NEWSKY – NOVEL SIMULATION CONCEPTS FOR FUTURE AIR TRAFFIC

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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. The main goal of NEWSKY is to integrate different communication technologies and different application classes into a global heterogeneous airborne network. The NEWSKY approach tries to achieve improved communication capabilities through a network centric service oriented architecture. In order to design and evaluate future aeronautical communication networks it is imperative to define new simulation environments which take the expected ATM paradigm shift from predominance of voice to data communications into account. The mutual dependency of mobility, topology and position related data generation create a challenging simulation environment. This is especially demanding as all of the three mentioned components are non-trivial. This document 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.

1. 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. These new services will have demanding requirements on capacity, availability and delay. Up to now the general trend has been towards 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 its 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 and 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" [2].

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 the ATN to another technological basis emerged soon. Most importantly there have been serious tendencies 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 [3,4,6].

As it is understood now 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 COTS IP equipment have already been deployed at comparatively low cost. However, there are still many challenges and obstacles to overcome before IP can serve as a full replacement for ATN/OSI[1], 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 the NEWSKY project is to integrate different communication technologies and various application classes into a global heterogeneous airborne network [5,8]. The NEWSKY approach aims to achieve improved communication capabilities through the use of IP based technology where possible and to extend existing technology where necessary. The integrated NEWSKY internetwork will eventually comprise a multitude of different communication technologies; its architecture will combine terrestrial and satellite links as well as mobile ad-hoc air-to-air networks.

The primary intent of the work presented in this document has been to define concepts for a simulation environment which is capable of evaluating the algorithms used in or designed for the heterogeneous mobile network environment of NEWSKY. 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 is trivial. The main focus of our evaluation approach as presented here lies on the evaluation of aeronautical network mobility and topology management. The secondary objective is to integrate the effects of the Single European Sky (SES) into the movement patterns of the simulated air traffic. In order to accomplish these objectives a modular system has been designed, integrating different mobility, topology and data models.

The second section of this document gives an overview of the intended scope and architecture of the NEWSKY system. The third section discusses the challenges encountered in large scale aeronautical simulations as they are needed for the evaluation of the NEWSKY network architecture. A set of simulation concepts are introduced to

[1] For a work in progress see for instance [7].

tackle the mutual dependencies specific to the simulated environment. Finally an outlook towards open issues and topics of future work is given.

2. NEWSKY CONTOUR

In the aeronautical communication architecture as it is deployed today each Air Traffic Control/Air Operational Control (ATC/AOC) application employs its own equipment 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.

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. The operation of voice communications is completely manual. The pilot has to select the appropriate frequency and perform any handovers (between sectors) on his own. 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. In addition to ATC/AOC data communication first attempts at the introduction of APC communication have been made (e.g. Connexion by Boeing). None of these technologies is integrated with the others.

2.1. Intended NEWSKY Architecture

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 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.
– 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. The leaf networks (e.g. onboard LANs, etc.) are ignored.

3. SIMULATION APPROACH

In order to design and evaluate the NEWSKY approach it is imperative to define new simulation environments which take the properties of the highly dynamic aeronautical environment into account. One of the greatest challenges in the evaluation of the NEWSKY concept is that its network centric architecture aims at a timeframe beyond the year 2020 and an operational context that is radically different from now. It is expected that the ongoing paradigm shift from voice to data communications will introduce fundamentally new approaches to the way air traffic is managed within Europe. These changes are expected to materialize especially in the context of SESAR. The development of new and appropriate evaluation environments is one of the goals of the NEWSKY project. However, in order not to duplicate existing work these simulation environments shall be based on FAA and EUROCONTROL studies [1,2] and open to future results from other sources.

3.1. Simulation Concepts

The numbers and positions of airports are not expected to change significantly in the mid-term therefore these characteristics are simply carried on for now. However, it is expected that the amount of air traffic will increase considerably and take different routes than today. This is partially due to the introduction of the SES and the emergence of new technologies like UAVs and 4-D trajectory operations. Thus one of the key elements of the evaluation is the generation of realistic future flight patterns that take these developments into account. The second key concept is the computation of the effective network topology. Within the aeronautical environment almost all access networks are wireless, which makes the effective link layer network topology a (time dependent) function of the applied mobility model. The third concept is the data generation model. The amount and type of generated communication differs according to the position and network attachment of the aircraft. Thus the data model has to be a function of the mobility and topology model. As indicated above the mobility model itself may in term rely on data communication services (ADS-B, 4D trajectory operations, etc.), which creates a circular dependency.

