

NEWSKY – BUILDING A SIMULATION ENVIRONMENT FOR AN INTEGRATED AERONAUTICAL NETWORK ARCHITECTURE

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Abstract

The expected evolution of aircraft traffic in the next decades and the foreseen lack of communication resources in the European airspace produce an increased need for efficient data communications. Up to now the general trend has been the implementation of new communication links and the optimization of existing resources. However, the main goal of NEWSKY is to integrate different communication technologies into a global IP based aeronautical inter-network. The NEWSKY approach tries to achieve improved communication capabilities through a network centric service oriented architecture. In order to evaluate this future aeronautical inter-network it is imperative to define new simulation environments. The primary intent of our work is to develop a simulation environment which is capable of evaluating algorithms designed for a heterogeneous mobile network environment, laying the main focus on the evaluation of mobility and connectivity management concepts. The secondary objective of this work is to integrate the effects of self separation algorithms, medium term conflict detection and resolution, and collision avoidance systems into the concept of the simulation environment. This paper introduces a set of fundamental concepts to the simulation of integrated aeronautical communications architectures. NEWSKY is funded by the European Commission within the 6th framework program.

Introduction

The expected evolution of aircraft traffic in the next decades and the foreseen lack of communication resources in the European airspace produce an increased need for efficient data communications. Currently, several European research initiatives with the goal to develop improved communication technologies for aeronautical communication are conducted. These initiatives comprise ground based, satellite based, aircraft to aircraft, and airport communication for different service classes, like ATC/ATM

communication, airline operational (AOC) and administrative communication (AAC), and aeronautical passenger communication (APC).

Up to now the general trend has been the implementation of new communication links and the optimization of existing resources. However, it has become apparent that none of the applied optimizations and newly introduced data links will be capable to satisfy the needs of all upcoming services on their own, which raises the need for the integration of different communication technologies into a large scale aeronautical inter-network. This situation has been identified at an international level by Eurocontrol and FAA. The task to integrate existing and future communication capabilities has been adopted in the context of the ICAO ANC work-plan and the “Future Communication Study” [1].

In the past there has already been an attempt to the integration of aeronautical communication technologies in the form of the Aeronautical Telecommunication Network based on ISO/OSI technology (ATN/OSI). Unfortunately ATN/OSI never came into the position to develop its full potential as the ISO/OSI network technology has never been adopted by the industry to a significant extent, keeping the number of equipment vendors low and the costs for ATN equipment high. ATN/OSI has therefore not been deployed widely. For this reason the tendency to move ATN to another technological basis emerged soon. Most importantly there have been serious considerations towards the implementation of ATN on top of the IP Protocol Suit (ATN/IPS). For the fixed (i.e. ground) communication infrastructure a decision for migration is about to be adopted at ICAO level, while the subject is still being studied for the mobile communication [2,3,4].

As it is understood today, the deployment of an IP based ATN/IPS network will offer many advantages over the current ISO/OSI based implementation. Apart from the superior technical approach huge numbers of commercial of the shelf

IP equipment have already been deployed at comparatively low cost. However, there are still many challenges and obstacles to overcome before ATN/IPS can serve as a full replacement for ATN/OSI¹, as IP has not yet been optimized for the stringent requirements of the aeronautical environment concerning mobility, security, reliability and integrity.

The main goal of NEWSKY is to integrate different communication technologies and different service classes into a global IP based inter-network [6,7]. It tries to achieve improved communication capabilities through the intelligent exploitation and integration of the varying characteristics of the underlying heterogeneous network. Thus the integrated NEWSKY network will have to comprise a multitude of different communication technologies. Its architecture will have to combine terrestrial and satellite links as well as mobile ad-hoc air-to-air networks. In order to evaluate this future aeronautical inter-network it is imperative to define new simulation environments. The development of such new and appropriate evaluation environments is one of the goals of the NEWSKY project (although the scope of the project goes far beyond that).

One of the greatest challenges in the evaluation of the NEWSKY concept is that its network centric architecture aims at a timeframe (beyond 2020) and at an operational context that is radically different from now. It is expected that the ongoing paradigm shift from voice to data communication will introduce fundamentally new approaches in the way air traffic is managed. Within Europe this is expected to materialize especially in the context of SESAR. For this reason it is not feasible to extrapolate existing simulation approaches or evaluation environments, which do not take these changes into account. Consequently new concepts are required.

