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Project Acronym: ATENAA

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Advanced TEchnologies for Networking in Aeronautical Applications

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Project coordinator organisation name: Selex Communications

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1. PROJECT EXECUTION

1.1 THE ATENAA PROJECT

ATENAA (AST3-CT-2004-502843) is a STREP of the Aeronautic and Space sector. The project began its activities in July 2004 and came to a conclusion in August 2007. ATENAA is coordinated by Selex Communications (Italy) and involves 7 partners from 4 EU countries.

- Selex Communications – Project coordinator (Italy)
- Deutsches Zentrum für Luft und Raumfahrt – DLR (Germany)
- European Aeronautic Defense and Space Company - EADS Germany
- INSIS SpA (Italy)
- Technological Educational Institute of Piraeus (Greece)
- Thales Avionics (France)
- Thales Communications (France)

1.2 OBJECTIVES

Future applications for CNS/ATM, AOC and cabin services require significant enhancements in aeronautical communications; digital links will be the cornerstone of next generation systems aiming to increase safety, capacity, efficiency and comfort in civil aviation.

Within such context ATENAA project has focused on the possible role of civilian aircraft as nodes of an ad-hoc network, capable of multi-hop transmission over omnidirectional and broadband directional data links. The key technological components investigated are:

- Aeronautical Mobile Ad-Hoc Network protocols
- Ka-band phased array antennas
- Free-Space Optics for inter-aircraft communications
- Free-Space Optics for inside-cabin data distribution

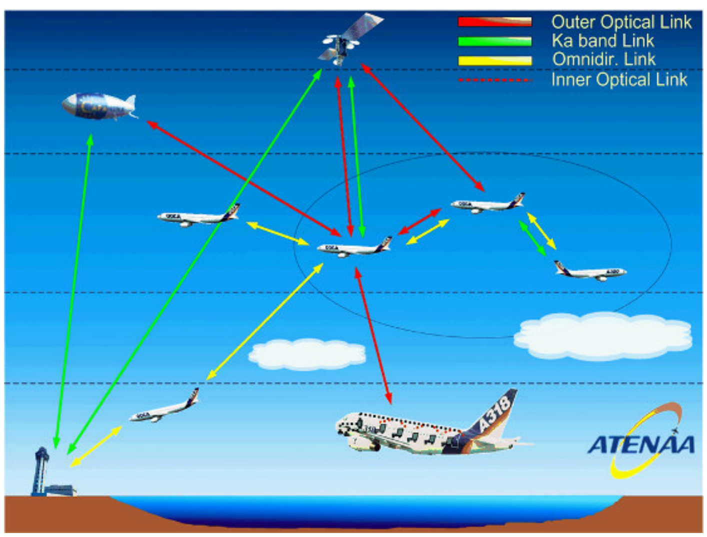


Figure 1: ATENAA network concept

The project objectives can be summarized as follows:

Obj-1 Identification of areas of application for Mobile Ad-hoc Networks in aeronautics;

Obj-2 Identification of MANET routing protocols suitable for aeronautical applications and relative assessment via simulations

Obj-3 Methodologies and technologies to establish and maintain Free Space Optics communication links between two platforms in relative motion, with identification of achievable performances;

Obj-4 Low profile and price competitive airborne Ka-band phased-array antenna design with steering capability, by adoption of promising technologies;

Obj-5 Feasibility study for a Cabin Free Space Optic system, which can deliver through diffused IR light, broadband communication to passengers;

Obj-6 Reduced scale validation platforms for testing the different technologies and assessing their capabilities.

Obj-7 Preparing a robust knowledge layer for subsequent related projects (e.g. MINERVAA)

1.3 WORK PERFORMED

The project performed research work in the following areas:

- Define the concept for a future networked avionic environment including both moving platforms (aircraft and satellites), ground infrastructures and the related users and communication systems
- Evaluate and develop the technologies needed for the networking and the security of the avionic network
- Assess a common set of requirements for the advanced technologies under investigation
- Identify Mobile Ad-hoc Network routing protocols suitable for aeronautical applications
- Assess HW technologies for Ka-band communication systems (with particular reference to TX and RX avionic phased array antenna realisation)
- Assess HW technologies for Optical communication systems for outside-aircraft data links realisation
- Assess HW technologies for Optical communication systems for inside-aircraft broadband bus implementation
- Test and validate such emerging technologies against their applicability in the realization of broadband communication systems for the avionic networked environment

- Dissemination of project results to a wider audience fostering the dialog with the research community and standardization/normative bodies, through journal publications, conferences, organization of a workshop and a constant updating of the project web page

Subsequent sections describe in more detail the work performed and the methodologies and approaches employed.

1.3.1 AERONAUTICAL MOBILE AD-HOC NETWORKS

Introducing Mobile Ad-hoc Networking capability in aeronautical applications, may provide the expected capacity, flexibility and availability required by future aeronautical communications network; high-speed data links are required for provision of broadband services to aircrafts and for their distribution within the aircraft itself; considering the aeronautical operational scenario, wide-band data links at medium-long range requires inherently (for link budget reasons) the usage of directional antennas: therefore it becomes necessary to integrate both omni-directional and directional data links in a MANET environment. This has been the main focus of the ATENAA project. Nevertheless the need for a reliable and robust MANET network based on omni-directional only antennas was identified both as a mid-term solution and as a platform that can be used for more time-critical ATN/CNS applications.

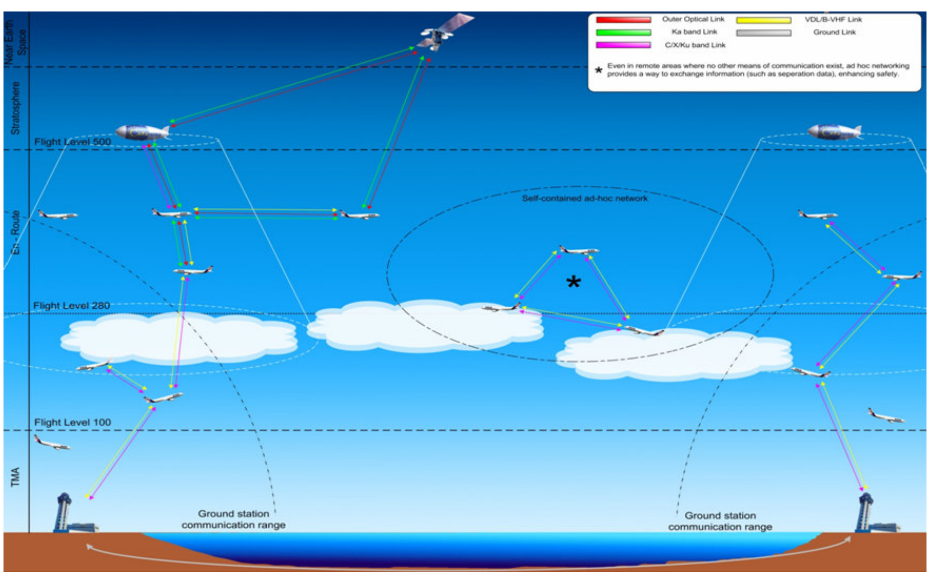


Figure 2: ATENAA scenarios

Developing and refining the concept of a unified future networked avionic environment including both moving platforms (aircraft, High Altitude Platforms and satellites), ground infrastructures and the related users and communication systems was the initial step in defining the MANET network. This allowed an assessment of a common set of requirements for the various platforms and allowed to evaluate the capabilities of each of them and their possible role in the network. This in turn was a stepping stone for the identification of the advanced protocol and datalink technologies that would be required to realize the aeronautical MANET.

The evaluation of existing MANET protocol technologies needed for the networking of the avionic network has been the next step. The literature review and subsequent comparison with the defined requirements led to identification of several gaps, which required the inclusion of additional functionality. In particular the ATENAA protocol stack includes a Data Link Selection sub-layer, which allows to logically separate the network layer from the different data-links layers installed onboard. A custom-tailored routing protocol (GeODV) has been designed, which combines the advantages of MANET reactive and proactive protocols, and takes advantage of the aircraft geographical position information expected to be exchanged among aeronautical nodes.

The developed protocols have been modeled into the OPNET network simulator and the simulation results have been used to provide proof of concept for proposed protocols.

Additional work was aimed at providing security extension to the above mentioned routing protocol. Initially the ATN security mechanism was analyzed and it's suitability to the MANET environment was determined. This was done in conjunction with an overview of MANET-specific security requirements. Then a comprehensive review of MANET secure routing and distributed key exchange algorithms was made to determine if and which protocols are suitable for use in the ATENAA network. Appropriate protocols were selected and integrated into the GeODV. Finally the performance of these protocols was briefly investigated theoretically.

