Data Link Technology Characterization for NEWSKY Aeronautical Communication Network

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***Abstract*—This paper presents a review and characterization of possible data link technologies for cockpit and cabin communications. This work was done in the context of the NEWSKY project[2] which aims at defining an integrated network based on IPv6 protocol, supporting both cockpit and cabin communications over different data sub-networks. The objective here is to characterize the data link technologies that could be interfaced with such a network and to define some high level categories gathering technologies with common characteristics. These categories are defined as the NEWSKY network should be interfaceable with a large range of data link technologies (current but also future technologies).**
For this purpose, a deep review of candidate technologies for cabin and cockpit applications is performed and presented in this paper.

Keywords: aeronautical communications, integrated network, ATS, AOC, AAC, APC, safety/non-safety related communications, cabin and cockpit, sub-networks, technologies characterization.

I. INTRODUCTION

The NEWSKY project (NEtWorking the SKY) [1] aims at defining an IP based networking architecture supporting different types of services: safety related communications (Air Traffic Services (ATS) and Aeronautical Operational Control (AOC)) and non-safety related communications (Airline Administrative Communications (AAC) for administrative and maintenance issues and passenger communications (Aeronautical Passenger Communications (APC)). One of the key objectives of NEWSKY is to specify common network solutions and interfaces with different data link technologies aiming at an integrated communication network to be used by a wide range of services.

In this context, one of the tasks of the NEWSKY project was to investigate all the possible data link technologies (already existing or under investigation) that could be interfaced with such a network, and to characterize them for the network definition and simulations.
This work is presented in [2] and the main results are presented in this paper.

The paper is organized as follows. Section II presents the objectives, contour and content of the NEWSKY project. Sections III and IV recall the context for this activity and review the data link technologies to be considered. As several projects or working groups already worked on technology screening, the activity consisted in summarizing existing projects and conclusions or to adapt them to the NEWSKY focus. Most technologies reviewed are kept for NEWSKY as the objective is not to discard any technology but rather to have an overview of the possible technologies for future data networks. Based on this review we define some high level technology categories with their main characteristics, before concluding on their use in sections V and VI.

II. THE NEWSKY AERONAUTICAL COMMUNICATION NETWORK

The current aeronautical communication systems are not adequate to cope with the expected increase in air traffic and the provision of new services for cockpit and cabin.
Several services, networking solutions and data links are foreseen to be in operation in the future aeronautical communication environment, enabling the global provision of distributed services. Different services, ranging from ATS, AOC, AAC and APC shall coexist and partly or totally share the aeronautical network infrastructure as well as a number of data links, through adequate pre-emption policies to prioritize safety critical applications in front of non-safety critical applications, considering also regulatory issues in terms of spectrum usage. Different levels of integration are possible and subject to trade-off between costs, reliability and security.

As networking solution, the ATN (Aeronautical Telecommunication Network) based on the ISO/OSI reference model is currently being deployed (e.g. Link2000 program) to enable advanced services. However, due to the marginal deployment of these ATN ISO/OSI protocols, operation and maintenance costs are considerable. When looking at the 2020 horizon and beyond, it is hence foreseen that the widely deployed Internet Protocol Suite (IPS) networking solution will be deployed for air/ground communication for cost savings, high reliability and an optimal alignment with the evolution of communication and security technologies.
ICAO WG-I is currently specifying such an ATN/IPS [3].

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On the other hand, several data links are required to fulfill the cockpit and cabin communication requirements: satellite links, high data rate airport links, direct long-range air-ground links or air-air links for certain applications shall be used.

Summarizing, users of aeronautical communication services face a highly complex and fragmented communication architecture with different services, data links and networking solutions. The NEWSKY project consortium, co-funded by the European Commission, addresses this issue and develops a concept and initial design of an integrated aeronautical communication network with focus on a/g communications.