The primary intent of our work is to develop a simulation environment which is capable of evaluating algorithms designed for the heterogeneous mobile network environment of NEWSKY, laying the main focus on the evaluation of mobility and connectivity management concepts. The mutual influence of aircraft and satellite

mobility, wireless and wired network topology and situation dependent data generation creates a highly dynamic simulation environment. This environment is especially challenging as none of the three components mentioned above is trivial. The secondary objective of this work is to integrate the effects of self separation algorithms, medium term conflict detection and resolution, and collision avoidance systems into the concept of the simulation environment. All of this has to be seen in strong correlation with EUROCONTROL and FAA its "Future Communication Infrastructure" documents.

The remainder of this paper is organized as follows: Section II gives a quick overview of the technical contour of the NEWSKY system, Section III provides a detailed description of the evaluation environment and Section IV presents conceptual directives.

NEWSKY Contour

This section gives a short overview of the current aeronautical communication architecture and how NEWSKY intends to reform it. Within the currently deployed communication infrastructure each Air Traffic Control/Air Operational Control/Air Administrative Control (ATC/AOC/AAC) application employs its own equipment and is operated in a separate frequency band. Thus each application is tightly coupled to its own physical layer characteristics. Increasing the number of applications inevitably introduces new hardware at the airborne site and raises additional demand for new frequency allocations.

Currently almost all tactical ATC communication is handled using DSB-AM radio systems. DSB-AM voice channels are allocated sector-wise and their deployment requires careful frequency planning. For data communications the ACARS system exists and is widely deployed. This system is based on 1970ies telex technology and often heavily customized to fit specific airline demands. The initial deployment of new digital data links has begun by the introduction of VHF-Digital Link Mode 2 (VDL2). Currently VDL2 is used for Controller Pilot Data Link Communication (CPDLC) based on ATN/OSI.

¹ For a work in progress see for instance [5].

Future Radio Systems (FRS) are currently investigated at an international level by Eurocontrol and FAA in the context of the ICAO ANC work-plan and the “Future Communication Study” [1] (For example technologies see for instance [8] or [9]). While the set of candidate technologies for long range communications is small, the number of available short-range data link technologies (e.g. for airport communication) is larger. Currently at least IEEE 802.11, IEEE 802.16 and several derived technologies are investigated.

In addition to ATC and AOC/AAC data communication, first attempts at the introduction of APC communication have been made. None of these technologies is integrated with the others.

It is the goal of the NEWSKY project to integrate these existing and future communication technologies into a global heterogeneous airborne inter-network. As the project has started only recently, no complete network architecture has been developed yet. However, the system contour is already defined:

- NEWSKY will integrate different existing and future communication technologies into a single global heterogeneous inter-network, thus NEWSKY will be a “system of systems”.
- NEWSKY will integrate different services - Air Traffic Services (ATS), Air Operational Control (AOC), Airline Administration Communications (AAC) and Airline Passenger Communication (APC) - into a network-centric service architecture on top of this inter-network.

From the technical point of view the scope of the project has been constrained to a subset of the possible network relations. Only aeronautical mobile communications between two end nodes involving at least one aircraft will be investigated in detail. This includes all types of (civil and military) airborne services (ATS, AOC, AAC and APC) that communicate with network nodes on the ground or other aircraft. To keep complexity at a manageable level all investigations stop at the access routers. Leaf networks (e.g. onboard LANs, etc.) and public networks are ignored. This is illustrated in Figure 1.

Evaluation Environment

The NEWSKY evaluation environment models a selected part of the future European sky. The challenges raised by modeling this complex and dynamic aeronautical environment have been decomposed into several mutually depended tasks. Each task has been implemented as a individual module: A mobility model, a topology model, and a data model. Each of these modules is quickly introduced below and will be discussed in detail later.

