Application of AirCell Cellular AMPS Network and Iridium TDMA Satellite system dual mode service to Air Traffic Management

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The AirCell/Iridium dual mode service is evaluated for potential applications to Air Traffic Management (ATM) communication needs. The AirCell system which is largely based on the Advanced Mobile Phone System (AMPS) technology, and the Iridium FDMA/TDMA system largely based on the Global System for Mobile Communications (GSM) technology, can both provide communication relief for existing or future aeronautical communication links. Both have a potential to serve as experimental platforms for future technologies via a cost effective approach. The two systems are well established in the entire CONUS and globally hence making it feasible to utilize in all regions, for all altitudes, and all classes of aircraft. Both systems have been certified for air usage. The paper summarizes the specifications of the AirCell/Iridium system, as well as the ATM current and future links, and application specifications. The paper highlights the scenarios, applications, and conditions under which the AirCell/Iridium technology can be suited for ATM Communication.

I. Introduction

It is expected that over the next 20 years, the demand for air travel will double. This will in turn cause increased delays and capacity bottlenecks unless new measures are taken. Several research and Industry organizations are actively involved in modernizing the air space to alleviate those future problems such as the Advanced Air Transportation Technologies (AATT) Project. AATT's objective is to improve the overall performance of the National Airspace System (NAS) as a whole [1].

A critical element of the modernization effort revolves around the communication technologies. Digital links are being developed to replace existing analogue voice systems for communications, as well as for surveillance (examples of links: VDL2, VDL3, and applications on links: ADS-B, CPDLC, and TIS and FIS).

This paper addresses the possible application of the dual mode service of AirCell AMPS network with Iridium Satellite service for ATM. That technology can possibly provide an interim service in the near term where there may be gaps in the more common aeronautical communication technologies. An Example of which is the delivery of ADS intent information in the terminal area where the Mode S systems are may not able to handle the bandwidth demand at very busy regions, and ADS and CPDLC broadcast over oceanic and remote areas where availability of Mode S and VDL links is an issue. Another example would be in the use of such systems as a back up for VDL-2 or VDL-3 in areas where those services are not yet available (other than oceanic and remote). The system studied can also serve as a cost effective way for experimenting with more advanced satellite, terrestrial integrated system architectures and concepts.

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This paper will briefly summarize the technical specification of the AirCell and Iridium systems. This will then be followed by a summary of the current and future requirements and specifications for air traffic communications systems and applications and a summary of possible applications, scenarios, and conditions in which the AirCell, iridium service can be utilized for ATM, linking the specification of the two previous sections together. The last section concludes the paper with several future recommendations.

II. AirCell and Iridium Network specifications

This section outlines briefly the specification best available to us on the dual mode system that is based on the AirCell and Iridium technologies. First the AirCell system is described, followed by the Iridium system, prior to the dual mode one.

A. AirCell Description

Aircell Network [2] is the only current Cellular technology for aeronautical users allowed by the FCC to operate with a current estimate of 1500 equipped aircraft. The service has been in commercial operation since year 2000. The system has a total of 134 terrestrial base stations located approximately 160 miles from each other and covering 95% of the CONUS. Figure 1 from [2] shows the locations of those base stations. Each base station has an antenna that is upward pointing covering the service cell area only and with little interference to any ground networks. Figure 2 from [2] depicts the cell coverage and antenna patterns based on air cell proprietary technologies.