NEWSKY pursues the vision of "Networking the Sky" by integrating different data link technologies (long range air-ground links, airport links, satellite links) as depicted in Fig. 1 and different services (ATS, AOC, AAC, APC) into a single, seamless network [4].
Fig. 2 sketches the focus of NEWSKY investigations with respect to the protocol stack. The main focus is on the development of IPv6 technologies for aeronautics in close collaboration with ICAO WG-I, the interface with the different data link technologies to be integrated and the transport layer design and adaptation (when necessary). Indeed the integration within the same network of data link technologies with different performances and characteristics (such as delay, PER (Packet Error Rate), bandwidth …) requires some adaptations of the end-to-end transport layer protocol depending on the type of link. Additionally, transition from ATN/ISO to ATN/IPS is considered as well.

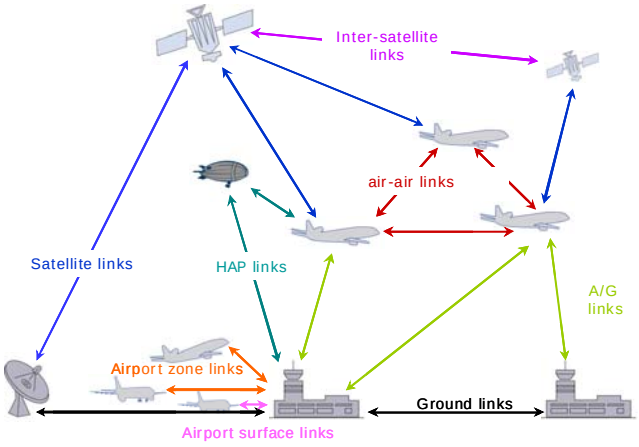

Figure 1. Integration of different data links into a global aeronautical communication network

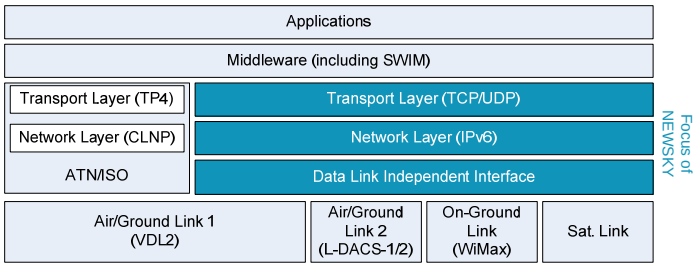

Figure 2. Focus of NEWSKY in the Protocol Stack

Benefits of the integrated approach include cost efficient operations, better economies of scale, a flexible and effective utilization of the available spectrum resources, optimized communications performance for each type of application, interoperability between different communication systems, and a highly modular and reconfigurable communication system permitting to easily integrate future data link technologies.

Key challenges of the network design include security, mobility and Quality of Service (QoS) provision [5]. For the integration of data links and services, issues related to the vastly different traffic patterns of the different services and certification aspects are addressed. Finally different implementations of such an integrated network could be envisaged and must be traded-off, with different implications in terms of cost, complexity, flexibility and safety. One could mention in particular the certification issues related to a single airborne router (e.g. Boeing 787 certification). Also constraints on spectrum allocation (see § III.C) shall be considered. These trade-offs are on-going within the project.

The activities of NEWSKY are carried out in a cooperative and coordinated way with standardization bodies and related projects of the aeronautical and networking community, in particular with SESAR, Eurocontrol, ICAO and IETF.

III. FRAMEWORK AND CONTEXT

This section contains first a number of important definitions for the paper and in particular highlights the difference between types of links and communications. Secondly, a summary of the conclusions of the state-of-the-art review on promising technologies for NEWSKY is provided. This review is necessary to support the definition of the data link technology. A particular emphasis is given to the outputs of the EUROCONTROL/FAA cooperative research and development activities in the framework of the Future Communications Study (FCS), which terms of reference are detailed in Action Plan 17 [6]. This work is well accepted by all aeronautical stakeholders and refers to safety related communications.

A. Definitions

Within NEWSKY, ATS and AOC communications are considered safety related communications, while AAC and APC are considered non-safety related communications. The next paragraphs detail the definition of each of these communication classes based on [7].