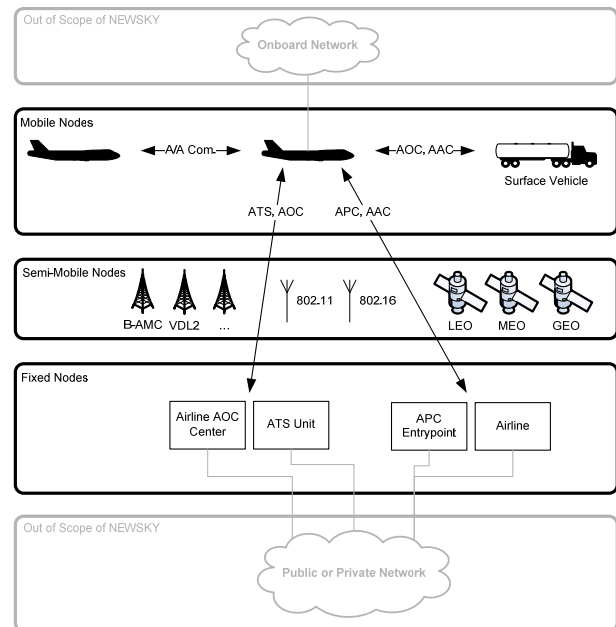


Figure 1. NEWSKY Technical Scope

The mobility module is the starting point for all evaluation scenarios. It provides a model for the physical properties of the aeronautical environment by defining the locations and movement patterns of all (semi-)mobile NEWSKY nodes (e.g. ground-stations, aircraft, Unmanned Aerial Vehicles (UAVs), satellites, etc.). It provides the position, heading and altitude of each single aircraft during the complete simulation time. This is crucial as these values provide the necessary information to derive the available data links (within the topology module) and influence the behavior of several communication applications (within the data module; e.g. collision avoidance and trajectory operations, etc.).

The topology model represents the underlying sub-network technologies by their link layer topology and their link layer characteristics. Given the technical scope of NEWSKY, both, nodes and communication cells, may move (e.g. satellite and aircraft ad-hoc communication), which makes the effective link layer network topology a (time dependent) function of the applied mobility model. Additionally, the data link characteristics (e.g. delay, throughput, etc.) may change according to the current node position, too.

The third module of the evaluation environment is the data generation model, where “data generation” includes network architecture (i.e. protocol stack) and position related data generation. Assuming that future aeronautical communication applications will be position related in many cases, there is a clear dependency on the link layer topology model and a possible impact on the mobility model (e.g. through 4D trajectory operations). Hence we can speak of “position related data generation”.

One particular property of the simulated environment is the mutual (actually circular) dependency of node mobility, network topology and data generation. These mutual dependencies between the modules are illustrated in Figure 2. The mobility model defines the movement of aircraft and communication cells. After each movement update the link level network topology and its characteristics are recalculated to reflect the new situation. Based upon this topology information (which includes the actual position of an aircraft) data communication is carried out. In some cases the data communication model may affect the mobility model as well, as some applications might trigger the correction of the aircraft’s flight path.

During the complete simulation process statistical data is gathered by an additional and independent statistics module.

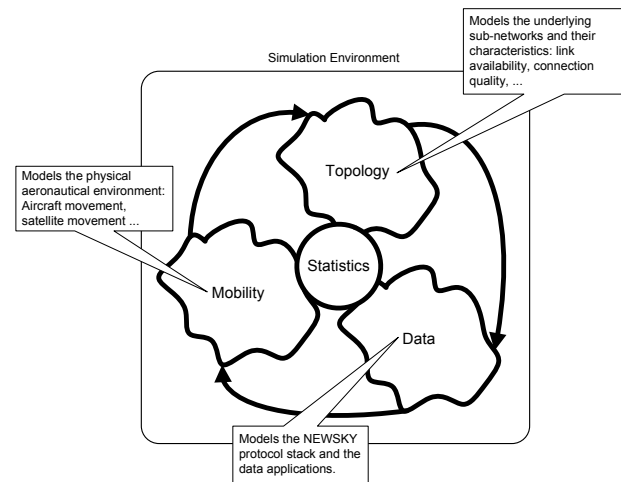


Figure 2. Mutual Dependency of Modules

Mobility Models

Due to the fact that almost all NEWSKY nodes are connected to the backbone using wireless or satellite links the NEWSKY network topology is heavily dependent on the current position of the nodes. That is: the mobility model has a major impact on the simulation outcome. The generated mobility patterns contain the initial position of mobile nodes and regular position updates (including heading and altitude). Dependent on the desired simulation granularity the intervals between consecutive position updates can range from less than a second to several seconds.

