitude **and 34°-420 North Latitude (500,000 km’); (2) Persian** Gulf with parts of adjacent Iran, Iraq, Saudi Arabia and Kuwait, 44°-560 East Longitude and 24°-320 North Latitude, (1 ,000,000 km’); and (3) Bosnia with parts of Eastern Croatia, 115.5°-19.5° East Longitude and 43°-45.5° North Latitude, (90,000 km²). Based on IRIDIUM and ORBCOMM coverage results shown in figure 3 and telecom capacity figures given in table 1 coverage and telecom capacity estimates for each of these critical areas were calculated. Table 2 gives a point by point comparison of IRIDIUM and ORBCOMM based approaches.

It is immediately apparent the IRIDIUM system provides far better coverage of the example critical areas. The ratio of data capacity of the two systems is somewhere between 1000:1 and 3000:1. Increased capacity can be achieved with the ORBCOMM system if one assumes that all resources of any ORBCOMM satellite that can be seen from the region of interest are dedicated to the purpose of military Tag communications.

	IRIDIUM	ORBCOMM
Region and Exten	Temporal Coverage by Full Satellite Constellation	
Korea **500,000** km²	34 hours/day	28 hours/day
Persian Gulf 1,000,000 km²	30 hours/day	**25 hours/day**
Bosnia **90,000 km²**	39 hours/day	27 hours/day
Sat. Beam Dia.	490 km to 930 km	5600 km
	Avg. Number Of Beams Covering the Region	
Korea	2.4	0.024
Persian Gulf	4.4	**0.040**
Bosnia	**0,48**	**0.0040**
	Average Channel C is based or	acity **if Satellite** Usage rea **Serviced**
Korea	**768 2-Way** Users @ 4800 bps voice or @ 2400 bps data 3.7 Mbps Voice or 1.8 Mbps **Data**	**0.5 Uplink** Users @ 2400 bps 1200 bps 0.4 **Downlink** Users @ 4800 bps **1920** bps’
Persian Gulf	**1830** 2-Way Users 8.8 Mbps Voice 4.4 Mbps Data 2-way	0.8 **Uplink** Users @ 2400 bps 1920 bps 0.7 **Downlink** Users @ 4800 bps 3.36o bps
Bosnia	246 2-Way Users 1.2 Mbps Voice 2-way 0.6 **Mbps Data** 2-way	0.08 **Uplink** Users @ 2400 bps 120 bps 0.07 Downlink Users @ 4800 bps 192 bps

Table 2: Example Coverage and Telecom Capacity for Militarily Significant **Areas**

Korea	Persian Gulf	**Bosnia**
25 Uplink Users @ 2400 bps **60 kbps**	**21 Uplink** Users @ **2400** bps 50 **kbps**	**23 Uplink Users** @ 2400 bps 55 kbps
22 Downlink Users @ **4800 bps** **106 kbps**	**18 Downlink** Users @ **4800** bps **86 kbps**	**20 Downlink** Users @ 4800 bps 96 kbps

Table 3: Average Channel Capacity and Throughput Provided By the ORBCOMM Constellation to Critical Areas Assuming That All of a Satellite's Resources are Dedicated to Tag Communications When the Satellite is in View **of the Region.**

In this case the average number of beams covering the region from the ORBCOMM constellation is roughly equal to the average number of satellites in view. The Channel capacity for ORBCOMM in this case is given in **Table 3.** The ratio of data capacity of the two systems for this assumption is a more respectable 10:1 to 100:1 depending on the region and data type assumptions.

7.0 Other Issues and Summary

Detailed link design, signal outage due to blockage, Scintillation effects, unintentional interference and general satellite/ground equipment trade-offs are some of the topics not covered in this paper due to space limitation. These' are covered in the parent study [5] Appendix A contains link budgets for IRIDIUM and ORBCOMM Tag communications. In our summary we cover the analysis described in this paper and key points covered only in [5].

We have proposed in brief a system approach to provide global tracking of electronically tagged military hardware. Two candidate global LEO satellite systems, IRIDIUM and ORBCOMM were analyzed as to their ability to provide coverage and telecom capacity globally and to specific "hot" spots. The following important findings were made.

1) Tag hardware limited to a O dBi omni-directional antenna and 5 watts of power is sufficient for robust link performance with LEO satellite systems. Data rates of 2400 to 50,000 bps can be achieved with path loss margin of 15 dB providing global coverage and good temporal coverage, (see appendix A and [5]).