ATS communications are related to air traffic services including air traffic control, aeronautical and meteorological information, position reporting and services related to safety and regularity of flight.
AOC are communications required for the exercise of authority for initiation, continuation, diversion or termination of flight, for safety, regularity and efficiency reasons.
AAC are communications used by aeronautical operating agencies related to the business aspects of operating their flights and transport services. These communications are used for a variety of purposes, such as flight and ground transportation, bookings, deployment of crew and aircraft or any other logistical purposes that maintain or enhance the efficiency of operation over all flight.

APC are related to non-safety voice and data services for personal communication of passengers and crew members.

The communication classes above may be established as different communication types: **air-ground (a/g) communication,** involving one aircraft and a terminal on the ground; **air-air (a/a) communication**, meaning a direct communication between two aircraft; and g**round communication,** which do not involve any aircraft and are out of the scope of this paper.

Finally, the types of communications may run over one or more types of links. The following wireless links are considered in this paper for the data link technology characterization: **a/g links** are access links that connect one air mobile node **directly** with a ground base station; **airport (APT) surface links** are a particular case of a/g links when the air mobile node is located within the APT domain and at ground, the APT domain being as defined in [8]; **a/a links** are links that **directly** connect two air mobile nodes (a/a links can be established for one hop a/a communications, or as a part of multi-hop a/g or a/a communications); **Satellite links** are links involving communication through satellite between an air mobile node and a ground station.

Figure 3. depicts through an example the difference between type of communication and type of link, with an example of a/g communication involving two wireless links.

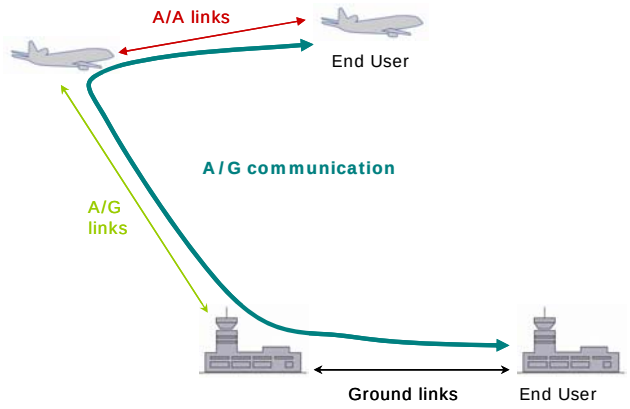

Figure 3. Type of communication vs. type of link

B. *Reference studies*

1) *Eurocontrol/FAA Future Communications Study*

The objective of this joint European and US study was to identify the most suitable data link technologies candidate for the Future Communication Infrastructure (FCI) for ATS and AOC communications. This was achieved by following an elaborated process: identification of candidate technologies, screening process to down-select the most promising candidates, and in-depth evaluation which led to development of data link technologies recommendations.

Table 1 summarizes the outcomes of this study, indicating the most suitable data link technology for each airspace.

TABLE I. JOINT EUROPEAN AND US RECOMMENDATIONS FOR THE FCS

Technology	Frequency Band	Proposed Coverage
IEEE 802.16eAV	C-band	Airport Surface
L-DACS	L-band	a/g comm. in all volumes except oceanic a/g
New Satellite System	L-band (AMS(R)S)	Oceanic/remote, possibly high density airspace

The main conclusions from the FCS are the following. It is recommended to develop a new high speed data link for airport communications. IEEE 802.16eAV is the aviation version of the IEEE 802.16 communication standard that needs to be developed. There is also a need to limit the number of L-band a/g data links. L-DACS refers to an L-band data link for which more work from concept into implementation needs to be conducted before deriving a final recommendation. At the moment there are four candidates identified for this L-DACS solution (LDL, AMACS, B-AMC and P34), with two access scheme/modulation combinations (Time Division Duplex (TDD) and Frequency Division Duplex (FDD)). Only one solution will be retained that offers the best solution for the L-band communication system. Finally, the need for a satellite component in the FCI was identified, but no existing system fulfills all requirements and hence the recommendation is to monitor all developments in this field.