Three different types of nodes are distinguished: The first type includes network nodes that do not need any position information. Usually these nodes are connected to the network through fixed links that are unlikely to change during the simulation period (e.g. fibre trunks or microwave links between backbone routers). These types of nodes are completely characterized by their static attachment to the network. Typical examples of these “fixed nodes” are border routers of the public network or ATC centers. The second type of nodes comprises semi-mobile nodes. These terminals are not fully mobile, but follow very predictive movement patterns (including immobility). The importance of their position usually arises from their function as communication relays for other, fully mobile, nodes. Typical semi-mobile nodes include ground-stations (VDL2, B-AMC, etc.) and satellites. The third type of NEWSKY nodes

features the fully mobile nodes. Usually these nodes represent aircraft and UAVs. Different node types and their relation to the NEWSKY contour are illustrated in Figure 1.

For the computation of the mobility patterns several complementary mobility models are available: The first available mobility model is based upon the evaluation scenarios published by EURCONTROL and FAA in [10]. These scenarios consist of a set of test volumes, which define a volume of air-space, its aircraft population and communication demands. Three types of test volumes have been defined: Airport (APT), Terminal Maneuvering Area (TMA) and En-Route (ENR). The APT volume is further divided into the airport surface and the airport zone². APT test volumes are cylindrical. TMA and ENR test volumes are cuboids with different edge lengths (49 - 400 nautical miles) and heights (TMA Medium and Large, ENR Small, Medium, Large and Super Large). Each of them has an associated Peak-Instantaneous-Aircraft-Rate (PIAC; see Table 1). Within a test-volume aircraft are uniformly distributed in space and travel at uniformly distributed speeds. When an aircraft reaches the boundary of the test volumes it is reflected.

These test volumes may be combined to create large-scale evaluation scenarios. Figure 3 illustrates this with a simple example. An APT Zone, TMA Large and ENR Large test volume have been combined to model the vicinity of Brussels airport (BRU).

A second slightly more complex mobility model has been derived from the FCI scenarios in [10]. Within this environment the same number of A/C is not uniformly distributed within a cuboid or spherical test-volume, but travels between a set of navigation points. Each aircraft is assigned two randomly selected waypoints. Whenever it reaches one of them, the A/C returns to the other. This particular mobility pattern is intended for the modeling of traffic relations between major airports. Figure 4 illustrates this mobility model with a simplified scenario consisting of only four waypoints.

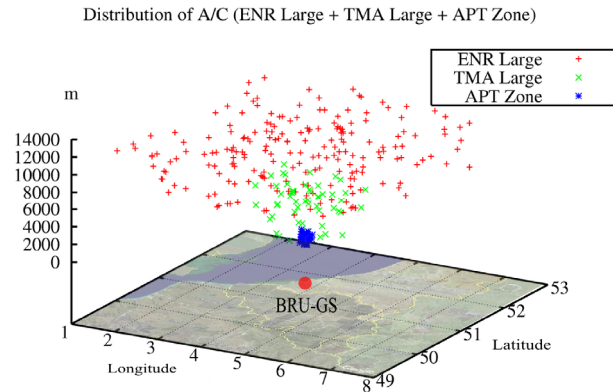


Figure 3. Distribution of A/C Positions in Three Combined Fci Evaluation Scenarios [10] (APT-Zone, TMA-Large and ENR-Large) over Brussels Airport

An alternative, even more realistic mobility model is provided by the NAVSIM³ tool, which has already been applied in a European research project (i.e. B-VHF [8]), in co-operation with industry (i.e. OnAir), and in studies with EUROCONTROL (i.e. VDL2 [11] and B-AMC [9]). The NAVSIM tool provides accurate simulations for air traffic situation in Europe based on EUROCONTROL CFMU data (around 27.000 flights on specific high/peak traffic reference days; see [11]).

