IMT2000 Satellite Standards with Applications to Mobile Air Traffic Communications Networks

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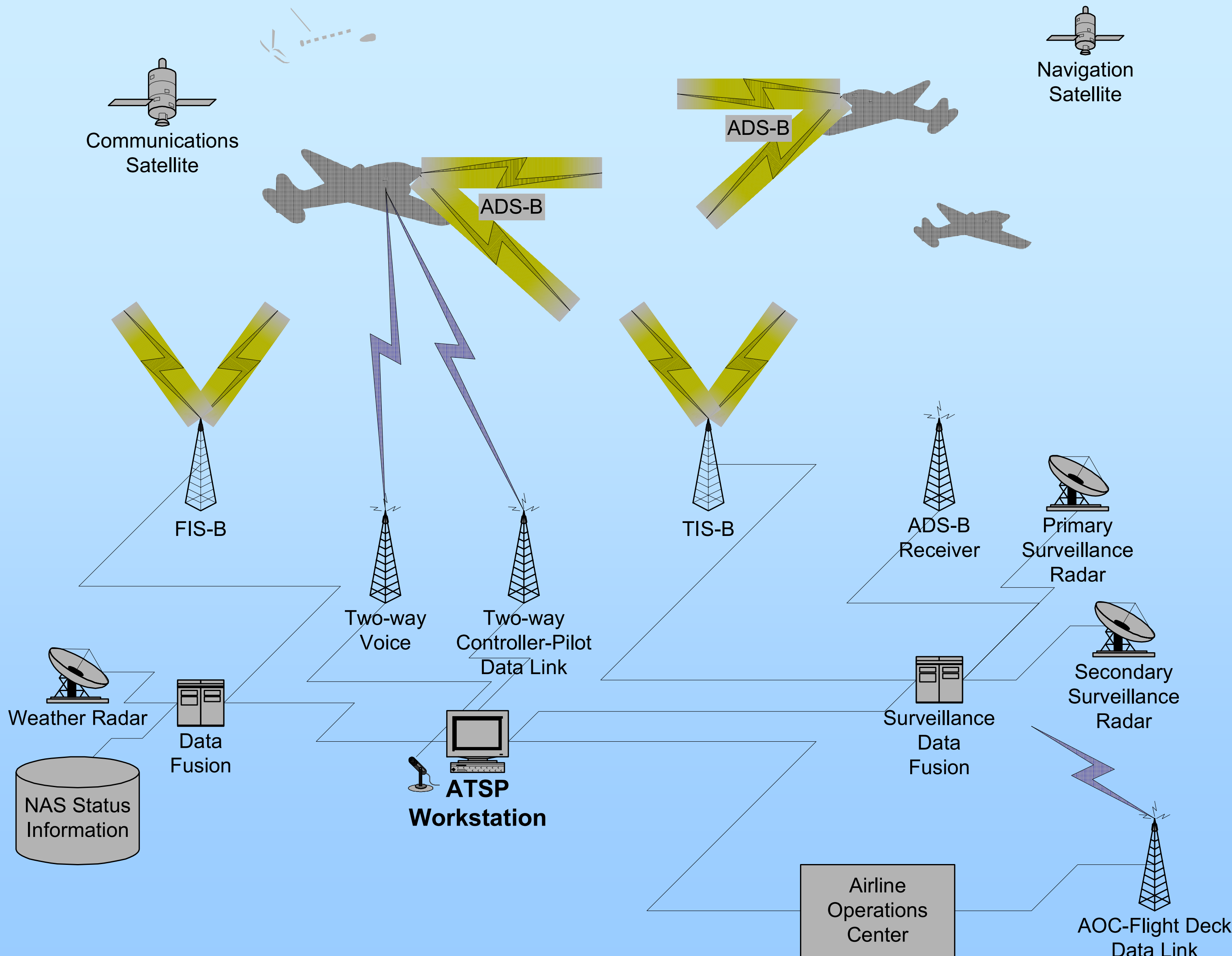
Project

- The work here was done as part of the Advanced Communications for **Air Traffic Management Project at NASA Glenn Research Center in Cleveland, Ohio**