2) *Further studies*

Besides the Eurocontrol/FAA FCS, other studies and projects need to be reviewed to complete the picture addressed by NEWSKY, i.e. including the support of AAC and APC applications and studying in depth the satcom area to complement the FCI/FCS study. This is a comprehensive list of all studies and technologies reviewed for the project:

- Related to safety services: MCNA [9].
- Related to satellite communication solutions: ANASTASIA [10], MOWGLY [11], Inmarsat fleet, MTSAT, Iridium system, the IRIS ESA program, Connexion by Boeing, OnAir, AeroMobile, Row 44, Thuraya, AceS, S-UMTS and Mobile TV (DVB-SH).
- Related to a/g links for non-safety services: AirCell.
- Related to optical technologies: ATENNA [12], MINERVA, LOLA, Alphabus/Alphasat and Argos.
- High Altitude Platforms (HAPs) based technologies were also reviewed.

The decision of retaining the technologies reviewed or not for the NEWSKY categories definition is based on the conclusions of the studies themselves, the analysis of their interest for NEWSKY and on the regulatory constraints (see § III. C).

Among all technologies reviewed, B-VHF was not retained for the medium term as it was difficult to integrate in the overcrowded VHF (Very High Frequency) band. The VHF band will continue in the short/medium timescale to support analogue voice and VDL Mode 2. In the longer term, a new technology operating in the VHF band may be possible.
DVB-SH, GMR2 and S-UMTS are satellite technologies for satellite mobile applications that could be used to provide APC services. However their behavior in mobile aeronautical environment is not known and they are not retained either.

Finally, though optical technologies have very good properties for secure and high data rate communications, it is not recommended to integrate them in the NEWSKY network yet because the link is very sensitive to clouds and de-pointing, which makes them not suitable for all phases of flight with possibly some interruption on the optical link.

C. Regulatory constraints

In ITU (International Telecommunication Union), some frequency bands are allocated specifically for "safety and regularity of flights" communications. From the regulatory point of view, these bands are reserved for ATS services but in practice AOC services also use these bands. In general, non safety services (AAC and APC) are excluded from these bands.

Safety related communications can be provided through terrestrial links in AM(R)S (Aeronautical Mobile Route Spectrum) or satellite link in AMS(R)S (Aeronautical Mobile Satellite Route Spectrum). The main allocations for AM(R)S are in HF (High Frequency) and VHF, and for AMS(R)S in L-band and C-band, being L band the only one used nowadays with operational systems like Inmarsat or MTSAT. However, due to the limited spectrum in the L-band and coordination difficulties for newcomers, as well as the need for new services with more bandwidth needs, the trends for integration of Unmanned Aerial System and new communications needs (e.g. airport communications), these allocations or usage could evolve (C band for example has already been retained for future airport communications).

Non-safety related communications can use terrestrial bands allocated to Aeronautical Mobile Service (AMS) or satellite bands allocated in the Mobile Satellite Service (MSS) including Aeronautical Mobile Satellite Service (AMSS). These services could be provided via terrestrial or satellite links but are more generally considered by satellite. Different allocations are possible for satellite, including L band AMSS (used for example for Inmarsat Swift64 and Swiftbroadband) or Ku band in AMSS (used for example by Connexion by Boeing, or foreseen in MOWGLY). The main issues in the spectrum allocation of non-safety related communications are the possibility to have a unique allocation for a wide coverage and the interference risks, which are higher than in AM(R)S/AMS(R)S bands.

This important distinction in regulation between safety related and non-safety related, for which distinct spectrum allocations are made, constrains the use of the technologies and the categories definition in the next section.

IV. DATA LINK TECHNOLOGIES CHARACTERIZATION

The process followed for the definition of the data link technology characterization for integration in the NEWSKY network was the following:

- Review of possible technologies
- Definition of the technologies retained for NEWSKY
- Definition of the categories
- Characterization of the categories for use in NEWSKY

These steps are further explained hereafter.