2) Selection of the number of satellites and their orbits can result in quite different coverage of the Earth. System designers can tailor the spacecraft constellation to prefer users at certain latitudes over others. ORBCOMM has demonstrated this. Their 20 satellite constellation provides essentially the same temporal coverage to all latitudes below 40° that the IRIDIUM system does but with 1/3 the number of satellites. Because of its polar orbits, IRIDIUM provides better service to far north and far south latitudes.

3) IRIDIUM'S use of L-band frequencies enables the implementation of the high gain multiple beam spacecraft antenna in a reasonably small package. This in turn enables higher data rate service, the reuse of limited satellite frequency spectrum and the support of many more users. Combined with the larger number of satellites, the result is an upper limit capacity for IRIDIUM that is 3000 times greater than ORBCOMM's global telecom capacity. On the other hand, the multi-beam spacecraft antenna and greater number of satellites makes the IRIDIUM system and satellites more costly. These higher costs are amortized over a much larger user base. The lower 137 to 148 MHz operating frequencies of ORBCOMM do not lend themselves to implementation of a compact, high gain spacecraft antenna.

Additional points frrrm [5]:

4) **IRIDIUM** uses identical frequency and channelization for uplink and downlink. The communication is only one-way at a time, or time-duplex. But, using a burst transmission rate of 50 kbps which is 10 times faster than the data rate of 4800 bps needed for compressed digitized voice, the IRIDIUM user terminals are capable of rapidly switching between receive and transmit modes, buffering the data and presenting it to the user as if it were a continuous 2-way or full duplex link. This feature of using only one set of frequencies for both uplink and downlink can simplify the user hardware in at least two ways. First, the range of frequencies that the RF components must operate over is minimized and makes their design less complex and allows them to pass more RF power, (less losses), in both the transmit and receive direction. Second, half-duplex operation eliminates the need for a diplexer, thus reducing mass, cost and RF losses again.

5) For all mobile systems, the inclusion of path margin is essential to combat shadowing and multipath signal fades. In reference [5] it is estimated that a 15 dB margin chosen by IRIDIUM should be sufficient to provide protection against greater than 95% of all shallowing and multipath fade conditions. The same 15 dB margin used by ORBCOMM is harder to evaluate. In particular amplitude scintillations at UHF frequencies can at times and in places exceed 10 dB peak-to-peak during severe solar activity. UHF ionospheric group delay effects can also limit the radio navigation or satellite ranging accuracy. These degradations are particularly important at high latitudes and in the equatorial regions and are worse during local night *time* than during the day, Hence, system performance may on occasion be adversely affected in these places and times. Additionally, man-made interference and galactic background noise at UHF frequencies can be much greater than receiver thermal noise, especially in populated areas.

7 Tag location on equipment or containers can impact link availability. For a Tag placed on the side of a container, the container itself will shade the Tag from a view of half of the sky, thus reducing the line-of-sight communications time by 50%. If sufficient path margin exists, the shadowed link may still be possible. If not, the side mounted Tag has 1/2 the link availability time of a Tag mounted on top of a container. A worse scenario is the same container with side mounted Tag stacked close to a second container. The second container effectively shades the Tag from nearly all of the remaining part of the sky. Line-of-sight communications would be possible only when a satellite passed directly overhead and could see down into the gap between the two containers. Again, the point of these two examples is to emphasize the impact of Tag and equipment positioning on link quality and/or availability.

8.0 Acknowledgments

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9.0 References

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Appendix A. Detailed Link Budgets for IRIDIUM and ORBCOMM