Objective

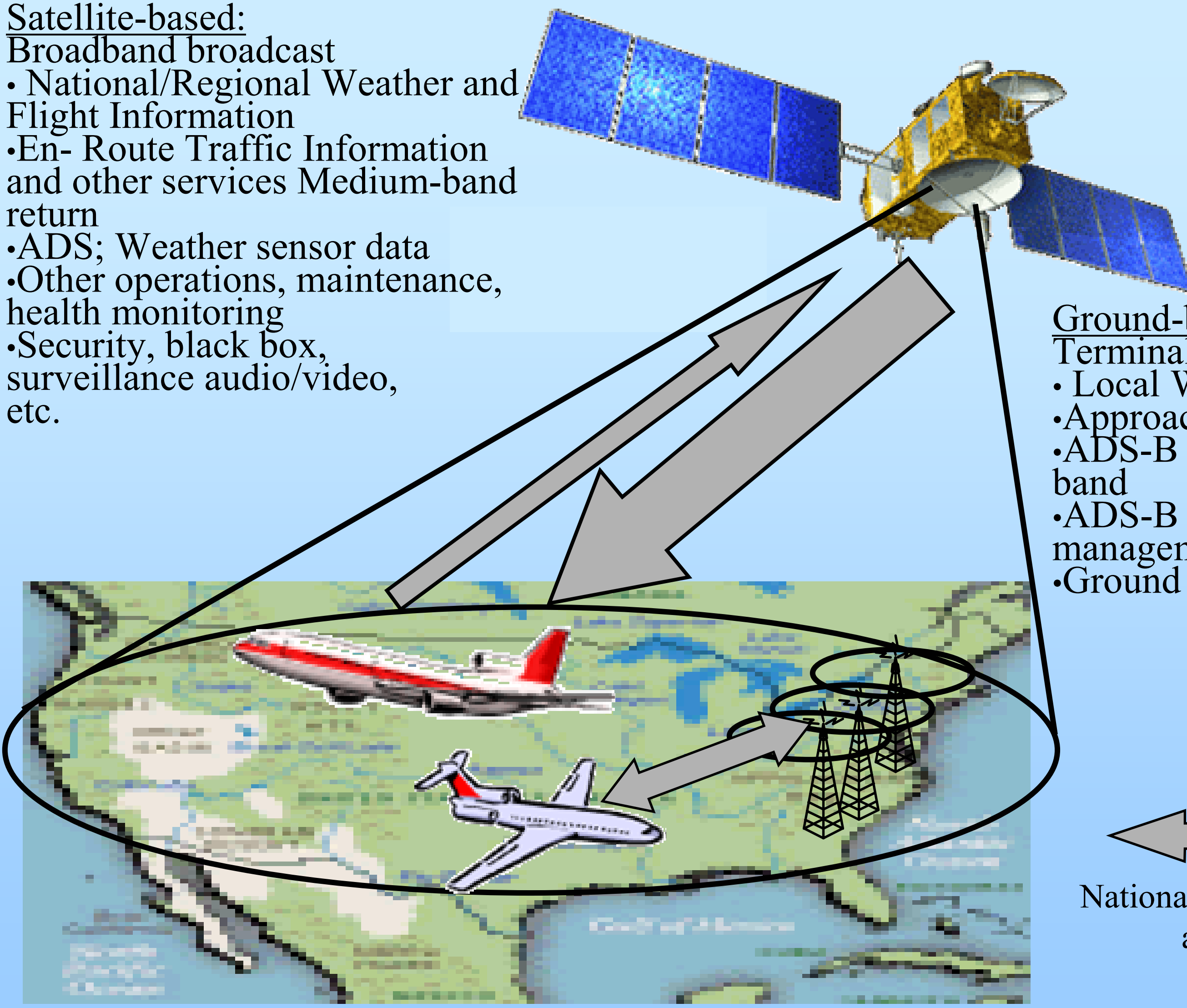
- Look at present standards of the Satellite services for Air Traffic Management
- Summarize technical aspects of IMT2000 satellite system standards
- Show applicability, advantages and disadvantages of the use of IMT2000 standards in Air Traffic Management communications

Future ATM Components



Future Satellite Subnetwork

<u>Satellite-based:</u>
Broadband broadcast
• National/Regional Weather and Flight Information
•En- Route Traffic Information and other services Medium-band return
•ADS; Weather sensor data
•Other operations, maintenance, health monitoring
•Security, black box, surveillance audio/video, etc.