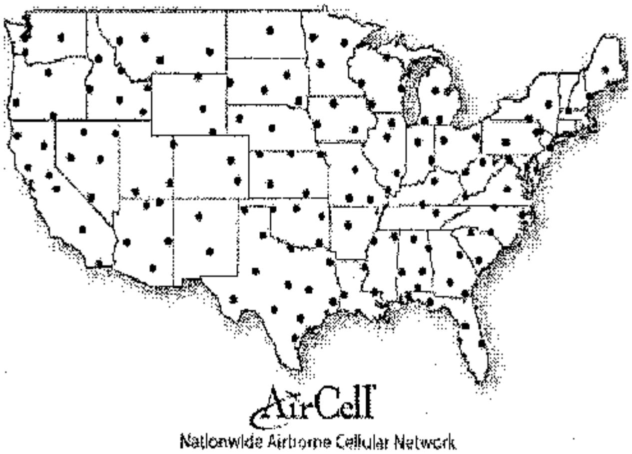

Figure 1. Base station location for AirCell

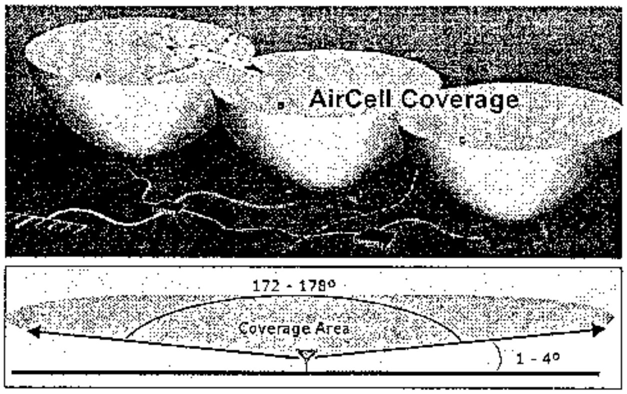

Figure 2. antenna patterns and coverage for AirCell base stations

While many capabilities exist that are relevant to the passenger, we mainly focus on the features that are useful for the cockpit crew. In general, the aircraft component of the system constitute the ability to send and receive faxes, emails, PDA displays of images, voice using Cordless and Corded telephone equipment. The most critical part for future Air Traffic management research revolves around the data capability followed by the classical voice service. The system through a connection via the PSTN, can establish communications with the other phone devices, networks (such as airline or air traffic control networks) or the internet.

The protocol used in the AirCell network is the Analog Cellular standard AMPS using FM modulations and frequencies in the cellular range of 824-849 MHz for downlink and 869-894 MHz for uplink, and causes no interference to the ground networks.

The system requires the installation of an AirCell Blade Antenna at the bottom of the aircraft. The type of antenna has a speed rating of 550 knots and operates with a power handling of 1 Watt (with a typical average power in operation of 0.6 Watts). The aircraft transceiver is limited to a maximum of only 75 mW output power), weights 1.1 lbs, with a size of 6.5"x4.2"x8.1" in length, Width and Depth respectively [2].

B. Iridium Description

The Iridium system operated by the Iridium Satellite LLC provides global mobile satellite voice and data services [3-4]. The global coverage includes all the oceans, airways, and polar regions, but is limited to outdoor capability (as oppose to indoor usage). The Iridium system constitutes of 66 satellites in operation with 13 in spare, orbiting at six polar planes with 11 satellites per orbit at an altitude of 435 Nautical Miles (Figure 3). The orbital period is 100 minutes, with the orbital inclination at 86 degrees, earth central angle of 19.9 degrees, with a plane separation of 31.6 degrees. Each Satellite (Figure 4) uses three phase array antennas to communicate with the mobile users. Each phased array antenna have 16 spot beams to give a total of 48 spot beams per satellite. Each spot beam covers an approximate area of 30 miles in diameter. Hence each satellite has 48 spot beams with a grand total for all 66 satellites of 2150 spot beams to cover the entire globe using cluster sizes of 12. Note that the actual total of iridium spot beams is 3168=66*48 but only 2150 are needed to cover the globe and hence those additional ones are not operated to conserve satellite power.