1.3.2 KA-BAND PHASED ARRAY ANTENNAS

The system engineering phase, focused on Aircraft-Satellite links, provided as outcomes the main characteristics of the Ka-Band satellite communications considered to meet ATENAA network needs and the aircraft antenna requirements definition. The following features have been defined for the Ka-Band satellite links:

- Use of Ka-Band Satcom communications in "En Route" phase,
- Some degraded capability which might be helpful for the global network in "Climbing" or "Approach" phases.
- Forward targeted data rate per aircraft: 16 Mbit/s
- Return targeted data rate per aircraft: 1 Mbit/s

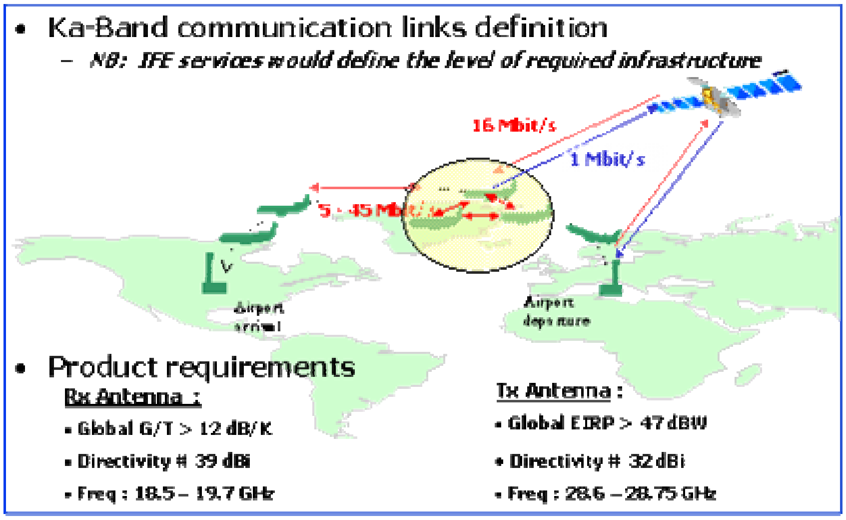
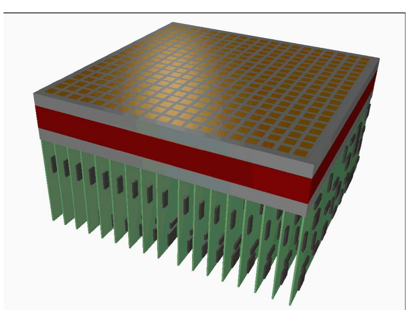


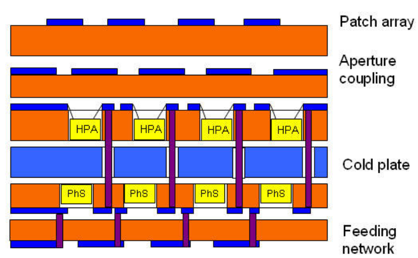
Figure 3 - Ka-Band Links definition and Antenna main requirements

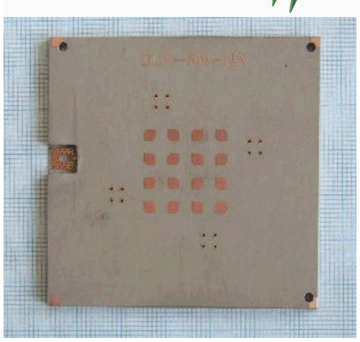
Technological studies relative to the aircraft antenna and main functions development as well as some critical aspect accurate analysis and simulation were carried out. Low cost phased array technology for the receive antenna as well as a thermal study for the transmit antenna have been addressed.

Two validation platforms were realized, integrated and characterized:

The Transmit Validation Platform is dedicated to high integration level and thermal dissipation technology assessment at small scale (4x4 active array) :







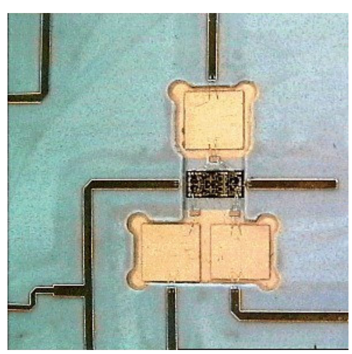


Figure 4 - Ka-Band Transmit Antenna concept and technology

The Receive Validation Platform is an 32x16 active array with steering capabilities and aims the future avionic product performances assessment as well as the flat multilayer structure validation from both technological and economical point of view.

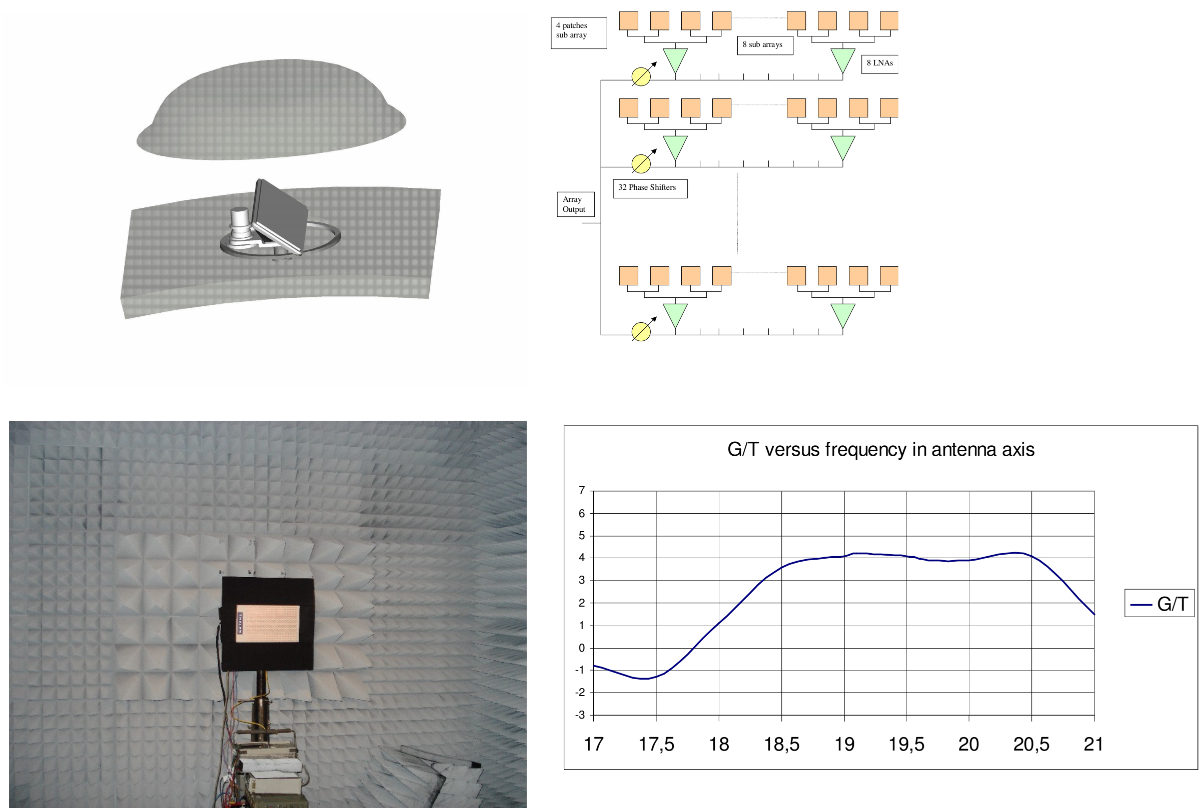
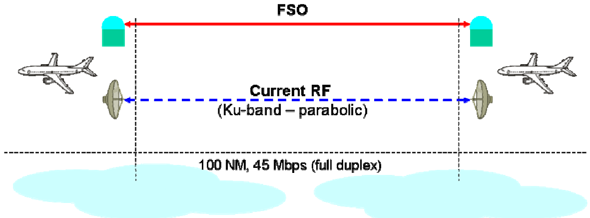


Figure 5 - Ka-Band Receive Antenna concept and measurements

Finally, the two Validation Platform measurements have been analysed, scaled up to the product size and recommendations regarding future product have been deduced.

1.3.3 OUTSIDE-AIRCRAFT OPTICAL LINKS

The laser free-space optical (FSO) communications technology has a major potential to outperform radio-frequency (RF) technology in terms of data rate and size, mass, and power consumption of the terminals – criteria that are of great importance for airborne use. The inherent advantage of laser communications is its much smaller transmitted beam-width, which concentrates a larger fraction of the transmit power onto the receiver aperture.