<u>Ground-based:</u>
Terminal area broadband:
• Local Wx, FIS, TIS
•Approach/departure
•ADS-B Surface medium-band
•ADS-B round traffic management
•Ground ops clearances, etc.

National/Global Interoperbility
and Networking

Prior to ATM Proposals

- Sat Communication Usage was very limited
- Mainly provided by Inmarsat Services since the 1980s Aero-H, H+, L (still Current AMSS Standard)
- ACARS provided Data services over satellite links (as well as HF and VHF)
- Systems were not heavily used due to experimental status and costs

ATM Proposals

- ATM proposal/standards by ICAO, ITU, RTCA fall into two categories:
  - Aeronautical Mobile Satellite (Route) Service (AMS(R)S) based on Annex 10, Vol. 3, part 1, chapter 4 standards, RTCA DO-210D, RTCA 215a
  - Next Generation Satellite Services (NGSS) based on AMCP/WGA-WP/666b, RTCA 262, RTCA 270

AMS(R)S

- AMS(R)S is based on the Inmarsat legacy Service
  - Geo Satellites (4 of them)
  - L band 1550-1630.5 MHz
  - TDMA channels packet data up to 10500 b/s (P channel ground to air), (T channel air to ground user data)
  - Circuit Switched (C channels) for voice, data, both ways
  - Random Access channel R for air to ground data requests

NGSS

- NGSS attempts to include newer technologies that have developed since AMSS SARPS were put in place
- It is not limited to the AMSS standards
- Uses GEO, MEO, or LEOs
- Service is not limited to any particular satellite systems or communications technologies, hence why we can look into IMT2000 satellite technologies as an option

NGSS specifications

Performance parameter	Specification
Coverage	World wide service.
Mean transfer delays of packet data	23-28 seconds
95th percentile transfer delay of packet data	25-30 s to aircraft 40-60 s from aircraft
Priority for data services	Priority for safety communications (3 levels). Preemption over non-safety services if necessary
Integrity of packet data	$1x10^{-6}$ for a block of 128 octets
Connection establishment delay	Maximum 50 seconds 95th percentile for connection oriented protocol
Constellation	GEO,LEO, or MEO
Frequency	1554-1555 MHz space-to-earth, 1646.5-1656.5 MHz in earth-to-space. Also 1610-1626.5 MHz is used.
Acquisition of signal and tracking speed	Can acquire and track aircraft up to 1500 km/h speeds (800 knots) with 2800 km/h (1500 knots) recommended
Interference	Each aircraft shall not cause more than -115 dBW/MHz in average spectral density in AMSS band (measured over 20 ms period) when operating in max power
Susceptibility	Can operate in an environment of up to 25% change in receiver temperature
Voice call blockage	No more than 0.01
Security	Protection against denial of service, degraded performance, reduction of system capacity
Voice service interface	Should conform to recognized international telephony standards when interfacing with external telephony networks
Transfer delay on connected channel for speech	.485 second maximum from time speed exists Aircraft to time enter Ground station and vice versa.
Recommend maximum aircraft attitudes while meeting performance	+20/-5 degrees in pitch, +/-25 degrees in roll

IMT2000 Standards (Terrestrial)

- **Five Terrestrial Standards:**

1-CDMA Direct Spread (also called Universal Terrestrial Radio Access (UTRA) FDD or wideband CDMA (WCDMA).

2-The CDMA Multi-Carrier also called CDMA2000 which consists of the 1X and 3X components.

3-CDMA Time Division Duplex TDD, also called UTRA TDD with a 1.28 Mcps TDD (TD-SCDMA) option, and a 3.84 Mcps TDD.

4-TDMA single carrier, also called Universal Wireless Communications-136, specified by the American National Standards TIA/EIA-136 and designed to maximize compatibility with the GSM general Packet Radio Service (GPRS).

5-FDMA/TDMA standard, which is also called Digital Enhanced Cordless Telecommunications (DECT).

IMT2000 Standards (Satellite)

- The first Service Link Specification for the satellite radio interface is termed the "A Specification" and is 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).