A. Step 1: Review of possible technologies

Objective of this step was to list and review the possible technologies that could be used for aircraft communications for all types of services (ATS, AOC, AAC, APC). The work already done by other projects or groups was reused, in particular the conclusions for the suitability of these technologies for certain services, airspace, etc …
The list of projects and studies reviewed has been presented in detail in §III.B. Existing results, in particular link screening from FCI/FCS study, were taken into account, putting more effort on satellite data link technology review as there isn't a single solution retained.

B. Step 2: Definition of technologies retained for NEWSKY

The objective of this step was to keep, among all technologies, those that should be considered for integration in the NEWSKY system. As explained in §III.B, the objective was not to discard any technology (except if it had been already discarded by other studies, e.g. FCS) but rather to remove those that are not mature or characterized enough for aeronautical environment. The selected technologies are examples that could be integrated in the NEWSKY network, however the objective is to design a network that could be interfaced also with future technologies. That is why consideration was given to some higher level categories with representative performances rather than the technologies themselves.

Among all technologies considered, and after removing a few of them (see §III.B), the final list considered for our study is: 802.16eAV, LDL, AMACS, B-AMC, P-34, SDLS, DVB-S2/RCS mobile, Classic Aero, Iridium NEXT, Inmarsat Swiftbroadband (SBB), WCDMA, CDMA2000, Globalstar, GMR and SkyLink.

C. Step 3: Definition of the categories

To define some high level categories with common characteristics that can be used in the project, a detailed review of those technologies from step 2 was undertaken and characterization of each of them performed. Results are presented in Table II. For each data link technology we define:

- Which types of services it supports (ATS, AOC, AAC, APC). Green is used when the service appears to be suitable or has been proven in service. Yellow means service could be possible but would need confirmation. Red means it is not possible to support this service. Technologies are considered hereafter when they are green or yellow.
- For which type of link (see definition in section III) they can be used: airport surface, a/g, a/a or satellite.
- For which airspace type they could be used (Airport surface, airport zone, Terminal Maneuvering Area (TMA), En-Route (ENR), Oceanic Remote Polar (ORP)). We also introduced an Oceanic Remote (OR) class for the technologies not able to cover the poles (typically geostationary (GEO) satellites).

For deriving the table we assumed satellite links can be used in APT zone and TMA for AOC, and AAC/APC are allowed at APT surface when aircraft is at the gate.

TABLE II. REVIEW OF DATA LINK TECHNOLOGIES CAPABILITIES

Technology	ATS/ AOC	AAC/ APC	Link Type APT surf, a/g, a/a, sat	Airspace APT surf, APT zone, TMA, ENR, OR(P)
IEEE 802.16eAV			APT surf (preferred link)	APT surf
B-AMC			APT surf, a/g, a/a	APT surf, APT zone, TMA, ENR ORP (if in a/a mode)
P-34			a/g, a/a	APT zone, TMA, ENR
LDL			a/g, a/a	APT zone, TMA, ENR
AMACS			APT surf, a/g, a/a	APT surf, APT zone, TMA, ENR ORP (addressed broadcast) in a/a
WCDMA			a/g	ENR
CDMA2000			a/g	ENR
SDLS			sat	ENR, OR Could be: APT zone, TMA
Classic Aero			sat	ENR, OR Could be: APT surf, APT zone, TMA
Inmarsat SBB			sat	ENR, OR Could be: APT surf, APT zone, TMA
Iridium (NEXT)			sat	ENR, ORP Could be: APT surf, APT zone, TMA
Globalstar			sat	ENR, OR Could be: APT surf
GMR1			sat	ENR, OR Could be: APT surf, APT zone, TMA
SkyLink tech.			sat	ENR, OR Could be: APT surf
DVB-S2/RCS+M			sat	ENR, OR Could be: APT surf, APT zone, TMA
CBB			sat	ENR, OR Could be: APT surf

P-34 and LDL have a/a capability, but have not been specifically designed to meet COCR requirements.
802.16eAV is not selected for APC because operating in a band not allowed for APC. Also it is supposed that the use of APC/AAC communications is not allowed priori to take-off.