	RF	FSO
Radiated Power	100 W	0 5 W
Beam Div	15 deg (250 mrad)	~ mrad
Antenna/Telescope Diameter	30 cm	7 5 cm
Term. Weight (typ.)	50 kg	~20 kg (prototypes) ~10 kg (product)
Available EM Spectrum	hundreds MHz (ITU regulated)	some THz

Lower range, lower rate, faster switching, more crowded

Figure 6: comparison FSO vs RF

Demonstrations of this kind of mobile optical free-space communication have proven that the technology is ready to be used in aeronautical and space environment. Examples are inter-satellite links e.g. the OICETS (LEO) to ARTEMIS (GEO) link (data-rate: 50 Mbps), or terrestrial links like the FASOLT experiment (100 Mbps over 61 km) or the CAPANINA-STROPEX downlink (1250 Mbps over 60 km out of the stratosphere). Inter-aircraft links have been instead in the focus of the ATENAA project.

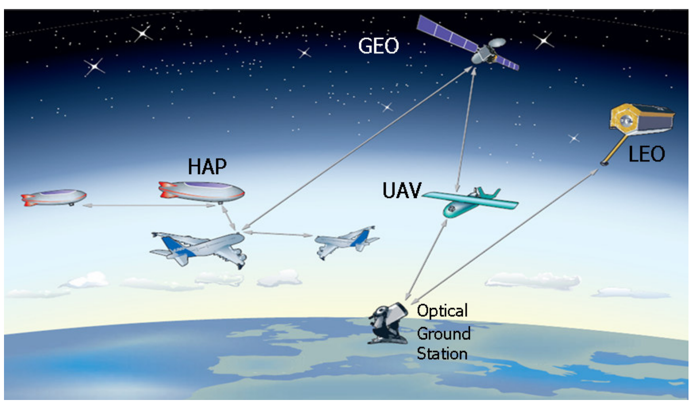


Figure 7: Aeronautical FSO possible links

The ATENAA research activity has identified and discussed possibilities, problems and design requirements for the exploitation of avionic free space optical link technology in the civil aviation environment. The different scenarios and requirements identified have been considered and evaluated in particular for what concerns A/C – A/C , HAP – A/C, Sat – A/C applications.

Since the optical channel is much different from the commonly known RF one, the channel behavior has been investigated. The atmospheric index of refraction behaves turbulently in most cases (IRT). Atmospheric disturbances on electromagnetic waves in the optical domain, such as intensity fluctuations and wave front distortions, reduce signal quality significantly. Theoretical investigations and channel measurements have been carried out.

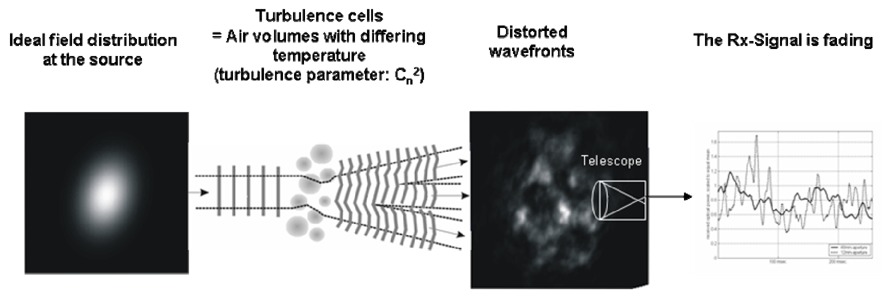


Figure 8: Index of Refraction Turbulence

Detailed link-budget calculations have been carried out considering free-space loss, atmospheric attenuation, receive telescope aperture, turbulence induced fading loss, receiver sensitivity, beam splitting for PAT and data receiver, miss-pointing, tracking errors, and further losses.

Main technology aspects used for free-space optical communication terminal design have been considered and analyzed, in particular with respect to modulation scheme, receive aperture size and beam divergence angle, system wavelengths, PAT-architectures, distances, IRT over link path, reliability and robustness as well as requirements from the network.

Basic concepts for FSO communication terminals have been analyzed considering the peculiar application environment, discussing and evaluating several design trade-offs for terminal design. Communication and beacon channel wavelengths and critical electro/optical components have been evaluated and proposed. Stabilization and tracking accuracies, together with pointing and acquisition time achievable figures have been provided considering affordable technologies in civil aeronautical environment.

A technological ground Validation Platform has been developed to allow concept and technology evaluation, in particular for what concerns acquisition time characteristics, communication robustness against obscurations, tracking and stabilization performances.

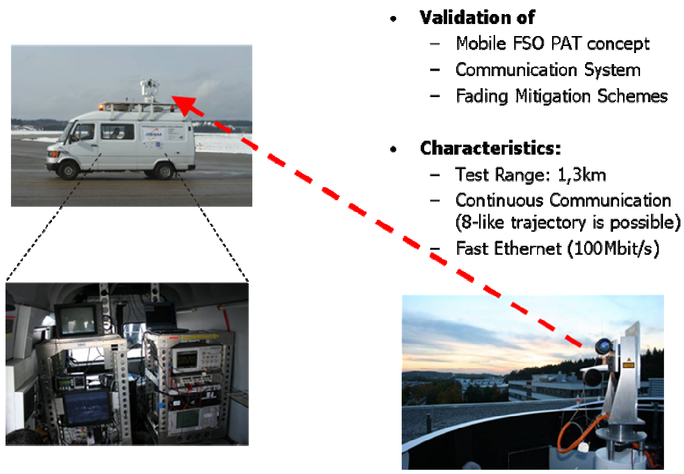


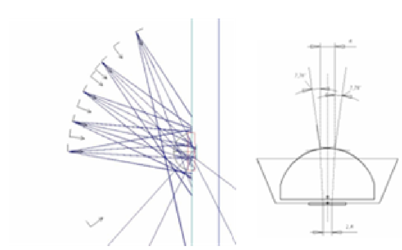
Figure 9: ATENAA OOL Ground Validation Platform

This included the realization of a Fixed and a Mobile Terminal, as well as an advanced transmission system exploiting a novel packet layer Forward Error Correction scheme to overcome some inherent restrictions related to optical links of this nature.

1.3.4 Inside-aircraft Optical Links

The requirements of inside-aircraft optical links have been analysed at system as well as component level. Data rate requirements have been taken from commercial application market, while component requirements have been identified respecting potential certification aspects (e.g. avoiding lasers, using LEDs, respecting eye safety etc.) and considering latest trends for e.g. high power LEDs.

Service	Data Rate	Direction
Video (movie / games)	0,5 - 1 Mb/s (MPEG4, DivX, H.264)	Downlink (and 9.6 kb/s for control uplink)
Audio (music)	128 kb/s (MP3)	Downlink (and 9.6 kb/s for control uplink)
Internet	64 – 128 kb/s	Downlink and uplink
Flight information services	64 kb/s	Downlink and uplink
Health monitoring	~9.6 kb/s	Only uplink
Phone	<64 kb/s	Downlink and uplink



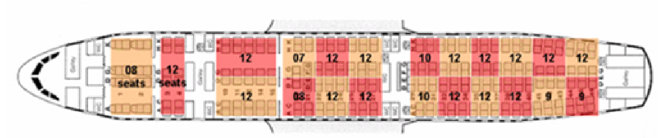


Figure 10: IOL Requirements definition

The data stream required is strongly asymmetric for downlink and bi-directional personal traffic, thus a combination of separate links is considered as optimum. Several scenarios of either using a combination of UDP and TCP/IP ethernet links or a combination of ethernet and CDMA links have been considered. Taking into account principal limitations from multipath interference, a cellular layout has been proposed using cells of limited bandwidth (10-25 Mbit/s), but forming an overall unlimited functional bandwidth space using the channel recycling strategy very easily applicable using optics. It was considered that the optical link will not be the sole wireless link in the aircraft cabin in future, but optical links will be co-existing with RF links (guaranteeing no interference), focus was taken where optical links show clear advantages (proprietary links, broadband links with no frequency regulations etc.). The diffuse IR link was chosen to provide easiest application (no directional requirements) and best link availability (low disturbance by shadowing).

Measurements of multipath limits have been carried out with the help of University of Oxford which has developed an equipment to measure multipath behaviour. This method was applied in the cabin mock-up to achieve results from realistic environment.

Hardware for modems and optical terminals has been developed. Validation of technological basis has been done by testing modems and terminals in a realistic environment (cabin mock-up), as realistic geometrical relations are very important for the investigated diffuse links. Principle tests have been carried out in lab environment, all final tests in the cabin mock-up.