Iridium Downlink to Tag			Tag Uplink to Iridium		
Iridum Xmit Power, Watts	3.5	Watts	Tag Xmit Power, Watts	5.0	Watts
Iridum Xmit Power, dBm	35,4	dBm	Tag Xmit Power, dbm	37,0	dBm
Iridum Ckts Loss	-2.1	dB	Xmit Ckt Loss	-0.7	dB
Iridum Antenna Gaim	24.3	dBi	Tag Antenna Gain	0.0	dBi
EIRP	57,6	dBm	EIRP	36.3	dBm
Orbit Altitude, km	785.0	km	Orbit Altitude, km	785.0	km
Elevation Angle to S/C	10.0	degrees	Elevation Angle to S/C	10.0	degrees
Range to S/C, km	2336.0	km	Range to S/C, km	2336.0	km
comm Frequency	1620.0	MHz	Comm Frequency	1620.0	MHz
Free Space Loss	-164.0	dB	Free Space Loss	-164.0	dB
Atm+Pol Loss	-0.8	dB	Atm+Pol Loss	-0.8	dB
Tag Antenna Gain	0.0	dBi	S/C Antenna Gain	23.9	dBi
Carrier Power	-107.2	dBm	Carrier Power	-104.6	dBm
Tag Noise Figure	0.9	db	S/C Noise Figure w/lo	2.4	dB
Antenna Circuit Loss	-0.7	dB	Antenna Circuit Loss	Incl. Abov	dB
Antenna Circuit Loss	120.0	K	Antenna Noise Temp	290.0	K
System Noise Temp	249.2	K	System Noise Temp	504.0	K
Noise Bandwidth	31,5	Khz	Noise Bandwidth	31.5	KHz
Noise Power	-129.7	dBm	Noise Power	-126.6	dBm
Tag G/T	-24.0	dB K	S/C G/T	-3.1	dB K
C/N	22.5	dB	C/N	22.0	dB
Eb/No Req (1E-5Ber)	5.8	dB	Eb/No Req (1E-5BER)	5.8	dB
Implementation Loss	0.5	dB	Implementation Loss	0.5	dB
Coded Channel Data Rate	50.0	kbps	Coded Channel Data Rate	50.0	kbps
Code Rate	0.75		Code Rate	0.75	
Uncoded Data Rate	37.5	kbps	Uncoded Data Rate	37.5	kbps
Uncoded Data Rate	45.7	dB-bps	Uncoded Data Rate	47.7	dB-bps
Pd/(No+Io) Required	52.0	dB/Hz	Pd/(No+Io) Required	52.0	dB/Hz
Pd/(N+I) Requred	7.1	dB	Pd/(N+I) Required	7.1	dB
C/I (Specification)	18.0	dB	C/I (Specification)	18.0	dB
Req C/N	7.4	dB	C/N Required	7.4	dB
Margin for Shadow	15.1	dB	Margin for Shadow	14.6	dB

Table A-1 IRIDIUM - Tag Link Budgets

ORBCOMM Downlink to Tag			ORBCOMM Downlink to Tag		
S/C Xmit Power, Watts	10.0	Watts	Tag Xmit Power, Watts	5.0	Watts
S/C Xmit Power, dBm	40.0	dBm	Tag Xmit Power, dBm	37.0	dBm
S/C Ckt. Loss	-0.5	dB	Xmit Ckt. Loss	-0.7	dB
S/C Antenna Gain	7.0	dB	Tag Antenna Gain	0.0	dB
EIRP	46.5	dBm	EIRP	36.3	dBm
Orbit Altitude, km	970.0	km	Orbit Altitude, km	970.0	km
Elevation Angle to S/C	5.0	degrees	Elevation Angle to S/C	5.0	degrees
Range to S/C, km	3135	km	Range to S/C, km	3135.0	km
Comm Frequency	137.3	MHz	Comm Frequency	148.0	MHz
Free Space Loss	-145.1	dB	Free Space Loss	-145.8	dB
Atm+Pol Loss	-7.1	dB	Atm+Pol Loss	-7.1	dB
Tag Antenna Gain	0.0	dBi	S/C Antenna Gain	6.5	dB
Carrier Power	-105.7	dBm	Carrier Power	-110.1	dBm
Tag Noise Figure	0.8	dB	S/C Noise Figure	0.8	dB
Antenna Circuit Loss	-0.7	dB	Antenna Circuit Loss	0.5	dB
Antenna Noise Temp	700.0	K	Antenna Noise Temp	700.0	K
System Noise Temp	819.6	K	System Noise Temp	801.2	K
Noise Bandwidth	31.5	KHz	Noise Bandwidth	31.5	KHz
Noise Power	-124.5	dBm	Noise Power	-124.6	dBm
Tag G/T	-29.1	dB K	S/C G/T	-22.5	dB K
C/N	18.8	dB	C/N	14.5	dB
Eb/No Req (1E-05BER)	10.0	dB	Eb/No Req (1E-05BER)	10.0	dB
Implementation Loss	1.5	dB	Implementation Loss	1.5	dB
Coded Channel Data Rate	4.8	kbps	Coded Channel Data Rate	2.4	kbps
Code Rate	1.00		Code Rate	1.00	
Uncoded Data Rate	4.8	kbps	Uncoded Data Rate	2.4	kbps
Uncoded Data Rate	36.8	dB bps	Uncoded Data Rate	33.8	dB-bps
Pd/(No+Io) Required	48.3	dB/Hz	Pd/(No+Io) Required	45.3	dB/Hz
Pd/(N+I) Requred	3.3	dB	Pd/(N+I) Required	0.3	dB
C/I (Spec.)	40.0	dB	C/I (Spec.)	40.0	dB
Req C/N	3.3	dB	C/N Required	0.3	dB
Margin for Shadow	15.4	dB	Margin for Shadowing	14.2	dB

Table A-z ORBCOMM - Tag Link Budgets