Fortunately enough some of the mutual dependencies of the different concepts can be uncoupled to an extent that makes modularization possible. Especially the last interrelation between data model and mobility model can be relaxed due to the fact that the large scale movement pattern of an aircraft is very predictable. Even under the influence of 4-D trajectory operations, the deviation from the original movement extrapolation is only seldom significant to the link level network topology. Therefore it is feasible to divide the simulation into several conceptual modules and to synchronize the different parts only when needed. An additional benefit of an modularized architecture is its openness to changes of the evaluation environment. New findings may be incorporated by the change of a module (e.g. new movement patterns, additional data links, etc.).

Apart from the modules mentioned so far a largely independent module for the collection of statistical data may process the output of any other module.

3.2. Objectives

The objective of our work is to develop a large scale evaluation environment for the NEWSKY system. Due to the fact that the current extrapolations of the European air space to the 2020+ time-frame are still uncertain and changing frequently modularization has been identified as one key asset to success.

In the first step of the evaluation process the suitability of the NEWSKY architecture for ATS and AOC communication shall be evaluated. In the second step APC communication will be included as well. The algorithms of the heterogeneous NEWSKY network will be evaluated at the ISO/OSI network and transport layer. The lower layers (data link layer and physical layer) will only be taken into account in the form of simplified models. The behaviour of the data generating applications (i.e. higher layers in the ISO/OSI reference model) will be derived from [1] and [2].

3.2.1. Challenges

The main challenges in developing the NEWSKY evaluation environment lie in the flexible modeling of the simulation rather than in the technical aspects of its implementation. So far three major challenges have been identified: The first challenge lies in the highly dynamic nature of the aeronautical environment and the modeling complexity induced by it. The second challenge is due to the frequent requirement changes within the aeronautical community. Currently it is not clear what the demands to a future communication network will be exactly and it is anticipated that the state of affairs will stay in flux for some time until final figures emerge. This issue is referred to as “requirements engineering”. The third and final challenge lies with the computation itself. Large-scale network simulations require huge amounts of processing power. Therefore appropriate methods to reduce and distribute the workload have to be applied. Each of these points will be discussed below.

3.2.1.1. Environment Complexity

The challenges raised by modeling the complex and dynamic aeronautical environment can be decomposed into several largely independent issues. As indicated previously one particular property of the simulated environment is the mutual (actually circular) dependency of node mobility, network topology and data generation, where “data generation” includes network architecture (i.e. protocol stack) and position related data generation. A rather different challenge is brought up by the necessity to ascertain the correctness of the environment model with regard to the specified evaluation scenarios. Confidence in the gained results can only be achieved by ensuring the comprehensibility and correctness of the implementation of the evaluation scenarios.

The complex nature of the simulated environment is tackled by modularity. The first module is the node mobility model. It is the starting point for all evaluation scenarios and defines the movement patterns of all mobile NEWSKY nodes (e.g. aircraft, Unmanned Aerial Vehicles (UAVs), satellites, etc.). The definition of aircraft movement patterns for the 2020+ time-frame is a non-trivial matter as current air traffic routes are most probably not valid then. Currently it is hard to predict how the air traffic growth of the next decades will affect the utilization of existing routes and eventually introduce new ones. Due to the introduction of the SES the path an aircraft takes when traveling to its destination will most likely be different than today. Various approaches to this issue are discussed in section 3.2.3.1. The second module is the link level network topology model of the evaluation environment. Given the contour of NEWSKY, both, nodes and communication cells, may move (e.g. satellite and aircraft ad-hoc communication). This is discussed in detail in section 3.2.3.2. The third large module is the data generation model. Assuming that future communication will be position related in many cases there is a clear dependency on the network 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”. This is discussed in section 3.2.3.3.

The mutual dependencies between the modules are illustrated in FIG 1. The starting point is the mobility model, which defines the movement of aircraft and communication cells. After each movement update the link level network topology model is recalculated to reflect the new situation. Based upon this topology (which includes the actual position of an aircraft) data communication is carried out. In some cases the data communication model will affect the mobility model as well. For instance a collision avoidance system might use data communication to trigger the correction of the aircraft course.

During the complete simulation process statistical data is gathered by the statistics module. Collecting useful results in a complex evaluation environment requires careful planning and preparation on its own. First of all 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 feat by the efficient and timely processing of the output of the other modules.

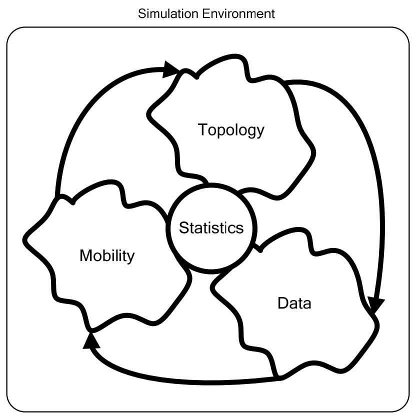

FIG 1. Mutual dependency of modules.