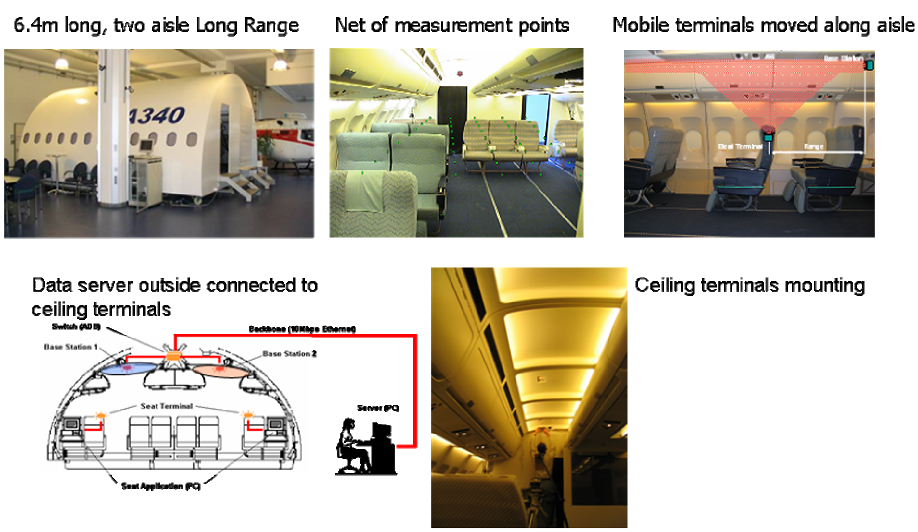


Figure 11: Validation of technological basis by tests in realistic environment

1.3.5 USER FEEDBACK

An ATENAA Advisory Group has been established by the consortium with the aim to receive recommendations about the possible future needs, required services and implementation strategies and promote the diffusion of ATENAA's results within the potential Users' community. The organisations that were part of the Advisory Group were Airbus Germany, Airone, Astrium, ENAV - Ente Nazionale Assistenza al Volo, IFALPA - International Federation Airline Pilot Association and IFATSEA - International Federation of Air Traffic Safety Electronics Association.

1.4 RESULTS ACHIEVED

The ATENAA project major findings can be summarized as follows:

- Aeronautical Mobile Ad-hoc Network protocols, despite the expected benefit which could provide to enhance capacity, flexibility and availability of current communications network, are still at an early maturity level
- These protocols could find earlier application when utilized in conjunction with next generation VDL-like A/A datalinks (2020+), for providing low data rate services (ATS/AOC) to aircrafts in Remote, Polar, Oceanic regions
- Aeronautical MANET networks utilizing directional datalinks, could find earlier application in specific scenarios such as oceanic corridors
- for wider application scenarios it is required substantial R&D activities before demonstrating feasibility of implementations and expected benefits
- Free Space Optics show that relatively stable Pt-To-Pt Connections are possible with current technology
- Optical links among mobile platforms over 200..400km / >100Mbit/s are feasible with relatively compact terminals, if adopting proposed advanced fading mitigation techniques

- Wireless cabin optical links feasibility has been demonstrated, and could find short term applications both for passenger services and cabin crew communications

- Future activities on IOL should include wireless cabin optical technology integration into real applications, and on miniaturization of optical terminals

- Targeted Ka-Band "a/c – satellite links" (Down 16 Mb/s ; Up 1Mb/s) are achievable by use of "Low profile 1D steering patch array antenna" concept which offers a cost effective solution

- The "Flat 2D Steering patch array antenna" technology concept maturity has been increased and may allow enhancing system flexibility at a longer term.

In subsequent sections are described in more detail results for each technology area addressed.

1.4.1 AERONAUTICAL MOBILE AD-HOC NETWORKS

The purpose of WP2000 was to investigate and evaluate the potential of Mobile Ad Hoc Networking in the future avionic environment.

The first step has been to identify the aeronautical communications environment characteristics, in terms of stakeholders, services, architectures and technologies. The need to have the aeronautical MANET as an add-on of currently defined ATN has been highlighted, as well as the benefit of utilizing an IP networking layer base.

Possible operational scenarios and related requirements have been identified considering existing and future applications and systems. Starting from this baseline specific requirements on ATENAA investigated technologies have been deemed.

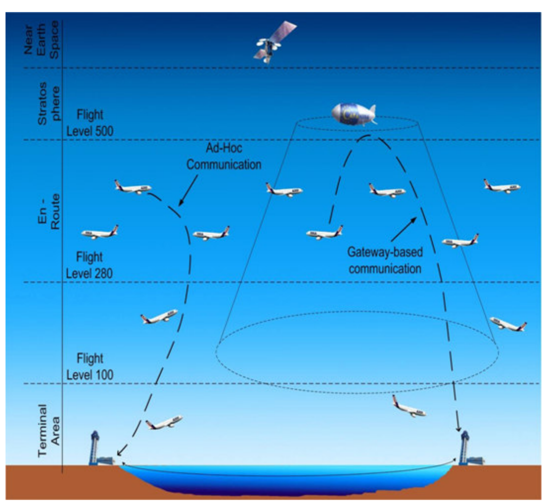


Figure 12: example of an aeronautical scenario

Within this context two different scenarios for MANET have been identified, with different levels of implementation difficulties and time schedule: a shorter term scenario where existing or under investigation omnidirectional datalinks are used on aircrafts, and a longer term scenario, where aircraft are foreseen equipped with wide-band and directional A/A datalinks.

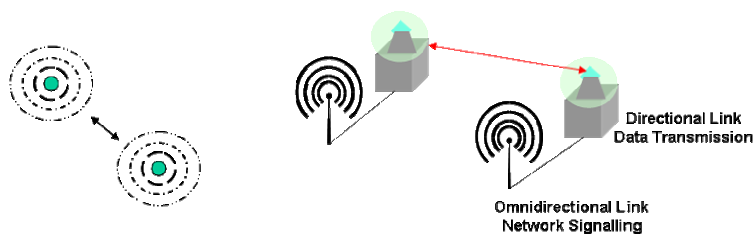


Figure 13: Omni-directional Antenna only equipped nodes (left); Directional Steered Antenna equipped nodes (right)

After an extensive review and analysis of current state-of-the-art MANET protocol literature, the above mentioned concepts were refined and included into the next level by developing specific node models, by defining a routing protocol for the ATENAA network (GeODV) and by defining an algorithm to manage multiple communication terminals onboard aircraft (DLSM).

The GeODV routing protocol uses a well-known MANET routing algorithm, AODV, as a basis and adds some critical ATENAA extensions. More specifically the new algorithm makes use of the geographical information that is available through the ADS-B application as a metric to choose the optimal routing path. Additionally a proactive route discovery capability was added, as a means to increase route availability to popular destinations (such as airports and/or HAPs). Finally protocol parameters were fine tuned in order to reduce the incurred protocol overhead.

The DLSM is a sublayer located between the Data Link and the Network layer, whose task is to select the appropriate terminal for data transmission. It's necessity stems from the fact that each directional terminal has a limited Field of Regard and that each data link type is expected to include multiple terminals so as to increase coverage. Responsibility of the DLSM is to determine which terminal is appropriate for data transmission to the destination node (taking into the account the above limitations) and to ensure that the required terminals on both sides have been aligned before transmission.

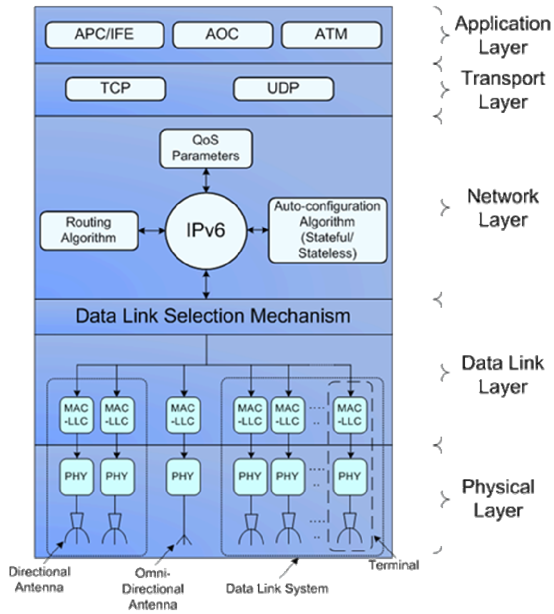


Figure 14: ATENAA protocol stack

A verification of the network concept and the newly defined protocols have been performed by means of a network simulation tool. A specific simulation environment based on a commercially available simulation tool (OPNET) has been developed, requiring extensive work to be adapted to the aeronautical environment.