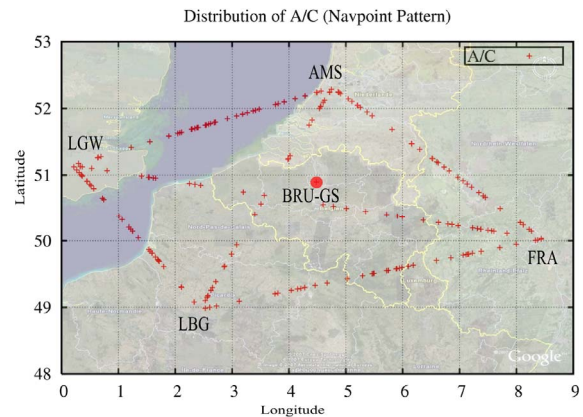


Figure 4. Distribution of an ENR Large Population of A/C (PIAC=204) Traveling Between Four Waypoints

² For an exhaustive description see [10].

³ The Air Traffic / ATC & CNS Simulation Tool "NAVSIM" has been developed by "Mobile Communications R&D GmbH, Salzburg" in co-operation with University of Salzburg.

Additionally, in order to support scenarios for air traffic situations in other areas, world-wide simulations based on scheduled airline, charter and freight flights can be carried out. These scenarios may include up to several thousand aircraft at the same time. The NAVSIM simulation respects the characteristic performance of each aircraft type. All flights are simulated from the aerodrome (gate⁴ or runway) of departure to the aerodrome (runway or gate³) of arrival, including SID, STAR, Holding, Approach and Final Approach. The flight movement patterns may be based on real flight plan data of scheduled flights, or on realistic extrapolations of statistical future scenarios.

Link Layer Topology

In the second module of the simulation tool chain the topology of the NEWSKY network is derived from the mobility patterns. Although the network topology changes constantly almost all topology transformations are confined to the wireless access networks. The static core of the network comprises the permanently installed backbone routes and the sites of ATC service providers. The borders of this unchanging region are defined by the semi-mobile nodes that represent ground-stations and similar points of access. The dynamic boundary of the network is populated by aircraft moving from ground-station to ground-station of different terrestrial links and changing between several (possibly moving) satellite beams. From the relative position of these nodes and the capabilities of the respective communications systems the applicable network topology is derived. Due to the fact that the link status may change with every movement the link level network topology has to be recomputed in regular intervals (usually after a fixed number of movement updates). Note that the effective network layer topology of the network (which depends on the routing protocols) is a part of the data module.

By the laws of physics the link level topology depends on the radio propagation properties of the underlying technology. Ground-stations have only finite range and aircraft may move between different cells. It is certainly not within the scope of the NEWSKY project to set up detailed large scale radio propagation models for all investigated aeronautical links, but some estimates have to be made. In order to get reasonable link-level topologies two simple propagation models have been defined. The first model approximates cell sizes of terrestrial links with circular ranges around the ground-station. The applied range may change according to the ground-station and is usually derived from nominal values. A simple refinement of this model is not to make a sharp cut at the cell perimeter, but to let the link quality degrade continuously. An analogue model is applied to (non-circular) satellite beams.

The second, slightly enhanced, model is only applicable to terrestrial communication systems. In addition to the nominal system range the geographical topology is taken into account. For each ground-station the area of radio visibility is computed on basis of the surrounding terrain. Please note that the resulting propagation model is still rather simplified, as it does not consider effects like refraction, reflection, diffraction and interference. Figure 5 displays an example link layer topology for a future L-band communication system computed with the enhanced radio propagation model. For illustrational purposes the number of A/C is very low. There are six ground-stations located near major airports (LGW, LGB, AMS, FRA, HAM, TXL). Ground-ground links are not displayed. A detailed description of the propagation model itself can be found in [12]. Other more advanced models may be introduced later if necessary.

⁴ In cases where digitalized airport data is available (gates, aircraft positions, taxiways, etc.).