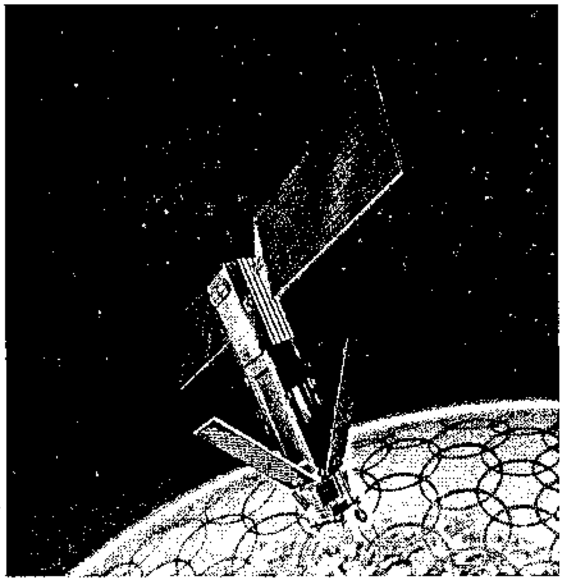

Figure 3. Iridium global network

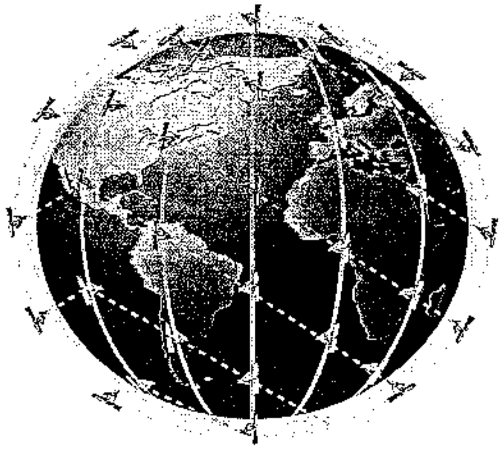

Figure 4. Iridium satellite with spot beam coverage patterns

The Iridium system uses L band operating between 1 and 2 GHz for the mobile user to satellite communications and vice versa. The frequency allocation in the L band is shown by Figure 5 (with 5.15 MHz awarded by FCC). In a 5.15 MHz band, 120 (41.67 KHz) FDMA channels are possible, and hence with a reuse factor of 12, there are 10 FDMA channels per spot beam. Hence for the CONUS, approximately 59 beams are needed, and hence 590 specific frequency FDMA channels are available, while for the globe there are approximately 21500 specific FDMA frequency channels available. With the TDMA accessing (to be discussed further in the packet format section to follow), 4 uplink/downlink users are able to use each frequency channel and hence the total users for CONUS and the globe quadruples to 2360, and 86000 respectively.

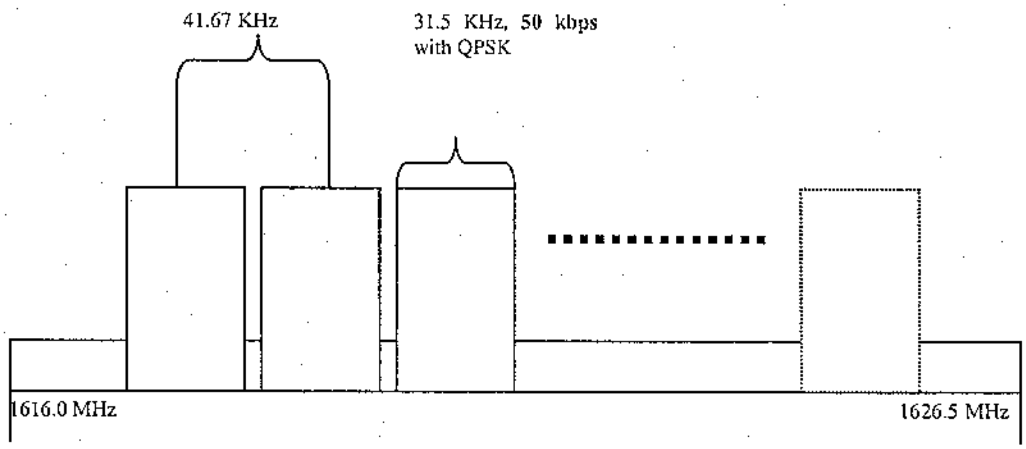

Figure 5. Frequency plan in L-band for Iridium satellite to Subscriber Unit Link (only upper 5.15 Mhz is allocated by FCC for Iridium with an additional 2.5 MHz added on temporary bases to accommodate more traffic in middle east region of the globe)

The ground network of the iridium system currently have in addition to the Central and backup operation centers in Leesburg, Virginia, and Chandler, Arizona respectively, 12 gateways located around the world (not all used at the present time) with 2 of them in North America. The satellites communicate with the gateways at a frequency ranges of 29.1-29.3 GHz for the uplink, and 19.4-19.6 GHz for the downlink (i.e. in the Ka band). The satellite uses four gimbaled K-band feeder link/gateway antennas. The satellite also communicated between each other making it possible to route calls from one satellite to the next directly. Each satellite is able to communicate to four of its neighbors using again the Ka band frequency range of 23.18 GHz to 23.38 GHz. Four gimbaled K-band antennas are used for East-West communications and two fixed k-band antennas are used for North-South. The satellite also has one nadir pointed k-band secondary link antenna.