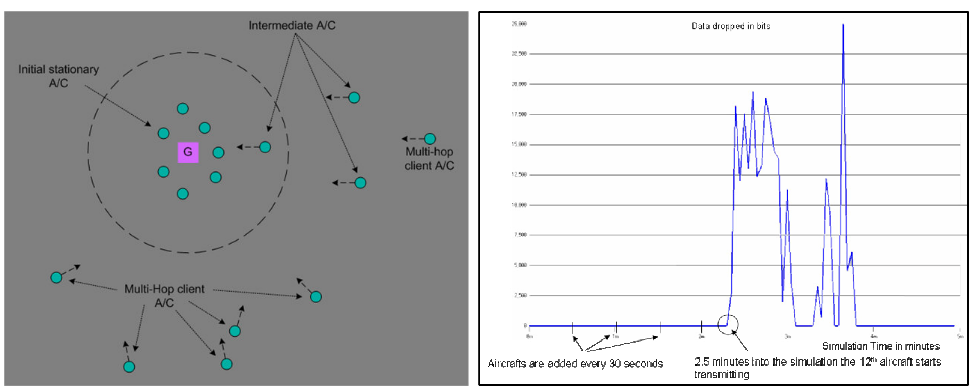


Figure 15: example of simulation scenario and OPNET simulation output

Preliminary simulations have been carried out considering specific applications and scenarios: the transmission of digitalized voice in terminal areas over multiple hops and for an increased number of A/C concurrently, graphical weather data over multiple hops and high bandwidth ad-hoc connectivity over oceanic scenario.

Simulations showed that it is possible to transmit critical CNS/ATM data over multiple hops for distances far greater that those currently possible and that it is possible to provide broadband connectivity to aircraft, as an alternative to current Satcom solution. Therefore with these results it has been gained further confidence in carrying on activities on the aeronautical MANETs.

Having considered the ATN Security requirements and developed mechanisms as a basis, critical aspects of Aeronautical MANETs and requirements for the Routing Layer have been identified. Figure below summarises main differences between the ATN and a MANET situation.

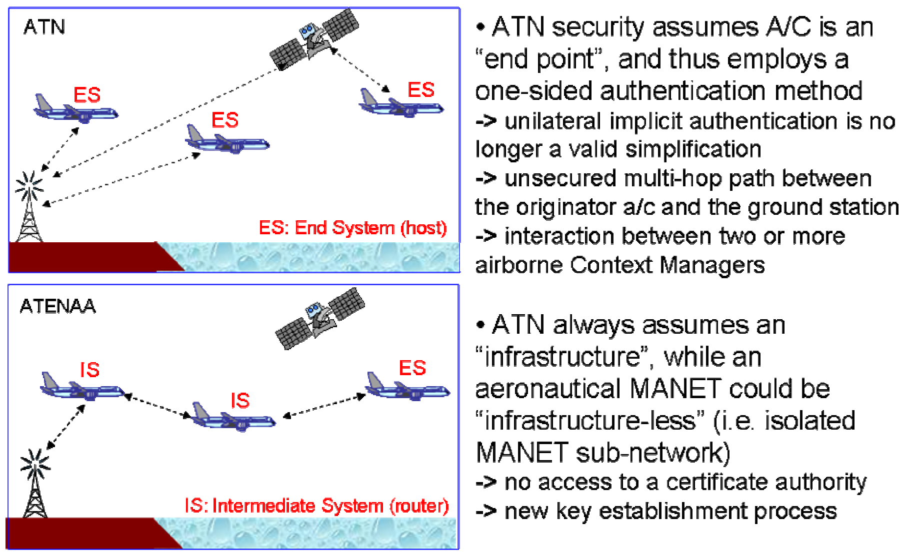


Figure 16: main security challenges w.r.t ATN

A review of the current literature has been used to identify suitable protocols for providing a secure routing mechanism. An adaptation of the Secure AODV protocol representing a Secure Extension of the GeODV has been proposed and evaluated in terms of threats which a MANET routing protocol has to deal with.

1.4.2 KA-BAND PHASED ARRAY ANTENNAS

The main results obtained on the Receive Validation Platform could be summarised as follows:

- Useful Bandwidth : 2 GHz from 18.5 to 20.5 GHz
- In axis Figure of Merit : G/T > 3.5 dB/K
- Figure of Merit over +/- 35° steering angle : G/T > 2.0 dB/K
- Steering capability +/- 40° to +/- 45°
- Azimuth Beam width : 4.8° +/- 0.2°
- Elevation Beam width : 3.5° +/- 0.2°
- Cross-polarisation < -30 dB

These results are very satisfying and coherent with expectation. This assesses the technological choices made along the project and allows to look to next step: higher integration, greater size , performances optimization.

From the above results and initial Link Budget established, the achievable data rate versus the antenna size has been calculated. In the following picture it is assumed the product may consist of a 32 lines x N columns phased array. Then , the antenna height when the active panel would be tilted to optimise the coverage would be close to 25 cm.

The x axis scale starts at a antenna length of 20 cm (16 columns) which is the size of the Validation Platform , up to 80 cm (64 columns).

The y axis depicts the achievable data rate with respect to the Budget Data Links established during the WP3100 for several scenarios :

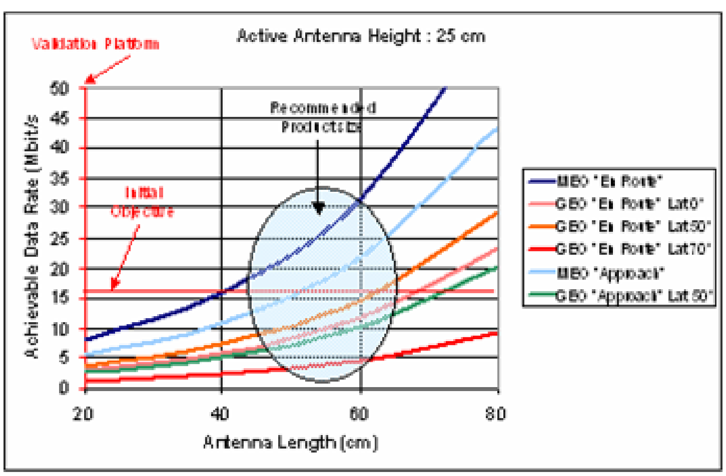


Figure 17: Ka-Band Rx-Antenna: Achievable Data Rate versus length for H#25cm

Regarding the transmit antenne validation platform, the thermal management concept used for the validation platform has been fully assessed and 32 x 24 array may fit the product 47dBW requirement.

The <u>use of an antenna of 50 cm long per 25 cm height</u> may provide a good trade off, offering:

- More than 8 Mbit/s with GEO satellite in "En Route" phase for latitudes up to 50° which may be already an interesting characteristic to initialise the market,
- More than 20 Mbit/s with MEO constellation once the satellites infrastructure would be deployed to enhance the system capability and coverage.

This last issue would be the product size recommendation for what concerns the receive antenna. Taking the option at first to place the transmit antenna beside the receive one, a 30 cm x 20cm may then be used to be able to implement the complete structure on the targeted 80 cm diameter area. Therefore, using the same kind of technology than receive antenna coupled to cold-plate solutions , for the Transmit antenna a 48x32 phased array may be considered.

<u>As main conclusions of the project it can be highlighted :</u>

- *Ka-Band Aircraft antennas for A/C – Satellite links*

– The studies and experimentations carried out have demonstrated the feasibility of the targeted performances.

– The Low profile 1D steering patch array antenna would offer low cost equipment easy to implement for mid term applications. It is well suited for both use of GEO satellite or MEO constellation.

– The Flat 2D steering patch array antenna is foreseen at longer term to meet the market price but would allow increasing system capability. It is well suited for MEO constellation use.

- *Ka-Band Aircraft antennas for A/C – A/C and A/C – HAP links*

– Preliminary analysis has been carried out and would be completed during MINERVAA project,

– Smaller and cheaper antennas are targeted for those links by integrating inside the same multilayer structure, both transmit and receive active antennas.

– Also calibration issues would be addressed in order to improve the pattern shape control and Beam Forming capabilities.

1.4.3 OUTSIDE-AIRCRAFT OPTICAL LINKS

FSO applications are less favorable for supporting ATC or ATM, due to limited availability due to link blockage (e.g. from clouds for altitudes lower than 10 km) and latencies due to link establishment procedures (between tens of milliseconds to several seconds depending on the link topology). The main use of FSO systems should be for connections from or into the terrestrial data networks via HAPs and satellites and for interconnection between A/C en-route which cruise above the cloud layer. Foreseen services include internet-download, VPN, IFE, TV/Radio-streaming, voice-phone, some non-time critical ATM data like weather maps or medical communications during emergencies en-route.