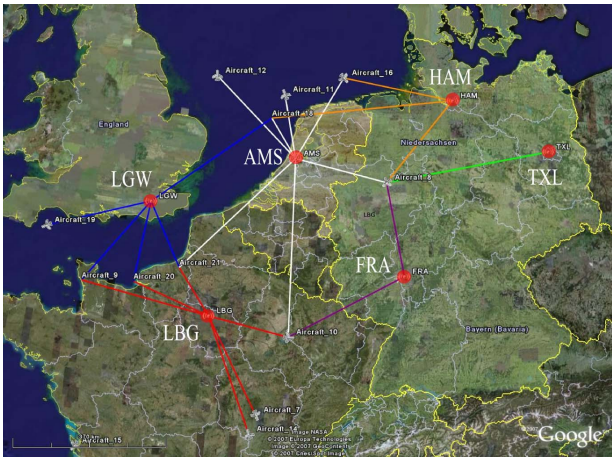


Figure 5. Effective Link Layer Topology for a Small Number of ENR Aircraft and Six Ground Stations for a Hypothetical L-Band Communication System Computed with the Enhanced Radio Propagation Model

Network Data Generation

The third module is the data generation module. Due to the fact that the data generation module has been designed to be modular itself, new data traffic sources, network protocol stacks and communication applications can be added easily to the simulation. If necessary, each service may invoke its own protocol stack, making the actual data generation process dependent only on the simulated services. Due to the modularity of the evaluation environment each mobility pattern and topology model (i.e. sub-network configuration) can thus be combined with different loading scenarios easily. See Figure 6.

Internally the data module is structured into two major sub-modules: Protocols and Services. Figure 7 illustrates the architecture of the protocol sub-module on the basis of the TCP/IP protocol stack.

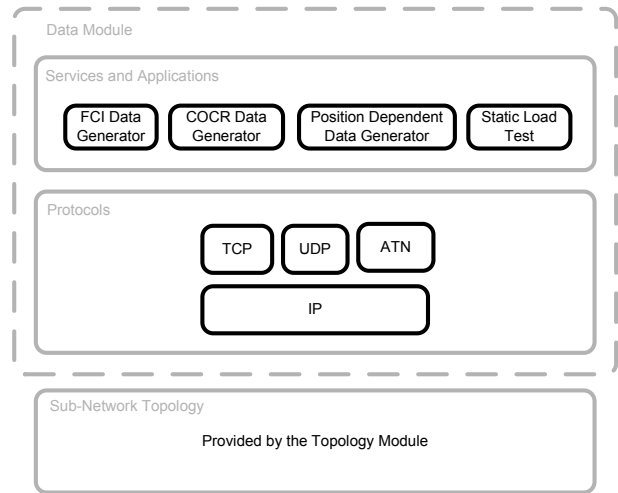


Figure 6. Structure of the Data Module

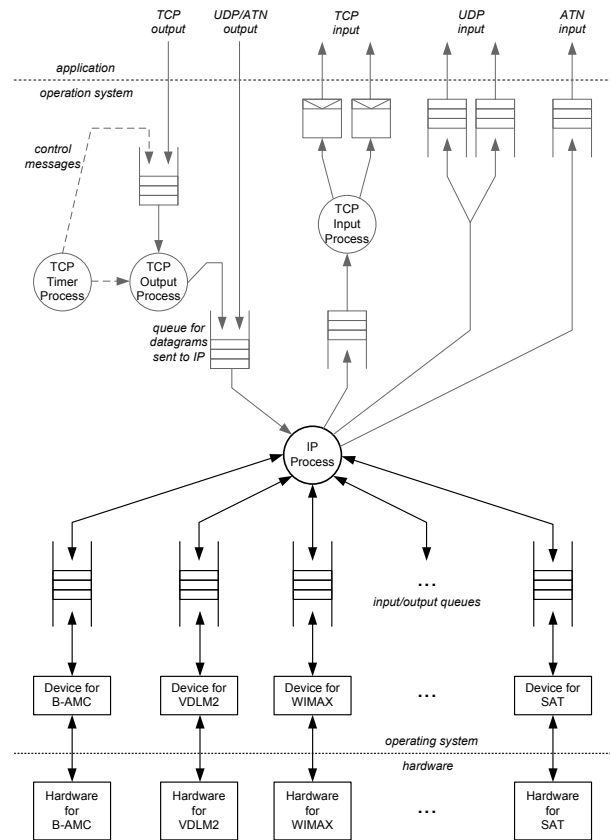


Figure 7. Implementation Architecture of the IP Based Protocol Stacks [13]

