IMT2000 3G TERRESTRIAL STANDARDS WITH APPLICATIONS TO AIRPORT AND TERMINAL AIR TRAFFIC COMMUNICATIONS

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Abstract

The International Mobile Telecommunications IMT2000 terrestrial standards are investigated as a potential alternative for communications to aircraft mobile users in airport and terminal domains. Specifically, its application to Air Traffic Management (ATM) communication needs is considered. The various specifications of the IMT2000 standards are outlined. It is shown via a system research analyses that it is possible to support most air traffic communication needs via the use of 3G technologies. This technology can compliment existing or future digital aeronautical communications technologies such as VHF Digital Links Mode 2, 3, 4 (VDL2, VDL3, VDL4).

Introduction

Over the next 20 years, it is expected that 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 examples of applications: Automatic Dependent Surveillance Broadcast ADS-B, Controller Pilot Data Link Communications CPDLC, Traffic Information Services TIS, and Flight Information Services FIS). Specifically in the terminal airspace, it is expected that the use of Cockpit Display of Traffic Information CDTI, and Flight Management System FMS, can be utilized in order maintain closer spacing than presently required in Instrument Meteorological Conditions (IMC) and also allow for the Flight Crew to conduct self spacing just as in the Visual Meteorological Conditions (VMC), and hence increase throughput of landing aircraft in runways. This will in turn rely heavily on the communication link capabilities.

This system level paper addresses the possible application of the IMT2000 terrestrial technologies within ATM communications. The benefits of the technologies are highlighted along with their disadvantages.

The next four sections will cover in order; an overview of the Terrestrial IMT2000 technology, an overview of the ATM applications and communication links technology relevant to this paper topic, followed by the application of IMT2000 technologies to the ATM, and ending with the Conclusions and future recommendations.

IMT2000 Terrestrial Standards

3G Systems are expected to provide universal mobility with a range of services including paging, messaging, telephony, and Internet and broadband data. The International Telecommunication Union (ITU) has been involved in defining the standards for third generation systems, referred to as International Mobile Telecommunications 2000 (IMT-2000) [2].

Initial work on standardization had started by the middle of the 1980s although practical work did not start until the 1990s with the allocation of 230 MHz bandwidth for IMT-2000 between 1885 and 2025 MHz, and between 2110 and 2200 MHz. Several dedicated committees were organized including; the ITU-R dedicated task group TG8.1. In Europe the European Telecommunications Standards Institute (ETSI) CODIT and ATDMA programs within the RACE II project were formed to enhance the Global System for Mobile Communications (GSM). In Japan, the Future Public Land Mobile Telecommunications System

FPLMTS study group was formed under the Research and Development Center for Radio Systems RCR (which thereafter became the Association of Radio Industries and Businesses (ARIB). The ITU-R put out a request for proposal and in response to that many organizations and industries submitted proposals and ten were selected in 1998. To harmonize the ten proposas for a more common global standard, the 10 were combined into 5 families. CDMA-DS; CDMA-MC; CDMA-TDD, TDMA-SC, and FDMA/TDMA.

3GPP and 3GPP2 and IMT2000 Specification Development

Two forums were then created to harmonize the three CDMA families (out of the five families). Those two forums are called the 3GPP and 3GPP2. The 3GPP was composed of six standards development organizations which are: ARIB, ETSI, T1, Telecommunications Technology Association and Committee (TTA and TTC), and the China Wireless Telecommunications Group Standard Group (CWTS). The task of 3GPP was to develop global specifications for 3G based on the Universal Terrestrial Radio Access (UTRA) which uses the W-CDMA FDD and TDD access methods which were part of the 10 original proposals. 3GPP is also responsible for transitional technologies from GSM up to the UMTS which include General Packet Radio Service (GPRS) and Enhanced Data rate for GSM Evolution (EDGE).

The 3GPP structure has five main UMTS standardization areas: Radio Access Network, Core Network, Terminals, Services and System Aspects and GERAN.