Based on the classification of technologies per services, links and airspace in Table II, and on a number of constraints defined hereafter, nine categories of technologies are defined.

The main constraints to define them are:

- the services that can be supported,
- the spectrum constraints between safety related and non-safety related,
- the different spectrum allocation between terrestrial and satellite,
- the vastly different characteristics between the different types of links, in particular terrestrial and satellite,
- The targeted rates (low, medium or high rates),
- the range for technology: short range (e.g. airport), medium range or large coverage (e.g. GEO coverage).

From the nine categories, two cover legacy systems (HF and VHF), they are not presented hereafter. The work concentrated on the other seven. Table III presents the seven categories and their association with the corresponding technologies.

TABLE III. DEFINITION OF THE CATEGORIES

	Technology Category	Example Technology
3	Short range, in airport surface, for safety related services	IEEE 802.16e
		B-AMC
		AMACS
4	Short/medium/long range, in high density airspace, for safety related services	B-AMC
		P-34
		LDL
		AMACS
5	Short/medium/long range, all airspaces, for non-safety related services	WCDMA
		CDMA2000
6	Satellite communications, in all airspace for safety related services	SDLS
		DVB-S2/RCS Mobile 'like'
		Classic Aero
		Inmarsat SBB
		Iridium (NEXT)
7	Satellite communications, in all airspaces, for non-safety related services	Classic Aero
		Inmarsat SBB
		Iridium (NEXT)
		Globalstar
		GMR 1
8	Satellite communications, in all airspaces, for safety and non-safety related services	Classic Aero
		Inmarsat SBB
		Iridium (NEXT)
9	Broadband satellite communications in all airspace for non-safety related services	SkyLink tech.
		DVB-S2/RCS+M
		CBB

D. Step 4: Characterization of the categories for NEWSKY

For each category we derived the main characteristics. The characteristics in terms of services are presented in Table IV. An important point is that some technologies support ATS/AOC only (categories 3, 4, 6), some technologies support AAC/APC only (categories 5, 7, 9), and some technologies support ATS/AOC and AAC/APC (category 8). Those supporting all services are set separately as they could lead to different network choices or optimizations.

Finally, the main characteristics in terms of performance per category were defined based on the performance of each technology. For this, all candidate technologies were reviewed following a number of criteria that we set, the main ones being: support of IP protocol, PER, modulation, coding and access scheme, coverage, availability, delay, latency, data rates, spectrum efficiency, support of mobility, support of QoS, number of CoS (Class of Service) and resistance to jamming. Detailed review can be found in [2]. Although each category covers some technologies similar in terms of service, technologies belonging to the same category have a wide set of technical performance.

Table V presents the main performances for each category. Characteristics that are common within a category are data rate range, coverage and access/waveform. All of them support IP protocol which was a minimum requirement for a technology to be retained. The categories have quite different performances in terms of PER and delay, reasons for which we did not retain a single value in the table.