Starting at the top, applications put user data into the output queues of the underlying protocol. For now TCP and UDP are the only available transport protocols. ATN/OSI is assumed to be emulated over IP (i.e. ATN/OSI over IP). In the case of the connection oriented TCP protocol two separate threads exist. The first one is processing outgoing user data (building segments and sending them over IP), while the second one puts received TCP segments into the applications input queue. If the connectionless UDP protocol is used, datagrams generated by the application are directly inserted into the IP input queue. The central element of the protocol stack is the IP process, which distributes the encapsulated user data onto the appropriate sub-networks. The available sub-network connections are derived from the output of the topology model and the actual devices are simulated by queues with the computed link characteristics (delay, loss and throughput).

Note that this model has been derived from the common implementation methodology used in current operating systems. It is roughly based on the OSI/ISO reference model and the reference implementation published in [13].

As indicated earlier applications may be added to or removed from an aircraft's data generation process dependent on the current mobility and topology situation. This means that applications have to be added or removed dynamically during the simulation run and therefore it may be necessary to create additional protocol stacks according to the used applications. Consequently some aircraft (or ground-stations, as this applies to all types of nodes) will have to maintain multiple protocol stacks simultaneously.

A similar and equally important situation for NEWSKY is the case that a single node has multiple simultaneous attachments to the sub-networks: In this case the IP process is multi-homed. At the bottom of Figure 7 this is indicated by the presence of multiple "hardware devices". Although these are only simulated with queues, it is important to include them in the protocol structure to reproduce the effects of address resolution.

As it has already been stated above, the NEWSKY project is still in an early stage and protocol details have not yet been specified. To indicate this, the protocol entities above IP have

been shaded gray in Figure 7. Currently they should be considered as candidate solutions only. However, the abstraction and structure of the application, transport, and network layer in the data generation module will remain the same even if some protocols should change.

The second sub-module of the data generation module contains the simulations of aeronautical applications and services. See Figure 6. The following four data sources have been defined so far:

- Data generation according to FCI scenarios [10].
- Data generation according to COCR [1].
- Position dependent data generation.
- Static load tests (network performance measurement).

In the first approach, the network load is based on the FCI scenarios published in [10]. Three example scenarios⁵ are displayed in Table 1. Due to the fact that the traffic capacity requirements do not include information on the proportion of the various service categories of the total data traffic, the different service classes can not be distinguished by the simulation.

Table 1. Example Scenarios from [10]

Scenario	PIAC	UL	DL
ENR Large	204 A/C	300 kbps	40 kbps
TMA Large	53 A/C	30 kbps	30 kbps
APT Zone	26 A/C	3 kbps	15 kbps

As the FCI scenarios provide rather static mobility and communication scenarios (the number of A/C and the amount of data traffic per sector is constant) interpolations for larger (or smaller) volumes of air-space may be needed. Algorithms for this have been provided in the last draft version of the document [10], but did not make it into the final version. A particularly positive aspect of the FCI scenarios is that they are comparatively simple to implement and easily combined.

⁵ The displayed three scenarios assume combined ATS and AOC data traffic including A-EXEC, except for APT Zone (where A-EXEC is not applicable).

In the second approach, the complexity of the simulation rises to reflect a more detailed picture of the behavior of aeronautical communication of current and foreseen applications. The according traffic patterns have been captured in [1]. This approach may enable a high degree of maintainability as new applications may be added quickly to (or removed from) the simulation environment. In this approach data generation can be controlled in a very fine grained way as applications are enabled and disabled according to the flight phase of the aircraft. This has the additional advantage that applications supporting user preferred trajectories (including airborne separation assistance systems (ASAS)) can be added later. The only disadvantage of this approach is the huge number of identified data applications.