- Maximum rate of 144 Kbit/s and the minimum 1.2 Kbit/s.
- Satellite diversity in reverse link when more than one satellite is used.
- Supported by Bent pipe constellation LEO, MEO, GEO, or HEO is possible.
- Maximum tolerated delay of 400 ms.
- Doppler precompensation for service and feeder links.
- High powered paging channel for indoor operation
- 50-100 Hz Power control rate with range of 20 db
- Two chipping rates 1.92 and 3.84 Mchips/s occupy 2.35 and 4.7 MHz of bandwidth in each direction.
- Frame period of 10 ms and 20 ms for the long and short chip rates.
- Three classes of services are supported with:
  - standard service (1/3 or 1/2 convolutional) and interleaving with BER 1x10-3.
  - High quality (inner 1/2 or 1/3 convolutional, interleaving and outer RS with Turbo Coding optional, BER 1x10-6).
  - services that have specific coding needs where higher layers will manage it.
- Modulation is done with QPSK for the Full rate and BPSK for the half rate in the downlink, and Dual Code BPSK for the uplink.
- Handoff could be beam, intersatellite, inter earth station, and inter frequency using C/(N+I) with User or Earth station making the final decision. Soft hand off is also supported.

IMT2000 Standards (Satellite)

The B Satellite Radio interface is the SW-C/TDMA also by ESA. Some of the features of this system include:

- Based on a hybrid code and time division multiple access
- Channel bandwidths of 2.35 or 4.7 MHz in each direction of transmission for 1.920 Mchips/s half rate, or 3.840 Mchips/s full rate.
- Bearer services range from 1.2 to 144 Kbits/s with BER supported from 1x10-3 to 1x10-6.
- bent pipe or regenerative LEO, MEO, GEO, or HEO constellation.
- Maximum delay tolerated of 400 ms.
- Satellite diversity in multiple satellite scenario is supported
- Frames are 20 ms in period divided to 8 slots with Multi Frame comprising 8 ordinary frames with one additional frame.
- Closed loop power control for forward and return links, with slower outer control loop based on FER measurement to set the target power value. Also open loop control for packet transmission and for initial setting of power is provided. similar to the A standard.
- Modulation is QPSK or dual code BPSK in the uplink and QPSK or BPSK for low data rate in the downlink.
- Coding is done with convolutional 1/3 or 1/2 constrained length 9, with RS over GF(28) concatenated with the inner convolutional code with Turbo coding optional. with or without RS are used with different levels of BER.

IMT2000 Standards (Satellite)

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. Some of the main features of this standard include:

- Use of a LEO satellite constellation using 48 satellites in 8 orbital planes with 54 degrees inclination with a 7.5 degrees of phase offset between orbit planes.
- Each satellite will have 37 spot beams each have diameter of approximately 519 km.
- Packet data services will range from 2.4 to 144 Kbits/s.
- The feeder links are at 4/6 GHz while the inter satellite links at 60 GHz.
- Various types of satellite handoffs are possible.
- Closed loop power control supported.
- The channel bandwidth is 5 MHz.
- Convolutional coding and Turbo coding is used in with constraint length 9 and coding rates 1/3 and 1/2.
- Orthogonal complex QPSK modulation is used for uplink with long code direct sequence spreading, and QPSK is used for the downlink with short code spreading for channelization and long code spreading for scrambling.

IMT2000 Standards (Satellite)

The D Satellite radio interface is SRI-D by ICO Global Communications is again specific to a constellation and is basically comprised of:

- 12 MEO satellites in 2 orbits inclined at 45 degrees, with 12 Earth stations.
- Each satellite will have 163 spot beams.
- Modulation is done with QPSK on downlink and GMSK on uplink, as well as BPSK depending on channel type.
- Convolutional coding with rate 1/6 up to 1/2 is used again depending on carrier type. Data rates range from 2.4 Kbits/s up to 38.4 Kbits/s depending on Terminal type with BER at 10-5.
- RHCP polarization is employed in the uplink and downlink.
- Frequency reuse of 4 is used.
- Satellite EIRP ranges from 58.2 up to 56.1 dbw with worst case G/T of 1.5 dB(K-1).
- A combination of FDMA and TDMA in each 25 kHz RF carrier is used.