Figure 18: application of OOL links in oceanic corridors

The wavelengths within the atmospheric optical window around 1550 nm have been found to be preferable for atmospheric optical free space communications as in this window there is low atmospheric absorption and scattering and low levels of background light (important for IM/DD-Rx). Furthermore, commercial of the shelf (COTS) technology and well developed components are available from terrestrial fiber communication at this wavelength range. Additionally, eye-safety restrictions allow high emission power levels for wavelengths longer than 1300 nm.

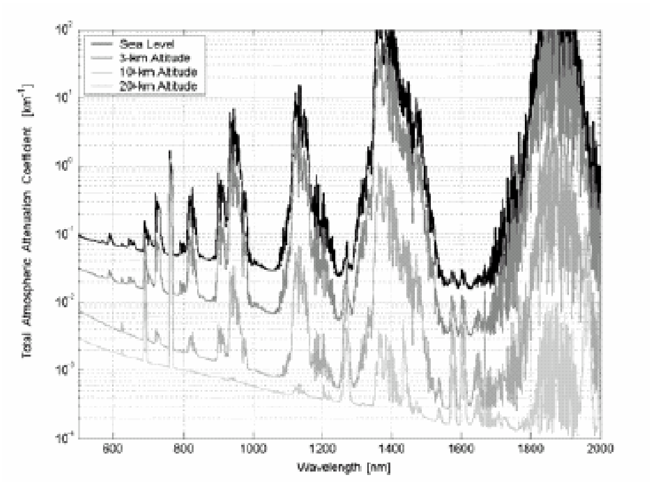


Figure 19: Altitude dependant coefficient of clear-sky atmospheric attenuation at different altitudes

For A/C and HAP connection maximum distances have been evaluated in the range of 200-400 km. For long links it is important to ensure that the lowest point of the link will not be too close to the ground. In general, link blockage probability due to clouds increases with lower altitudes. Without considering infrequent weather situations like thunder storms, thick clouds typically occur below 6 km altitude.

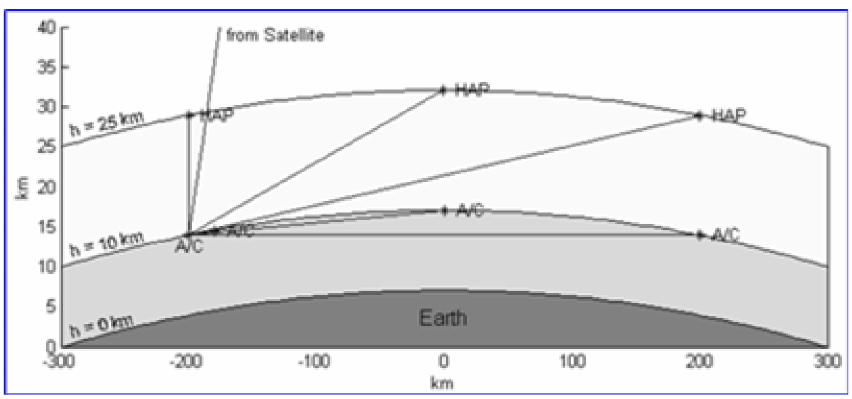


Figure 20: FSO link distances for links between A/C, HAP and satellites

An asynchronous - packet-oriented - datagram transmission has been found to be preferable to a synchronous transmission. Each packet has its own clock-synchronization preamble and thus synchronization is independent of preceding fades. If the synchronization gets lost, e.g. in a deep fade with very low received power, the synchronization will be locked again upon receiving the start of the next packet.

Two promising IRT fading mitigation techniques (Packet Level Forward Error Correction, Wavelength Diversity) have been proposed and evaluated. FEC on packet-level (PL-FEC) together with interleaving of the packets has been found a robust mechanism for total recovery of data packets in this kind of fading channel.

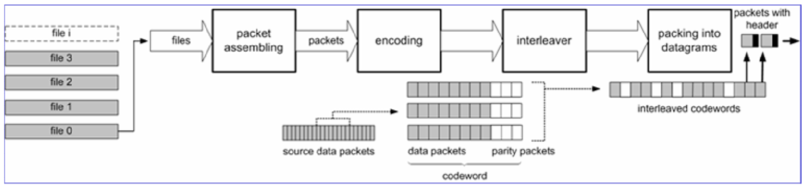


Figure 21: Async Transm. and Packet-Layer FEC

An important consideration for optical networks is the ability of optical communication terminals (OCT) to quickly locate one another and align their laser beams to initiate the acquisition sequence. A possible solution for the required inter-terminal communication has been proposed and evaluated based on existing Autonomous Dependent Surveillance-Broadcast (ADS-B) air traffic surveillance system.

Due to narrow beam divergence and limited switching capability, the number of active connections that can be supported by an airborne platform (A/C, SAT or HAP) is today limited to the number of terminals equipped on board. Furthermore the system to fit into a flexible network structure would demand each terminal to be able to inter-work with any other terminal to achieve an arbitrary connectivity. For a fully flexible and meshed connection topology, it would be then required advanced terminal architectures which need dedicated further investigations.

The development process was finalized with a test campaign that proved the main operability of the complete system. The acquisition time has proven to be mainly influenced by pointing process and acquisition/tracking algorithm's efficiency: problems related to re-acquisition after short time were recovered (see Figure 23), whilst long time link-blockings involved the system's pointing procedure, influenced by AHRS accuracy limitations. Regarding the Communication Channel, long-term Bit Error Rate (BER) measurements were made with a resulting value of 10-6; Packet Erasure rates between 2 and 20 percent were measured, but the code implemented for ATENAA Project allowed their complete recovery.

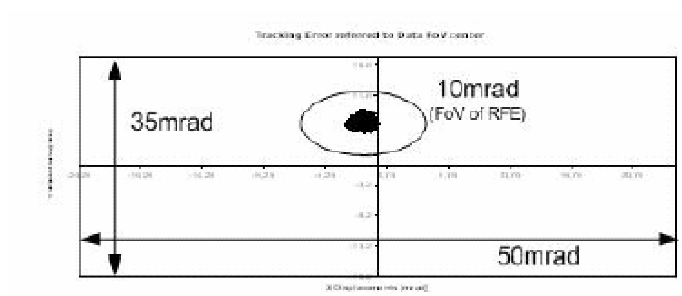


Figure 22: Tracking Error

The plot in Figure 22 shows a scatter diagram of the measured spot positions on the tracking CCD sensor during measurements, in which the transmitted signal is maintained within the receiver FoV, irrespective to platform movements and vibrations (the offset between the center of gravity and the center of the diagram can be justified by the misalignment between RFE and CCD).

The validation tests demonstrated for mobile Free Space Optical Communications that: 1) it is possible to point, acquire and track a laser beam for communication among moving platforms in relative motion; 2) packet-layer coding could be beneficially used to overcome fading problems due to atmospheric effects and L:OS blockings due to object or structure obscurations; 3) coded asynchronous packet based transmission outperforms synchronous transmission because of synchronization issues and of the ability to implement error correction.

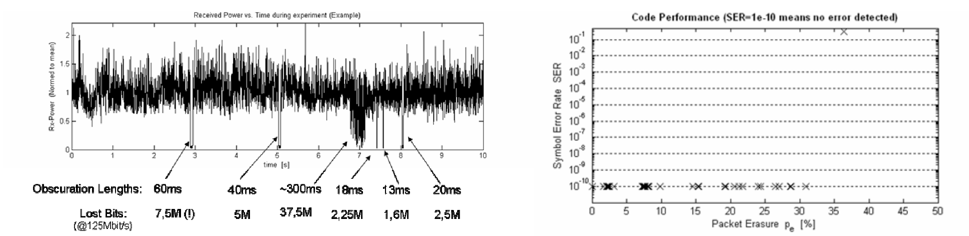


Figure 23: the power vector (left) shows the obscurations, and the complete errors recover by the Packet-Layer FEC Coding Scheme

1.4.4 INSIDE-AIRCRAFT OPTICAL LINKS

A novel concept of optical communication for aircraft inner cabin links using diffuse, non-line-of-sight optical links was tested, hardware was developed and tested in a cabin mock-up. The advantages of the concept (wireless connection, no EMI, no frequency band regulations, no interference with RF links et. al.) were found to be convincing also by the advisory group.