- The 3GPP Radio Access group is responsible for; Radio Layer 1, 2 and 3 RR specification, Iub, Iur and Iu Interfaces, UTRAN Operation and Maintenance requirements, Conformance test specification for testing of radio aspects of base stations, BTS radio performance specification, and radio performance aspects.
- The 3GPP Core Network group is responsible for: Core network signaling between the core network nodes, Definition of interworking functions between the core network and external networks, Mobility management, call connection control signaling between the user equipment and the core network, Packet related issues, Core network aspects of the lu interface and Operation and Maintenance requirements.
- The 3GPP Terminal group is responsible for: Universal Subscriber Identity Module (USIM), Mobile terminal Services and Capabilities, and Conformance testing.
- The 3GPP Services and System group is responsible for Services, Architecture, Security, Codec, and Telecom Management.
- Finally the TSG-GERAN GSM EDGE group is responsible for the radio, protocol, base station, terminal radio and protocol testing and aspects of those transitional technologies toward UMTS.

The 3GPP specifications evolution started with Release 99, in December of 1999, followed by Releases 4 in 2001 and Release 5 in 2002, with Release 6 in the works. The main additions between the releases was the addition of the W-CDMA TDD standard in version 4, and the IP Multimedia Subsystem (IMS) to enable IP services such as Voice and Video, as well as Location Services in version 5. Broadcast of multimedia, as well as internetworking between Wireless Local Area Networks (WLAN) and UMTS, along with Orthogonal Frequency Division Multiple Access Modulation methods are added to the not yet frozen release 6.

The Third Generation Partnership Project 2 (3GPP2) was formed for technical development of cdma2000 technology which is an evolution from IS95, as well as to promote the ANSI/TIA/EIA-41 specifications. The 3GPP2 considered an IP based core network. The members of the 3GPP2 Forum include: ARIB, CWTS, Telecommunications Industry Association TIA, TTA, and TTC as well as Market Representative Partners that include IPv6

Forum, and CDMA Development Group (CDG). The structure of the 3GGP2 group is very similar to the 3GPP group focusing on various subsystem specifications ranging from IP multimedia core network group, to radio access group, as well as interface between radio access and core network group, and service capability group. In addition there is a CDMA 2000 group.

Similar to the GSM to UMTS transitional technologies (i.e. GPRS, and EDGE), the IS95 to cdma 2000 has also adopted its own technologies. Those technologies are the 1X Evolution Data Only and 1X DATA and Voice (1xEV DO and 1XEV DV).

The specifications and documentation from 3GPP2 group evolved from the IS2000 Release 0 which offers, turbo coding, transmission diversity, high speed channel of 144 Kb/s, and fast power control for downlink channels. This was then followed by Release-A in year 2000 which included: 3xmulti carrier mode, up to 2 Mb/s channel rates with voice and data simultaneously.

The IMT-2000 specifications are based on the 3GPP release 99, and 3GPP2 release 0, and are defined in the form of Recommendations ITU-R M.1457. Revisions to that document added the IP based services, as well as the evolutions of 1xEV DO and 1XEV DV. The IMT2000 terrestrial standards involve five subsystems or technologies. Those standards are as follows:

- CDMA Direct Spread (also called Universal Terrestrial Radio Access (UTRA) FDD or wideband CDMA (WCDMA).
- The CDMA Multi-Carrier also called CDMA2000 which consists of the 1X and 3X components.
- CDMA Time Division Duplex TDD, also called UTRA TDD with a 1.28 Mcps TDD (TD-SCDMA) option, and a 3.84 Mcps TDD.
- TDMA single carrier, also called Universal Wireless Communications-136, specified by the American National Standards TIA/EIA-136 and designed to maximize compatibility between TIA/EIA-136 and the GSM general Packet Radio Service (GPRS).
- FDMA/TDMA standard, which is also called Digital Enhanced Cordless Telecommunications (DECT).

Table 1 summarizes the major specifications of the five technologies comprising the IMT2000 standards. The IMT2000 technologies will offer connection and connectionless point to point as well as point to Multipoint services. The Bearer services have different QoS parameters for maximum transfer delay, and bit error rates depending on the types of traffic class which are categorized by: Conversational class such as voice, video telephony; Streaming class such as video on demand and webcast multimedia; Background class such as email, downloads; and Interactive class such as web browsing and database access.