The third approach models position related aeronautical applications like ADS-B and 4-D trajectory operations. In this case the generation of user data is generally dependent on the current aircraft position or flight phase and may, in some cases, influence the future A/C position, too (e.g. ASAS). In addition to the absolute position, the relative position of the aircraft with respect to other nodes in its vicinity (e.g. Airborne Collision Avoidance System; ACAS) can trigger data packets as well.

The last approach is not related to current or future aeronautical applications at all. The network is only evaluated under varying levels of static load. The advantage of this simple approach lays in its independence from the extrapolated evaluation scenarios and the generality of the produced results.

Due to the modularity of the simulation concept all these approaches (and possible future ones) can be applied to any mobility and topology model. This offers the opportunity to evaluate the suitability, efficiency and robustness of the NEWSKY architecture in the aeronautical environment at different levels of granularity.

Set of Directives

Directive I – Modularity

Currently there are several efforts to the extrapolation of today's air-space situation to the time frame beyond the year 2020, the most

prominent of which are [10] and [1]. Unfortunately the aeronautical environment is a highly dynamic one, which makes predictions difficult and subject to frequent adaptations. Even well known studies like [10] and [1] had to be amended lately. It is the authors' opinion that this situation is unlikely to change in the near future, if the different scenarios will converge at all. Consequently one has to live with different, probably incompatible, evaluation scenarios and performance requirements.

In order to be able to adapt to changing scenarios and requirements the methodology has to be modular. Respecting the various assessments of air traffic growth and communication requirements, different implementations of some modules are necessary. Changes in single modules (mobility, topology, or data) should not affect the implementation of others but should change the behavior of the overall simulation due to their mutual dependencies.

Directive II – Simulation Builder

In order to keep the complexity of the NEWSKY simulation environment at a manageable level a separate instance has to coordinate the creation of objects. This simulation builder should be able to create any evaluation scenario out of the described methodologies.

Additionally, the simulation builder should rely on a centralized parameter set. This set should be preconfigured with fail safe default values and adaptable by command line input parameters (configuration files) and/or graphical user interfaces.

Directive III – Data Collector

It is necessary to derive the set of key performance values from the technical requirements and to devise a method to compute them efficiently from the observable properties of the system. Tracing every known simulated value in a log file is seldom an option, as this approach commonly leads to intractably large data collections. It is the task of the statistics module to accomplish this feature by the efficient and timely processing of the output of the other modules.

Directive IV – Model communication

In the context of the simulation architecture presented in this document this issue has been alleviated to some extent by the introduction of modularization. The different models are connected either by the use of XML trace files (for static testing of single modules) or by the direct exchange of XML elements over the network. This fosters the application of different development paradigms in different modules, as, in the authors' point of view, the key issue is not efficiency in terms of computation time but modularity, comprehensibility, scalability and adaptability.

Directive V – Comprehensibility

In order to develop confidence into the simulation results the implementation of the evaluation environment has to be comprehensible and correct. Naturally these two points account for each other. Correctness can only be verified in a comprehensible implementation, while a comprehensible implementation is more likely to be correct. Complex systems such as NEWSKY have to be described at a high level to remain traceable by humans; consequently their evaluation also tends to be implemented in high level languages, which fosters the confidence into the correctness of the evaluation.

Conclusion

The work presented in this article introduced some architectural concepts leading to a set of directives on the implementation of the heterogeneous NEWSKY evaluation environment.

A modular system has been designed which integrates a topology model, a mobility model, and a data model. The mobility model provides input parameters for the position of each single aircraft during the simulated time. The topology model incorporates all available sub-networks like satellite, terrestrial, air to air, or airport communications to derive effective link layer topologies. The data model provides the traffic load for the network. This load may be generated according to several static evaluation scenarios or dynamically as position related data. Special attention has been given to the feedback mechanism of the data model towards the mobility model, as

this is of vital importance for simulation of position related applications. This class of applications offers an especially interesting perspective with regard to the enabling capabilities of the network centric approach of NEWSKY (e.g. usage of 4D trajectory, etc.).

Considerable parts of the different modules (and different versions of single modules) have already been implemented and existing software (NAVSIM) has been used to provide input to the mobility model. First versions of the evaluation environment have already been used for performance evaluations in another context [9] with very good results.

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