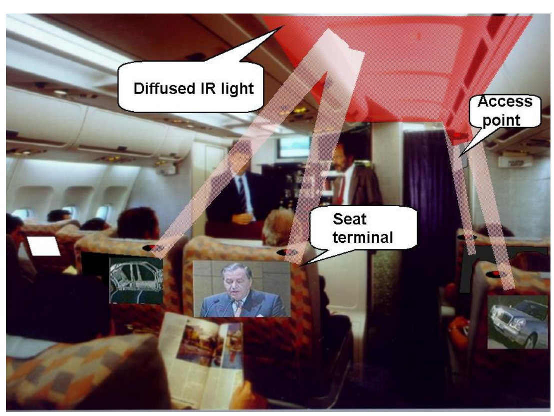


Figure 24: Cabin link scenario

The cellular concept was found to be feasible (optical filters are slightly to be improved). The multipath limit was found by measurement to be in the order of 30 Mbit/s per cell and length of about 4 m.

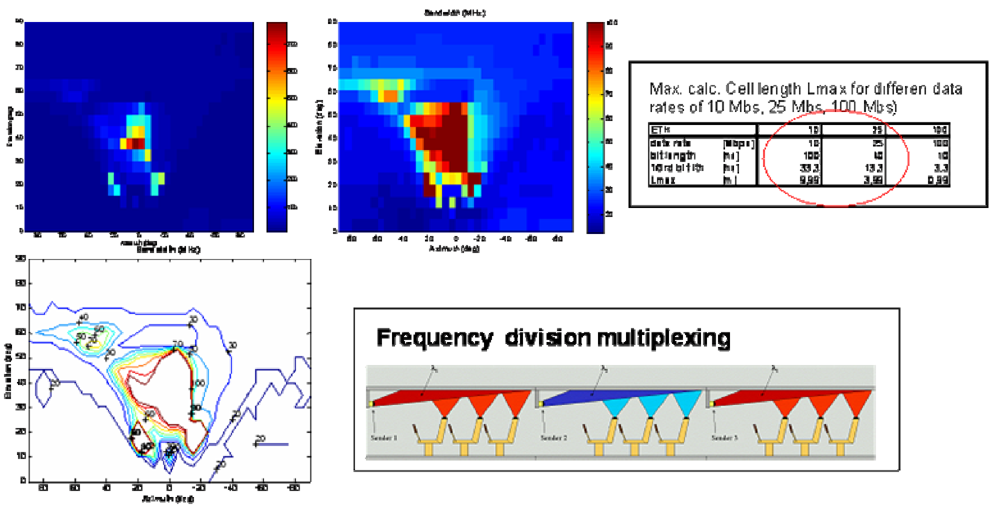


Figure 25: multipath interference limits

The total bandwidth availability within the aircraft is unlimited using recycled cellular layout. Several examples of aircraft cell layouts are given for different types of aircraft. For cross-interference free cellular operation, a set of different wavelengths have been identified and tested to guarantee isolation between adjacent cells, which are the basis for high bandwidth in the a/c cabin. Both Ethernet data interface and a CDMA data interface have been built. Ethernet is to be used mainly for broadband downstream (and possibly upstream at lower net usable bandwidth using TCP/IP), while CDMA shows clear advantages for multi-user low rate traffic.

Different scenarios were developed for ethernet and CDMA traffic. Several scenarios have been tested with different wavelengths, cellular/single cell layout, different transmission protocols (UDP, TCP/IP).

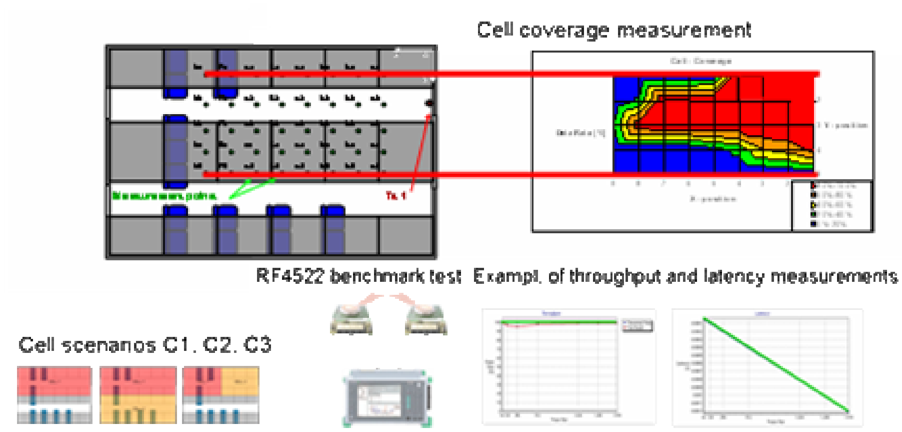


Figure 26: Scenarios tested in cabin mock-up

The potential of the inner optical link was clearly demonstrated and strong interests have been fed back by the user group: the application of the technology for wireless aircraft seat data communication will be further developed within the EC project MINERVAA; use for aircraft wireless crew communication will be tested within the EC project ECAB; for the application of next generation cabin management systems the technology will be further developed within the German national project NIKITA/KabTec.

Thus the technology developed within ATENAA has shown strong impact on further research and is a large step towards short-mid term application in next generation aircraft cabins.

1.5 CONTRIBUTION TO STANDARDS

Most of the technologies dealt within the ATENAA project are still at a premature stage for a product standardization process. As a first step (or even a pre-requisite) for beginning any standardization process consortium focused attention to bodies/associations/groups of interest.

One of the most relevant "non normative" body is the Air/Ground Communications Focus Group (Eurocontrol) dealing with Future Communication Study, pertaining to ATM/AOC communications, which has been added and analysed in relation with ATENAA concepts and technologies.

ATENAA partners have also presented various papers (see section 2.2.2) to: International Council of the Aeronautical Sciences (ICAS), International Society for Optical Engineering (SPIE), Communication Systems, Networks and Digital Signal Processing (CSNDSP), International Conference on Mobile Computing and Ubiquitous Networking (ICMU), European Air and Space Conference (CEAS), European Microwave Conference (EuMC), International Federation of Air Traffic Safety Electronic Associations (IFASTEA).

1.6 PROJECT OVERALL IMPACT

Aeronautical MANETs

Since the start of the ATENAA project, other parallel efforts have dealt with aeronautical MANET concept (e.g. FAA, DARPA, Salzburg Univ., Sidney Univ.), confirming a growing interest on the subject

Involved partners have considerably increased understanding of technical matter, of which they now own a robust knowledge base

The MANET subject developed within ATENAA has shown impact on further proposed research (COMNET, BACOSS)

The SESAR concept of “an aircraft as a node of a network” is likely to be implemented through the ATENAA MANET concept

Outside-aircraft Optical Link

Involved partners gained significant technical knowledge, in particular w.r.t. communication protocols, error correction techniques, and airborne optical terminal design

The technology base developed within ATENAA has strong impact on further research (MINERVAA)

Therefore the European industry started to fill the gap with respect to the US industry for what concerns FSO communication links for aeronautical mobile platforms

Ka-band phased array antennas

The capability of Ka-Band phased array technology to ensure the expected data rate for Satellite communications has been proven and solicited big interest of ADG members,

The technologies developed within ATENAA have strong impact for both Mid Term and Long Term applications:

- The Phase Shifters and Multilayer technologies developed would be extended to Tx/Rx antenna integration for inter-aircraft links -> This would give the opportunity to offer at mid term cost effective Ka-Band links to initiate this system deployment.
- HPA integration solutions within a 2D Flat array
- Liquid Cooling cold plate for thermal management -> Let foresee system capability improvement at longer term by using Flat 2D steering patch array antenna.

Inside-aircraft Optical Link

The potential of the Inner Optical Link was clearly demonstrated and strong interests have been fed back by the Advisory Group

The technology developed within ATENAA has shown strong impact on further research and is a large step towards short-mid term application in next generation aircraft cabins:

- the application of the technology for wireless aircraft seat data communication will be further developed within the EC project MINERVAA
- the application for aircraft wireless crew communication will be tested within the EC project ECAB
- the application for next generation cabin management systems will be further developed within the German national project NIKITA/KabTec

1.7 PROJECT WEBSITE

For more information about ATENAA please visit our website at: http://www.atenaa.org.

Figure 27: the ATENAA web site

2. DISSEMINATION AND USE

2.1 EXPLOITABLE KNOWLEDGE AND ITS USE

In the following table are presented exploitable results, i.e. knowledge having a potential for industrial or commercial application in research activities or for developing, creating or marketing a product or process or for creating or providing a service.