Table 1. Summary of Specification of IMT2000 Terrestrial Standards

Parameter	UTRA FDD WCDMA	CDMA 2000	UTRA TDD	UWC -136	DECT
Multiple access technique and duplexing scheme	Multiple access: DS-CDMA Duplexing: FDD	Multiple access technique: CDMA Duplexing scheme: FDD	Multiple access: TDMA/CDMA Duplexing: TDD	TDMA	TDMA Duplexing: TDD
Chip rate (Mchip/s) or Symbol Rate	3.84	$N \times$ 1.2288 Mchip/s (currently N = 1 and 3 is specified, and N can be easily extended to N = 6, 9, 12)	3.84 Mcps TDD option: 3.84 1.28 Mcps TDD option: 1.28	136+ bearer: 24.3 ksymbols/s EDGE bearer: 270.833 ksymbols/s 136HS Indoor bearer: 2.6 Msymbols/s	1 152 kbit/s for 2-level modulation 2 304 kbit/s for 4-level modulation 3 456 kbit/s for 8-level modulation
Frame length and structure	Frame length: 10 ms Slot length: 10/15 ms. Transmission Time Interval TTI: 10 ms, 20 ms, 40 ms, 80 ms, 2 ms (HS-DSCH only)	5, 10, 20, 26.666, 40, 80 ms frame and channel interleaving	3.84 Mcps TDD option: Frame length: 10 ms 15 slots per frame, each 666.666 μs 1.28 Mcps TDD option: Frame length: 10 ms Sub-frame length: 5 ms 7 main slots per sub-frame, each 675 μs TTI: 10 ms, 20 ms, 40 ms, 80 ms, 5 ms (HS-DSCH and PRACH, 1.28 Mcps option only)	136+ bearer: 40 ms EDGE bearer: 4.615 (120/26) ms 136HS Indoor bearer Number of slots per frame: 4.615 (120/26) ms 136+ bearer: 6 EDGE bearer: 8 136HS Indoor bearer: 16-64	10 ms 12 double slots 24 full slots 48 half slots
Occupied bandwidth	Less than 5 MHz	Nx1.25 MHz (currently N = 1 and 3 is specified, and N can be easily extended to N = 6, 9, 12)	3.84 Mcps TDD option: Less than 5 MHz 1.28 Mcps TDD option: Less than 1.6 MHz	Minimum operating bandwidth: 136HS Outdoor bearer: 2x600 kHz 136EHS: 2x600 kHz COMPACT bearer: 2x2.4 MHz 136EHS Classic bearer 2x1.6 MHz FDD 136HS Indoor bearer: 1x1.6 MHz TDD Carrier Spacing: 136+ bearer: 30 KHz EDGE bearer: 200 KHz 136HS indoor bearer: 1.6 MHz	Channel Spacing: 1 728 kHz
Adjacent channel leakage power ratio (ACLR) (transmitter side)	UE (UE power class: + 21 dBm and +24 dBm): ACLR (5 MHz)= 33 dB ACLR (10 MHz)=43 dB BS: ACLR (5 MHz)=45 dB ACLR (10 MHz)=50 dB	—	3.84 Mcps TDD option: UE (UE power class: + 21 dBm, +24 dBm) ACLR (5 MHz)= 33 dB ACLR (10 MHz)= 43 dB BS: ACLR (5 MHz)= 45 dB ACLR (10 MHz)= 55 dB 1.28 Mcps TDD option: UE (UE power class: + 21 dBm, +24 dBm) ACLR (1.6 MHz)= 33 dB ACLR (3.2 MHz)= 43 dB BS: ACLR (1.6 MHz)= 40 dB ACLR (3.2 MHz)= 50 dB	------	Peak Transmit power Level 1: 2.5 mW (4 dBm) Level 2: 250 mW (24 dBm) Adjacent channel leakage power 1 channel: 160 μW 2 channel: 1 μW 3 channel: 80 nW >3 channel: 40 nW
Adjacent channel selectivity (ACS) (receiver side)	UE:ACS (5 MHz)= 33 dB BS:ACS (5 MHz)= 45 dB		3.84 Mcps TDD option: UE: (UE power class: + 21 dBm, +24 dBm) ACS (5 MHz) = 33 dB		With a received signal strength of – 73 dBm on RF channel M, the BER in the D-field