The propagation delays for the Iridium is significantly less than those of GEO satellites, equaling 2.6 milliseconds vs. 167 milliseconds respectively. Hence the transmission delays which are double those, i.e. including uplink and downlink, in addition to coding, modulation, and processing delays, is still significantly less than that in a GEO based system. The power requirement on the iridium mobile terminal (aircraft in our application) is less or equal to 1 watt, although the dual mode transceiver by AirCell specification is listed at 7 Watts maximum, which can take into account the higher data rates for multiple users in the cabin or aircraft in general. The Iridium patch antenna specification which would be mounted on top of the aircraft, are listed in [2] as: 0.4 lbs in weight, 60 Watts power handling (not all needed), frequency operation in 1565-1625.5 MHz range, Mach 2 Indicated Air Speed, with dimensions of 3.5"x0.66" in diameter and thickness respectively.

Iridium is capable of providing a 2.4 Kbs voice or data service. Note this capability is reduced from a much higher one mainly due to the encoding, delays, and error detection capability. The Iridium system uses the GSM technology protocols with some differences. Multiple Accessing is done with a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). Each connection has a designated frequency and time slot, and the frequency is slowly hopped to reduce multipath fading. Signals are modulated using quaternary phase shift keying (QPSK) where the Iridium differs from the GSM terrestrial standard in which the modulation is based on Gaussian Distribution.

The frame format for the iridium packets is illustrated in Figure 6. The Frame length is 90 milliseconds, with each transmit burst time of 8.2 milliseconds. There are 8 traffic slots per frame with 4 for uplink and 4 for downlink for duplex operation. The coded data rate is 50 Kbps, and the coding is convolutional FEC, r=3/4,k=7.

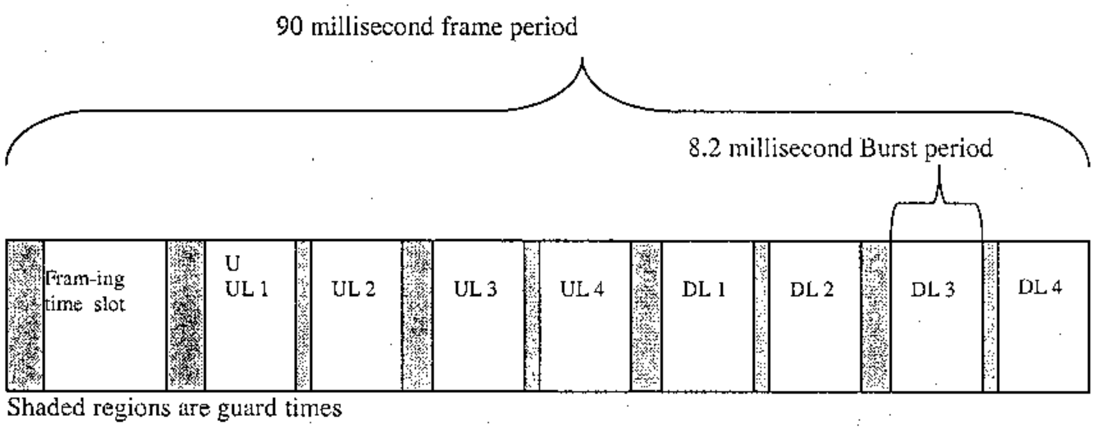

Figure 6. Iridium TDMA Frame format

The Iridium call registration, setup, and hand off works as summarized in Table 1 below [5]. Note there are three types of handoffs in the iridium, intrabeam, interbeam, and intersatellite. Intrabeam is done when a new frequency is allocated to a user within same spot beam due to possible interference from other sources or another Iridium satellite, or when certain frequencies are not allowed in specific areas of the globe. Interbeam is done regularly due to satellite (and spot beams) movement. In this case it is done with the intelligence of the subscriber unit (as oppose to gateway in the Intrabeam case) after sending request to the satellite overhead to gain access to a new beam with better signal quality. Finally, the Intersatellite is discussed in Table 1.

Call Registration: (SC roaming out of home territory) Subscriber (SC) Visited Gateway (VG) Home Gateway (HG) Mobile Unit (MU) Mobile Telephone Switching Office (MSTO) Visited Location Register (VLR)	SC turns MU on VG identify HG via SC number and create a VLR entry VG sends signal to HG to identify location of present SC for routing HG updates SC registration status VG request SC profile information from HG HG verify and clear SC profile in VLR HG grants VG permission for call access SC now registered with visited MSTO.
Call Setup: (call originates in home territory, incoming call to roaming subscriber)	HG sends request to ring message to VG VG identify SC location VG sends signal to MU MU rings and SC goes off hook Off hook message sent from MU to VG then to HG Incoming call ready for connection HG receives off hook message from VG HG routes digital voice packets back to SC
Call Handoff: (intersatellite handoff scenario)	Gateway aware of SC location Gateway aware when SC reaches boundary between two satellites Gateway alerts trailing and leading satellite of impending handoff Gateway commands MU to resynchronize Satellite assigns new channel to MU