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable for commercial use**	**Patents or other IPR protection**	**Owner & Other Partner(s) involved**
New MANET routing protocol	Avionic Communication equipment	Civil Aeronautics	2020	None sought at this stage	TEI (Owner) SC
Novel algorithm for Multiple Datalink Management in MANET networks	Avionic Communication equipment	Civil Aeronautics	2020	None sought at this stage	TEI (Owner) SC
Architecture and components for a diffuse Wireless optical link for aircraft intra-cabin passenger commuications	In-Flight-Enterteinment communication systems	Civil Aeronautics Train Transportation Naval Transportation	2012	None sought at this stage	EAD (Owner) TEI
Packet-Layer Forward Error Correction Coding for Fading Mitigation	Free-Space Optic Communication Systems	Aeronautics Terrestrial FSO communcations		None sought at this stage	DLR (Owner)
Concepts for Fast Acquisition in Optical Communicatio	Aeronautical Free-Space Optic Communication Systems	Aeronautics		None sought at this stage	DLR (Owner) SC

Exploitable Knowledge (description)	Exploitable product(s) or measure(s)	Sector(s) of applicatio n	Timetable for commerci al use	Patents or other IPR protection	Owner & Other Partner(s) involved
n Systems					
Concept of active antenna integration for G/T optimisation	Mobile Ka-Band satellite Communicati on Systems	Aeronautic s – Terrestrial mobiles	2009	None sought at this stage	THC (Owner)
Low cost Ka-Band phase shifter	Ka-Band steering antennas	Aeronautic s – Terrestrial mobiles	2008	None sought at this stage	THC (Owner)

2.2 DISSEMINATION OF KNOWLEDGE

The project has adopted a high profile dissemination strategy, creating and managing a project Web Site (www.atenaa.org), producing two videos describing the ATENAA concept and the Optical Link Ground Validation tests, designing "ATENAA posters" and "ATENAA Flier" (used in Vienna Aerodays 2006, Le Bourget Airshow workshop and in other public events), participating in numerous International conferences.

Over the lifetime of the project the ATENAA partners have produced 9 among conference papers, journal papers, book chapter and 2 videos. All ATENAA dissemination material was made available to the public via the project's Web site.

Representatives of the conference organized panels, seminars, workshops, demonstrations and special presentations in a large number of important international events.

The project contributed significantly to the growing acceptance of the need for advanced networking in aeronautical telecommunications. The recognition of the role of the ATENAA partners as key players in this area is attested by numerous quotations and invitations to participate to key events in the European R&D scene.

It can be said that the ATENAA concept described in the previous pages has been introduced and substantiated by this project, and later on accepted and followed by others. Thus, we can conclude that this project has exerted a significant influence on the R&D community.

2.2.1 MAIN EVENTS

2nd International Conference on Information Quality and Technology Spetses (Greece) Presentation of project in July 2005. Given the fact that there were no clear results as yet, the presentation helped raise awareness to the audience consisting of Academia , Research community and Industry

33rd International Assembly of ATC Engineers IFATSEA

The project was presented at the October 2005 International Assembly of ATC Engineers in USA, within the Technical committee. A specific session was reserved for it. IFATSEA also is a member of the ADG panel.

ATM Maastricht, October 2005

An extensive article was published in the autumn 2005 issue of NAVAIRE, a technical magazine focused on aviation and Air Navigation Systems and Technologies, which was distributed at the ATM event at Maastricht (Oct 2005)

25th Congress of ICAS - International Council of the Aeronautical Sciences

The paper "Avionic Optical Links for High Data-rate Communications" was presented in September 2006 in Hamburg. It discusses the possibilities, problems and design requirements for avionic free-space optical links, that will provide over 100 Mbps for throughput.

5th International Communication Systems, Networks and Digital Signal Processing Symposium

The paper "Ad-hoc Routing Protocol for Aeronautical Mobile Ad-Hoc Networks" presents ARPAM a routing protocol for ad-hoc networks that has been adapted to work optimally within the defined architecture of the ATENAA network. The paper was presented in July 2006 in Patras, Greece.

The paper "Diffuse wirelss optical link for aircraft intra-cabin passenger communication" was presented at the same conference. The paper investigates implementation schemes for the creation of an in-cabin optical data network and provides measurements for signal transmission in a cabin environment.

3rd International Conference on Mobile Computing and Ubiquitous Networking

The paper "Multiple terminal management in Mobile Ad Hoc Networks" will be presented in October 2006 in London. The paper describes an algorithm to manage the multiple data-link and terminals that will be available in each ATENAA node.

Aerodays event in Vienna in June 2006

The project was presented by SC at the Aerodays event in 2006 in Vienna in front of a broad European and international audience from the entire aero-nautical community.

Le Bourget Airshow in June 2007

ATENAA project held its final workshop at the Paris Le Bourget AIrshow event, within the Finmeccanica stand. The workshop was aimed to update the aeronautical stakeholders on project results and to share with them the possible further advancements. The work-shop has been chaired by Theodore Kyritsis, CNS/ATM Senior Engineer, Vice-President of IFATSEA and NAVAIRE magazine editor, and presentations has been provided by key persons of SELEX Communications, Technological Educational Institute of Piraeus, Thales Communications, DLR and EADS. Apart personalities of relevant consortium organizations and members of the Euro-pean Commission, many other organizations and industries participated to the workshop, among these it is worth to mention Astrium, International Federa-tion Airline Pilot Association, Italian Flight Safety Association, Embraer, Alitalia, Sagem Defense & Securite

First CEAS European Air and Space Conference, 10-13 September 2007 in Berlin, Germany

DLR will present the paper titled "Broadband Communications for Aero-nautical Networks: The ATENAA Outer Optical Link Validation". The Council of the European Aerospace Societies (CEAS) comprises the eight aerospace societies from France, Germany, Great Britain, Italy, The Netherlands, Spain, Sweden and Switzerland with more than 25.000 individual members. Each society represents the leading national society in the field of aeronautics and astronautics. CEAS is a non profit organization based in Brussels, Belgium. The objective of CEAS is to promote the interests of the constituent societies on a European scale and European aerospace activities internationally.

European Microwave Conference (EuMC) 2007, 8-12 October 2007 in Munich, Germany

DLR will present the paper titled "Tx–Terminal Phased Array for Satellite Communication at Ka-band". The event focuses on the needs of engineers and researchers and seeks to serve both academia and industry. The week provides an opportunity for both communities to consider the latest trends and developments that are widening the field of application of microwaves.

IFATSEA 37th General Assembly, 18-23 November 2007, Rome, Italy

The International Federation of Air Traffic Safety Electronics Association, part of the ATENAA Advisory Group, will hold the annual General Assembly in Rome from 18 to 23 November. A presentation on the ATENAA project and its results will be given.

An article in the new issue of Navaire magazine, the IFATSEA official magazine, describing ATENAA project and its results will also be distributed.

2.2.2 PROJECT PUBLICATIONS

ATENAA Project presentation article in NAVAIRE, Official Journal of the International Federation of Air Traffic Safety Electronic Associations, Volume 24, winter 2005.

"Multiple Terminal Management in Mobile Ad-hoc Networks", K.Karras et al., 3rd ICMU 2006 London (11-13 October 2006)

"Ad-hoc Routing Protocol for Aeronautical Mobile Ad-hoc Networks", M. Iordanakis et al., Communication Systems, Networks and Digital Signal Processing - 5th International Symposium (19-21 July, 2006)

"Tx–Terminal Phased Array for Satellite Communication at Ka-band", L. Greda, A. Dreher., EuMC 2007

"Avionic Optical Links for High Data-rate Communications", H. Henniger et al., ICAS 2006

"Concepts for fast acquisition in optical communications systems", B. Wilkerson et al., Volume 6304 -- Free-Space Laser Communications VI Arun K. Majumdar, Christopher C. Davis, Editors,September 2006

"Wavelength diversity transmission for fading mitigation in the atmospheric optical communications channel", D. Giggenbach et al., Volume 6304 -- Free-Space Laser Communications VI Arun K. Majumdar, Christopher C. Davis, Editors,September 2006

"Packet-layer Forward Error Correction Coding for Fading Mitigation", H.Henniger, Volume 6304 -Free-Space Laser Communications VI Arun K. Majumdar, Christopher C. Davis, Editors,September 2006

"Broadband Communications for Aeronautical Networks: The ATENAA Outer Optical Link Validation", C. Fuchs, H.Henniger, B. Hepple, D. Giggenbach, M. Amirfeiz, M. Jentile, G. Di Nepi, G. Martini, F. Mazzi, CEAS 2007 Conference, September 2007

"Diffuse wireless optical link for aircraft intra-cabin passenger communication", C. Vassilopoulos et al., Communication Systems, Networks and Digital Signal Processing - 5th International Symposium (19-21 July, 2006)

ATENAA Project results and perspectives, NAVAIRE Official Journal of the International Federation of Air Traffic Safety Electronic Associations, autumn 2007.