Parameter	UTRA FDD WCDMA	CDMA 2000	UTRA TDD	UWC -136	DECT
		———	BS: ACS (5 MHz) = 45 dB 1.28 Mcps TDD option: UE: (UE power class: + 21 dBm, +24 dBm) ACS (1.6 MHz) = 33 dB BS: ACS (1.6 MHz) = 45 dB	———	shall be maintained better than 1×10^{-3} when a modulated,reference interferer of the indicated strength is introduced on the RF channels: M - 84 dBm, M±1 -60 dBm, M±2 -39 dBm, any other - 33 dBm
Access mechanism	Acquisition indication based random-access mechanism with power ramping on preamble followed by message	Basic access; power controlled access; reservation access; or designated access	3.84 Mcps TDD option: RACH burst on dedicated uplink slot(s) 1.28 Mcps TDD option: Two step random-access with fast physical layer signalling	Level 3 layer manages switching between circuit and packet	Instant dynamic channel selection for every setup
Pilot structure	Uplink: dedicated pilots Downlink: common and/or dedicated pilots	Code division dedicated pilot (UL); code division common pilot (DL); and code division common or dedicated auxiliary pilot (DL); and time division common pilot	——	N/A	N/A
Inter-base station asynchronous/synchronous operation	Asynchronous; synchronous	Synchronous operation is required	Synchronous operation	Synchronous Operation	Synchronous Operation
Modulation and detection	Dual Channel QPSK with option for adaptive and higher order modulations in higher speed downlink channels	Data modulation: BPSK; QPSK, 8PSK, and 16QAM Spreading modulation: HPSK (UL); QPSK (DL) Detection: Pilot aided coherent detection	QPSK with 8PSK option	136+ bearer: π/4 DQPSK, 8-PSK EDGE bearer: GMSK, 8-PSK 136HS Indoor bearer: Binary offset QAM, Quaternary offset QAM	GFSK, π/2-DBPSK, π/4-DQPSK, π/8-D8PSK
Power control	Closed loop power control	Open loop Closed loop (800 Hz or 50 Hz update rate) Power control steps: 1.0, 0.5, 0.25 dB	Closed loop power control	Power control per slot and carrier	———
Channelization code	Long gold codes (384000 chips UL and DL) with short 256 chips codes capability	Walsh codes and long codes (UL) Walsh codes or quasi-orthogonal codes (DL)	OVSF codes	N/A	N/A
Channel Code	CRC, and Convolutional 1/2 and 1/3, as well as Turbo 1/3	Convolutional K=9, R=1/2,1/3,1/4, or 1/6 Also Turbo coding option K=4,R=2/3,1/2,1/3,1/4,or 1/5	CRC, and Convolutional 1/2 and 1/3, as well as Turbo 1/3	136+ bearer: Punctured convolutional codes EDGE: convolutional codes Incremental redundancy 136HS Indoor bearer: Punctured convolutional codes, Type II hybrid ARQ	———

Satellite – IMT2000 Standards Summary

While the focus of this study is on the terrestrial standards, the satellite and terrestrial UMTS elements are to compliment each other with satellite coverage being global and covering areas where the terrestrial components are not yet available. The specifications for the Satellite component of the IMT2000 come from six different standards. The satellite system specifications deal mainly with the service link, which is the link between the satellite and the

Mobile Earth Station (or User Terminal). The other links which include the Feeder link from the satellite and ground stations and the inter-satellite links are not governed by IMT-2000 standards but are governed by the satellite system designer standards. Similarly, Handover requirements from satellite to terrestrial links are not part of the IMT-2000 standards. The interface from the satellite system to the Core Network on the other hand, is to follow standards that are very similar to the terrestrial interface to the Core Network. Those requirements affect call routing, billing, roaming mechanism, and other functions. The six satellite standards are all specified in detail in [2] and are:

- "A Specification" developed by the European Space Agency ESA. That system is also called the SW-CDMA standard. It is based largely on the CDMA Direct Spread terrestrial radio Interface (UTRA FDD).
- The B Satellite Radio interface is the SW-C/TDMA also by ESA. It uses hybrid code and time division multiplexing.
- The C Satellite radio interface standard is the SAT-CDMA by the technical assembly of TTA of South Korea. This system is different than the previous ones in that it specifies the satellite constellation to be used. This will be a 48 satellite constellation in 8 low earth orbits with 37 spot beams per satellite.
- The D Satellite radio interface is SRI-D by ICO Global Communications is again specific to a constellation of 12 satellites in 2 MEO inclined orbits. Each satellite will have 163 spot beams. This system will use FDMA and TDMA accessing technologies.
- The E Satellite radio interface (SRI-E) by Inmarsat (Horizons) is a standard that have been optimized for a geostationary satellite configuration with worldwide coverage and multimedia services. It uses TDM/TDMA with FDMA accessing.
- The Satellite radio interface F specification by Irridium is called Satcom2000. It promotes the use of smart antennas, hybrid multiple access schemes, on-board processing and switching. It consists of 96 LEO satellites in 8 near polar orbits, with 12 228 spot beams per satellite It uses FDMA/TDMA and FDMA/CDMA to maximize users of different technologies.

Table 2. ATM Communication System Applications [3]

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

ATM Communications System Specifications

The air traffic management modernization effort has resulted in advancements in the communication technologies and their applications. Table 2 from [3] 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. All services currently have their designated links although studies have shown that some of those links could reach a capacity limit requiring additional alternative links. Table 3, also from [3] shows the capacity provided by various communication links currently proposed for ATM. The satellite portions shown in the Table are not currently employed. Finally, Table 4 also from [3] shows estimated data rates for the applications in Table 2, by year 2015. The data rates are based on an airport domain and terminal domains that are defined based on flights that are 10 minutes long. The data loads shown are for a total of 192 aircraft in the airport domain, and 137 in the terminal domain. Hence if we are interested in obtaining traffic load for any other number of aircraft we can simply divide the loads shown by the number of aircraft (i.e. 137 or 192 depending on the domain) giving traffic per one aircraft, then we may multiply by any number of aircraft desired.

Table 3. Aeronautical Communication Links Capacities [3]

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 4. Estimated Peak Communication Loads for 2015 [3]

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

Applicability of IMT2000 to ATM Communications Systems

In this section the applicability of the IMT2000 terrestrial technologies within the ATM communication needs is investigated. To do that one need to observe the data and specifications shown in the last two sections and determine where the advantages and disadvantages lie. Starting with the advantages that define the applicability of the IMT2000 standards to the ATM communication needs, the following observations can be made:

- Given that all the IMT2000 standards can support data rates of 64 Kbits/sec at minimum, and up to 2 Mbits/sec, it is evident that the airport and terminal traffic can be easily supported using any of the IMT2000 standards in terms of data loading and throughput. This is concluded from simply looking at the total traffic loads in uplink, or downlink in Table 4 and noting that the sum off all the traffic is much smaller than what can be supported with any of the IMT2000 technologies. Note again that traffic in Table 4 was for 192 and 137 aircraft for airport and terminal and based on traffic capability of the IMT2000 technology, a very large number of aircraft can be accommodated. In summary the IMT2000 technology capability of up 2 Megabits/sec for each user is much more than what the basic ATM services requires.
- The obvious advantage of having the additional capacity is to open the door for future applications and services for the ATM.
- The BER specified for IMT2000 are generally within the ATM application requirements.
- Priority and QoS can be utilized if the networks are shared between passengers and cockpit. Since services to aircraft will have to come from base stations and antennas that are tilted upward (for terminal specifically), only air users (passengers and cockpit crew) will have accessing to those upward pointing base stations hence there may be no issues sharing services based on the current ATM services. That is data loads shown in Table 4 with the APAXS are still very much within the capabilities of the IMT2000 technologies and when there is a need for more capacity support, additional sectors or frequencies can be added.
- Multicasting and broadcasting can be taken advantage of in various applications within the ATM.
- Aircraft to aircraft connections can be done via air to ground, then ground to air. This may present some additional delay although depending on the ground network this may be very minimal. The throughput and quality of service would remain the same as in an air to ground connection. The air to air communications is especially needed when in terminal approach, and for pilots to communicate to nearby aircraft.