Besides the issues raised by the modeling of the evaluation environment another set of challenges may not be overlooked. 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 by 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 lend themselves to be implemented in high level languages. Systems described in high level languages are implemented faster and tend to be less error-prone, which fosters the confidence into the correctness of the evaluation.

3.2.1.2. Requirements Engineering

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 [1] and [2]. Unfortunately the aeronautical environment is a highly dynamic one, which makes predictions difficult and subject to frequent adaptations. Even well known studies like [2] and [3] 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. Within this document we refer to this process of ongoing refinement as "requirements engineering".

In order to respect the various extrapolations of the air traffic growth and communication requirements, different implementations of some modules may be required. Each modification within one scenario module (mobility, topology or data) affects the output of the other modules due to their mutual dependencies.

3.2.2. Computation Time

The challenges discussed so far were concerned with the aspects of modeling the evaluation environment. This section takes a brief look at the issue of simulation computation time. There are two general views on this topic. The first one emphasizes the need for fast programs and highly optimized code. Usually this is accomplished by the use of low level languages and fine tuned (manual) memory management. The drawback of this approach is that such programs are often difficult to understand and that their implementation is time-consuming. The second view tends to extend the scope of efficiency to the whole project cycle by arguing that the time gains achieved by highly optimized programs are often nullified by the longer development times. The second approach lends itself to the usage of high-level programming languages. Programs written in a high level language may be slower in execution than their low-level language pendants, but are more comprehensible, less error-prone and faster developed.

In the context of the simulation concepts presented in this document this issue has been relaxed 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.

3.2.3. Methodology

In the view of the experiences gathered in other large scale evaluations (e.g. B-VHF [9] and B-AMC [10]) the benefits of modularity, comprehensibility and adaptability over fast execution times became rather clear. In another form this extends to the usage of existing simulation frameworks (e.g. ns2 [13] or OMNET++ [14], etc.). These frameworks have not been designed to support the specific properties of the aeronautical environment and do not support mobility patterns and radio ranges at the scale of several hundred miles. In the past the adaptation of existing simulation tools to the special requirements of the aeronautical environment proved to be tedious and time-consuming, while the comprehensibility of the final programs was low. Additionally the correctness of the approach was sometimes difficult to ascertain with heavily modified tools. This lead to the result that the usage of a modular and custom built simulation tool written in a high level language offers the most advantageous approach.

In the next section the main concepts for the different modules of the simulation environment are presented. First the three core modules (mobility, topology, and data) are discussed, then the collection of statistics is investigated.

3.2.3.1. Mobility and Air Traffic Generation

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. In the simulation methodology presented in this document the generation of mobility patterns is the first module in the overall simulation tool chain. The time dependent simulated network topology is then derived from these mobility patterns. The generated mobility patterns contain the initial position of mobile nodes and regular position updates. Dependent on the desired simulation granularity the intervals between the position updates can range from less than a second to several minutes.

Generally 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. 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. For the computation of the mobility patterns several complementary mobility models are available. Two of them have been implemented so far.

The first available mobility model is based upon the evaluation scenarios published by EURCONTROL and FAA in [1]. 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 Manoeuvring Area (TMA) and En-Route (ENR). The APT volume is further divided into the airport surface and the airport zone. 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). Within each 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 turns around to return. These test volumes may be combined to create large-scale evaluation scenarios. FIG 2 illustrates this with a simple example. An APT Zone, TMA Large and ENR Large test volume have been combined to model the vicinity of a large airport.

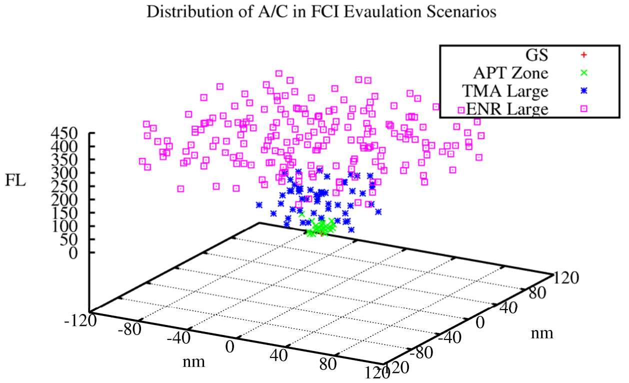

FIG 2. Distribution of A/C positions in three combined FCI evaluation scenarios [1] (APT-Zone, TMA-Large and ENR-Large) and one ground-station.