Table 1. Iridium Call setup, registration and handoff procedures from [5]
(Each Mobile unit subscriber of the Iridium is initially registered in a Home Gateway which serves as its base)

Lastly, it is worth noting that the results in [5] show great similarity between the AMPS and Iridium call setup, registration and handoff even though the two technologies are vastly different. The one advantage of the Iridium system over its AMPS counterpart is the ability to communicate directly from a satellite to a user bypassing the Gateway when both end parties are Iridium users. This reduces the delays in general.

C. AirCell/Iridium Dual mode system:

Both systems (AirCell and Iridium) have been used and certified to Aeronautical services. The AirCell for example provides the capability for Internet connection (using circuit switched data) and have been used [2] with transmission of low resolution graphics from NEXRAD weather images. The Iridium has been shown to support ADS-A via experimental tests in Alaska with the Capstone Projects [6]. In addition the Iridium was designed to include distinction between safety and non-safety communications, priority, precedence, and preemption for safety services, all through work with International Civil Aviation (ICAO) Aeronautical Mobile Communication Panel (AMCP) [7-8]. The current system AST-3500 by AirCell/Iridium uses the two technologies described to provide global coverage for aeronautical services [2].

III. ATM Communications System specifications and AirCell/Iridium system applicability

The air traffic management modernization effort has resulted in advancements in the communication technologies and their applications. Table 2 from [9] below summarizes those applications. With the exception of the passenger service (APAXS), all other services are key elements of the ATM communications infrastructure. Some of those services can be localized to regional areas while others are broadcasted over wider areas such as the entire CONUS. For example CPDLC communication is well suited for local region while TIS and FIS can be broadcast over the entire CONUS giving pilots and crew situational awareness and additional ability to plan ahead. Table 3, also from [9] shows the capacity provided by various communication links currently proposed for ATM. The satellite portions shown in the Table are not currently employed and hence a system such as the AirCell/Iridium can serve as a bench mark for experimental testing of possibly newer and future technologies (with much higher data rate and capabilities). Hence the scenarios envisioned where an AirCell/Iridium system can be used include:

- Use as an experimental platform for future technology testing. The benefits of that approach come from the fact that the system can be easily installed on aircraft and does not require any modification with the coverage being available in all the CONUS (and Globe for Iridium).
- Use as a backup system for services that may need them (applicable for all the applications)
- Use as an actual system for temporary transition to a more permanent one.

Finally, Table 4 [9] shows estimated data rates for the applications in Table 2, by year 2015. Those rates are actually for three domains defined to be over a 10 minute period over the airport and terminal areas, and 50 minutes for en route. As such the rates shown correspond to a total of 192, 137, and 500 aircraft in the airport, terminal, and en route domains. If the data rate of interest is per aircraft then we simply divide the numbers shown by the number of aircrafts in the domain. Hence much smaller numbers are associated with each aircraft hence making the application support feasible. They therefore would be used and applied according to the application which may require local or regional services as will be further noted. In any of the roles that are proposed for the AirCell/Iridium system, the following scenarios can be envisioned based on the results of Table 4, Table 3, and the previous section which outlined the specifications of the AirCell/Iridium system:

- All applications with the exception of TIS and FIS can be supported using Iridium or AirCell channels. Since channels are not shared there will significant room even if all applications are added together per aircraft.
- Regional (not CONUS) FIS and TIS can be supported with either AirCell or Iridium depending on the region For example aircraft in oceanic or outside CONUS can utilize the Iridium and as they approach the CONUS can switch into an AirCell where the capacity is larger (data rate of 9.6 vs. 2.4 Kbps).