- Location based service can possibly be utilized along with the navigation capabilities already on the aircraft.
- Applications such as ADS-B, TIS-B, and FIS-B require broadcasting the information to a group of aircraft. The multicast, and broadcast capabilities of the IMT2000 technologies can be exploited to provide such services. None the less, it is expected that if ADS-B application will be present on the aircraft then the Mode S, or UAT links will most likely remain to be the choice for aircraft to aircraft communications and hence ADS reporting from air to ground then up to the air may not be needed. For TIS-B and FIS-B it may be advantages to utilize the capabilities of the IMT2000 technologies.
- Research on the use of 3G for air traffic communications and management has already shown promise via actual experiments with the use of UTRA TDD technology. That work was done as a collaborative effort between Eurocontrol and Roke Manor Research with the use of Siemens, NEC, and Roke Manor equipage that was contracted by NTT DoCoMo. The experiments involved a BAC1-11 aircraft flying over several base stations transmitting live video of cockpit activity, with simultaneous voice call, and video streams from ground, supporting data rates up to 1.2 Megabits/sec at aircraft speeds up to 600 Km/hr [4].
- The Satellite IMT2000 services provide a powerful back up service as well as a necessary service for oceanic and remote users. Extensive research has been done [5] showing integration between terrestrial and satellite services and as such providing a wealth of knowledge and expertise in a very critical area. In addition the homogeneous nature of some of the satellite and terrestrial standards such as the UTRA FDD, and SW-CDMA provides a likely avenue for the integration efforts.
- The packet based services (as oppose to the circuit data services) is a tremendous advantage, as well as a necessity for the applications of the ATM. The packet data service essentially makes the aircraft in an always ON mode and free channels when no data is being transmitted. This is necessary since most applications such as ADS reporting, as well as automet, continuous black box downloading, and others are continuously generated through out any flight and hence would not be practical with circuit based data services if a large number of aircraft is present.

Some of the possible difficulties of the IMT2000 technology for use with ATM applications include:

- The spectrum is an issue, unless the technology is used within other protected aeronautical bands such as the 5 MHz band.
- Dedicated circuit switched voice channels may limit capacity.
- The choice of a single technology out of the five mentioned in the IMT2000. The technologies can not be intermixed and hence a single technology has to be chosen nationally or globally to make the concept more financially feasible. Having more than one system equipage in addition to being costly, it will also waste equipage space on the cockpit. Note although still in its premature ages, Software Radio manufacturers are already putting out dual mode systems that can proof to solve this problem if more than one technology is utilized.
- With the exception of the Roke Manor Research, not enough research has been done for the technology potential for air mobile users (vs. ground users).
- A typical 500 Km/hr speed limitation is seen for most terrestrial standards that reflects maximum speeds for ground transportation (fast trains). Again it is mainly due to the minimal research for

air users that such limitation are stated in the standards and external mounting antennas, as well as other enhancement may prove to make the service acceptable for much higher speeds. Regardless, the air traffic in the terminal and airport tends to fall within those limits simply due to the slower aircraft speeds in those domains as it compares to en route domain speeds.
- The TCP/IP protocol is still not very definitive within the ATM, as it compares to the ATN protocol. As such more research may be required to accommodate the ATN protocol.
- Sharing, security, and band protection is a major issue depending on how the services can be implemented. Again a protected band within 5 GHz can prove advantages but will require new and not readily available equipage. Use of the IMT2000 band is on the other hand not a likely option given the requirements on band protection for aeronautical communications. Nevertheless, the higher security, integrity, and reliability of those future services may change that perception and allow for more sharing of services.

Recommendations for Future Work

Further research in more detailed aspects of the application of IMT2000 to the ATM communication needs can minimize some of the disadvantages outlined, while emphasizing the advantages. A simulation and modeling effort can pave the way for future research and ideas. Tools such as the Opnet UMTS [5] can be utilized for more detailed studies into the UTRA FDD standard.

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