IMT2000 Standards (Satellite)

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. Some of the main features of this system include:

- Geostationary satellite configuration
- Forward link can deliver between 21.6 kbit/s to 512 kbit/s. Return link able to support 19.2 kbit/s up to 512 kbit/s.
- Up to 300 spot beams per satellite, with 1 degree beam widths (800 Km diameter)
- Frequency reuse of 7 beam cluster.
- Average G/T of satellite beam of 10 dB/K with saturation EIRP of maximum 53 dBW (minimum 38 dBW) and a satellite total of 67 dBW.
- Power control step size of 0.5 dB, and a dynamic range of 8 dB, with 1 cycle per second rate.
- no assumptions on the protocols used in the upper OSI layer allowing any type of traffic
- Location management service with the use of GPS.
- Dynamic channel allocation where frequencies are assigned to spot beams based on traffic TDM/TDMA/FDMA multiple access
- To support a wide range of antenna specifications and EIRP levels, a range of bearer services are used with different modulation schemes. 16-QAM and 4-ary modulation is used in the return link. 16-QAM and QPSK is used for the forward link.
- Variable coding (puncturing of turbo codes in a pre-defined manner) to maximize efficiency

IMT2000 Standards (Satellite)

The Satellite radio interface F specification by Iridium is called Satcom2000. It promotes the use of smart antennas, hybrid multiple access schemes, on-board processing and switching, with other advanced technologies, to optimize spectral, spatial and power resources. Some of the features of this system include:

- Consists of 96 LEO satellites in 8 near polar orbits, 12 satellites per orbit in addition to the spares. coverage entire earth.
- 228 spot beams per satellite (can be adjusted to improve performance)
- Inter satellite links, with onboard processing, with dynamic beam traffic distribution.
- Uses both FDMA/TDMA and FDMA/CDMA access technologies on every satellite in order to support diverse users
- Supports bandwidth on demand, bit rate on demand, asynchronous data, and asymmetric data.
- Minimum satellite channelization of 27.17 kHz in TDMA, and 1.25 MHz in CDMA.
- QPSK modulation with TDMA, and 16-QAM/QPSK for CDMA.
- FEC for TDMA is 2/3 convolutional, and for CDMA 1/2 convolutional in down link, and 1/3 in uplink. In addition outer RS used, and ARQ for non-real time services.
- Data link using multiple channels can be used to provide up to 144 kbits/s.
- Supports up to 500km/h for hand held and 5000 km/h for aero.
- It will operate a service link at the 2 GHz band. Separate bands will be allocated for the CDMA and TDMA components.
- Power control rate 50 Hz. Power step of 0.5 dB in CDMA and 2 dB in TDMA with power control range of 25 dB.
- Doppler compensation.

ATM Applications

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 Applications Traffic Loads

Based on predicted traffic by year 2015 (referenced from ARINC/TRW/SAIC report)

Domains are defined as 10 minutes flights in airport and terminal and 50 minutes in en route

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

Advantages of IMT2000 Satellite Services

- Meets most of the data, and voice requirements and recommendations of the aeronautical satellite
- Constellations open to various architectures in both standards (GEO, LEO, MEO)
- Coverage is world wide for both systems
- IMT-2000 equipage in the future may proof to be cost effective due to the global usage of the systems and the large number of users.
- Multicasting, paging, are additional features in IMT-2000 standards that can prove to be useful in air traffic management.
- IMT-2000 is the future satellite technology, hence will most likely replace current 1G/2G systems such as the Iridium
- The foreseeable integration of Terrestrial and Satellite IMT-2000 services will proof to be very advantages for terminal area as well as en route over land. Terrestrial services will be capable of providing data rates up to 2 Mb/s in micro-cell environment which can be very useful in terminal areas
- Example of current systems using both satellite and ground services is the AirCell/Iridium service which is based on 1 G technology and still capable of offering voice, low data (up to 9.6 Kb/s), and weather PDA display services.
- The RTCA/ICAO specifications for NGSS do not specify RF and base band technologies (example CDMA, or TDMA, modulation, coding, etc.). Therefore the researched links of the IMT-2000 technology are beneficial for any future system implementation.

Disadvantages of IMT2000 Satellite Services

- The frequency bands for the service links while both are within the L band (and lower S band), they are not the same. The AMSS band is protected for only aeronautical services and is a current requirement for new NGSS system proposals.
- AMSS and NGSS standards specify 3 classes of priority to be accommodated within any new system. IMT-2000 standards do have priority and class quality of service that can be exploited but require more research.
- IMT-2000 satellite standards are geared to vehicular users on ground and more research is needed for aeronautical users
- TCP/IP is the accepted protocol to go on top of IMT-2000 physical interfaces. the ATN protocol is the chosen one for aeronautical networks requiring more research.