TABLE IV. NEWSKY CATEGORIES SERVICE CHARACTERIZATION

Technology Category	**Example technology**	**Type of service**	**Link Type** APT surf, a/g, a/a, sat	**Airspace** APT surf, APT zone, TMA, ENR, OR(P)
Short range, in airport surface, for safety related services	IEEE 802.16e	ATS/AOC	APT surf	APT surf
	B-AMC			
	AMACS			
Short/medium/long range, in high density airspace, for safety related services	B-AMC	ATS/AOC	a/g Opt. 1: APT surf Opt. 2: a/a	APT zone, TMA, ENR Opt. 1: APT surf Opt. 2: ORP
	P-34			
	LDL			
	AMACS			
Short/medium/long range, in all airspaces, for non-safety related services	WCDMA	APC/AAC	a/g,	ENR
	CDMA2000			
Satellite communications, in all airspaces, for safety related services	SDLS	ATS/AOC	sat	ENR, OR Opt. 1: ORP Opt. 2: APT zone, TMA
	DVB-S2/RCS Mobile 'like'			
	Classic Aero			
	Inmarsat SBB			
	Iridium (NEXT)			
Satellite communications, in all airspaces, for non-safety related services	Classic Aero	APC/AAC	sat	ENR, OR Opt. 1: ORP Opt. 2: APT surf
	Inmarsat SBB			
	Iridium (NEXT)			
	Globalstar			
	GMR 1			
Satellite communications, in all airspaces, for safety and non-safety related services	Classic Aero	ATS/AOC APC/AAC	sat	ENR, OR Opt. 1: ORP Opt. 2: APT surf Opt. 3: APT zone, TMA
	Inmarsat SBB			
	Iridium (NEXT)			
Broadband satellite communications, in all airspaces for non-safety related services	SkyLink tech.	APC/AAC	sat	ENR, OR Opt. 1: ORP Opt. 2: APT surf
	DVB-S2/RCS+M			
	CBB			

TABLE V. NEWSKY CATEGORIES PERFORMANCE CHARACTERIZATION

	Technology Category	**Throughput (kbps)**	**Coverage (nm)**	**Access/ waveform**
3	Short range, in airport surface, for safety related services	High data rates FWD/RNT: 10 - 30 Mbps	1	OFDMA based
4	Short/medium/long range, in high density airspace, for safety related services	Low data rates FWD/RTN: 100 – 500 kbps	200	Not fixed
5	Short/medium/long range, in all airspaces, for non-safety related services	High data rates FWD: 3 – 300 Mbps RTN: 2 – 100 Mbps	200	CDMA, WCDMA or OFDM
6	Satellite communications, in all airspaces, for safety related services	Low data rates FWD/RTN: 5 – 500 kbps	From regional to global	CDMA or MF-TDMA
7	Satellite communications, in all airspaces, for non-safety related services	Low data rates FWD/RTN: 5 – 500 kbps	From regional to global	CDMA or TDM/MF-TDMA
8	Satellite communications, in all airspaces, for safety and non-safety related services	Low data rates FWD/RTN: 5 – 500 kbps	From regional to global	CDMA or TDM/MF-TDMA
9	Broadband satellite communications, in all airspaces for non-safety related services	High data rates FWD: 2 –100 Mbps RTN: 50 kbps–5 Mbps	From regional to global	CDMA or TDM/MF-TDMA

V. USE OF THE TECHNOLOGIES FOR NEWSKY

The main benefit for the rest of the project regarding this data link technology review was to obtain some high level categories with common characteristics representative of existing, currently developed, or future data link technologies. These categories are now considered in the rest of the project in different ways.

The characteristics in terms of airspace type, link type, coverage/range are considered for the mobility scenarios, mobility solutions and HO (Hand-Over) framework. Some characteristics such as delay or PER inside or between categories are also an important feature for HO decision.

For the studies related to QoS support and definition of the common interface with the technologies, it is important to note that the performances (delay, PER, bandwidth) of the different technologies will constrain the interface definition, congestion control, resource allocation or transport layer solutions.

For the security analysis an important point is on the spectrum limitations, and which services will use which technologies. Although security support is usually not specified for the technologies, the way to use them and the spectrum will highly impact the security.

VI. CONCLUSION

The analysis of the technologies allowed characterizing a large set of candidate technologies for aeronautical communications. In complement to some existing studies analyzing cockpit or cabin only, this work provides a wide screening of existing or possible future data link technologies both for safety (ATS/AOC) and non-safety (APC/AAC) related services and for a large variety of links (a/g, a/a, satellite). Based on these characteristics and on the limitations set by the regulatory framework, we defined nine data link technology categories. The example technologies considered supported the description of these categories in terms of service and performance characteristics. The different characteristics of the different categories are now used for the design of the NEWSKY network and transport layer.

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