Application	Definition
Flight Information Services (FIS)	Aircraft continually receive Flight Information to enable common situational awareness
Traffic Information Services (TIS)	Aircraft continually receive Traffic Information to enable common situational awareness
Controller - Pilot Communication (CPC)	Controller - Pilot voice communication
Controller-Pilot Data Link Communications (CPDLC)	Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)
Decision Support System Data Link (DSSDL)	Aircraft exchange performance / preference data with ATC to optimize decision support
Automated Dependent Surveillance-Broadcast (ADS-B)	Aircraft continuously broadcast data on their position and intent to enable optimum maneuvering
Airline Operational Control Data Link (AOCDL)	Pilot - AOC messaging supports efficient air carrier/air transport operations and maintenance
Automated Meteorological Transmission (AUTOMET)	Aircraft report airborne weather data to improve weather nowcasting/forecasting
Aeronautical Passenger Services (APAXS)	Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service

Table 2. ATM Communication System Applications [9]

Data Link	Single Channel Data Rate	Capacity for Aeronautical Communications	Channels Available to Aircraft	# Aircraft Sharing Channel (Expected Maximum)	Comments
	kbps	Channels	Channels	Aircraft	
HFDL	1.8	2	1	50	Intended for Oceanic
ACARS	2.4	10	1	25	ACARS should be in decline as users transition to VDL Mode 2
VDL Mode 2	31.5	4+	1	150	System can expand indefinitely as user demand grows
VDL Mode 3	31.5*	~300	1	60	Assumes NEXCOM will deploy to all phases of flight
VDL Mode 4	19.2	1-2	1	500	Intended for surveillance
VDL – B	31.5*	2	1	Broadcast	Intended for FIS
Mode-S	1000**	1	1	500	Intended for surveillance
UAT	1000	1	1	500	Intended for surveillance/FIS
SATCOM	-	-	-	-	Assumes satellites past service life
Future SATCOM	384	15	1	~200	Planned future satellite
Future Ka Satellite	2,000	~50	~50	~200	Estimated capability - assumes capacity split for satellite beams
Fourth Generation Satellite	>100,000	>100	>100	Unknown	Based on frequency license filings

* channel Split between voice and data

** Limited to a secondary, non-interference basis with surveillance and has capacity of 300 bps per aircraft in track per sensor

Table 3. Aeronautical Communication Links Capacities [9]

Data Message Traffic for All Classes of Aircraft (K-bits per second)						
2015	Airport Uplink	Airport Downlink	Terminal Uplink	Terminal Downlink	En Route Uplink	En Route Downlink
FIS	0.2	0.0	0.9	0.0	6.9	0.0
TIS	23.7	0.0	7.0	0.0	20.5	0.0
CPDLC	3.4	2.9	1.3	0.9	1.1	1.3
DSSDL	0.2	0.3	0.1	0.2	0.1	0.1
AOC	0.4	8.4	0.6	8.5	0.2	3.5
ADS Reporting	0.0	16.1	0.0	3.3	0.0	1.5
AUTOMET	0.0	0.0	0.0	4.4	0.0	6.2
APAXS	0.0	0.0	0.0	0.0	131.7	115.5

Table 4. Estimated Peak Communication Loads for 2015 [9]

Although the AirCell/Iridium system has many advantages such as its cost effectiveness, easy installation, current usage record, aeronautical certification, and its possible future potentials with technology improvements, the system as it apply to the ATM has some possible disadvantages. Among those disadvantages:

- While the AirCell link has a moderate capacity of 9.6 Kbps, the Iridium 2.4 Kbps limits more applications, unless possibly compression methods are applied to higher data rate applications such as TIS for example.
- While the Iridium system has a large capacity using its present 5.15 MHz band (with 2.5 MHz additional granted on temporary bases in 2003), the AirCell system capacity can support only 2-5 users simultaneously per each cell. Nonetheless future additional frequencies, more and smaller cells, and future migration to digital technologies such as UMTS could alleviate that disadvantage where sharing of channels becomes feasible.
- AirCell can support users at all altitudes including commercial jets in enroute, but for super high altitude (i.e. much higher than 10 Km), users may need to switch to Iridium service. This is not so much of a problem as the capacity is limited at super high altitudes in general and the Iridium is readily accessible.
- The current handoff between the Iridium and the AirCell Networks is not a smooth one requiring a new call setup procedure.

IV. Recommendations for Future Work

While there are no limitations for the use of the AirCell/Iridium system for several of the ATM communications needs in one of the roles outlined in the previous section, more work in the future in several areas can increase the understanding and confidence in the system applicability to ATM. For one, a modeling and simulation effort can prove useful in answering questions that may be difficult using only an analyses approach. This can be paralleled by an actual real life testing of a dual mode system such as the AST3500 to test both the AirCell and Iridium simultaneously with ATM applications and scenarios. In summary, the benefits of experimenting with this technology outweigh its disadvantages and may prove to be useful for looking into future more advanced technologies such as UMTS or S-UMTS, as primary, back up, or test platform systems.

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