An alternative, more realistic mobility model is provided by the NAVSIM[2] tool, which has already been applied in a European research project (i.e. B-VHF [9]), in co-operation with industry (i.e. OnAir), and in studies with EUROCONTROL (i.e. VDL2 [11] and B-AMC [10]). 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 FIG 3). 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 (gate[3] or runway) of departure to the aerodrome (runway or gate[3]) 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.

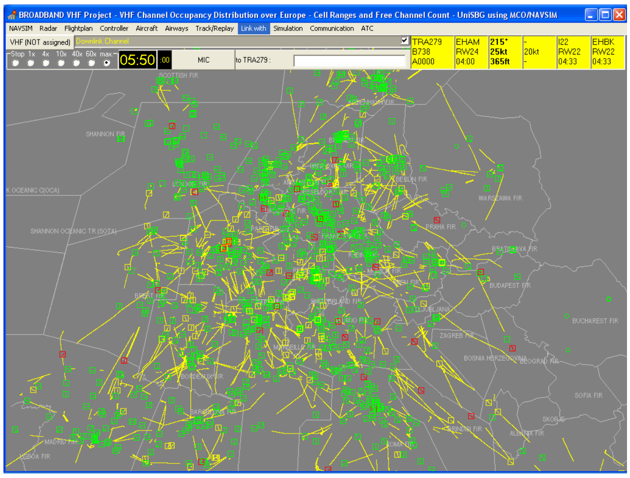

FIG 3. Screenshot of European Air Traffic simulated by NAVSIM[4].

These future air traffic scenarios have been modelled in the following way. First, a detailed analysis of the current European/world-wide air traffic situation has been carried out, resulting in traffic statistics (see FIG 4 and FIG 5 below) with regard to:

- Total number of European/world-wide flights per day.
- Number of departing/arriving flights per airport per day.
- Number of passengers[5] per airport per day.
- Number of departing/arriving flights per 60nM (exclusive) areas around airports per day.
- Number of passengers[4] per 60nM (exclusive) areas around airports per day.
- Evaluation of relations between pairs of airports with regard to number of flights per day.
- Evaluation of relations between pairs of airports with regard to classification of short-haul, medium-haul, long-haul flights.

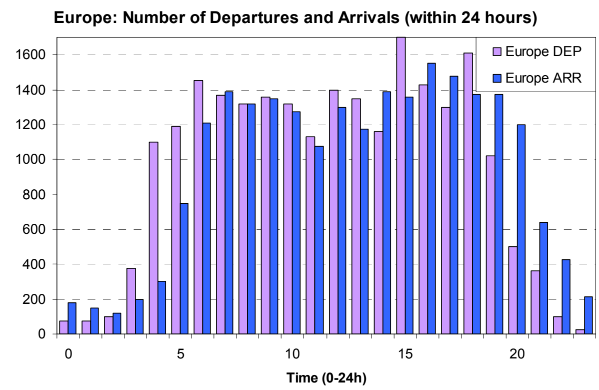

FIG 4. Number of flight departures and arrivals scheduled for Aug. 31st 2007 in Europe.

[2] 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.
[3] In cases where digitalized airport data is available (gates, aircraft positions, taxiways, etc.).

[4] With tracks and delay characteristics (green: on time; yellow: > 15 minutes delay; red: >30 minutes delay).
[5] Max. capacity based on aircraft type.

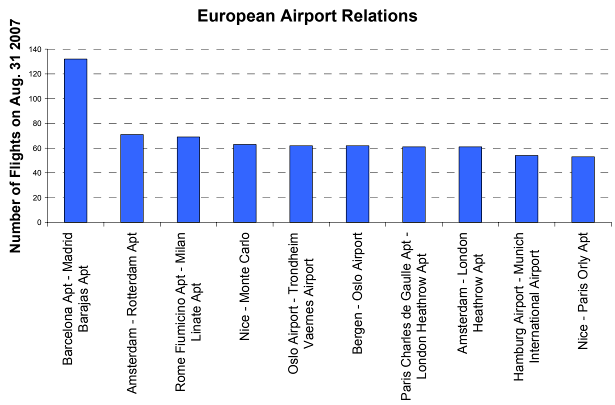

FIG 5. European ranking of airport relations. Number of scheduled flights for Aug.31, 2007.

Based on these statistics, future air traffic can be generated by the introduction of additional flights. These additional flights may be generated by three different mechanisms:

1) Increased air traffic between existing airport relations caused by more frequent flights and/or aircraft with larger passenger capacity.
2) Additional air traffic between new airport relations, which can be either existing hubs or new direct airport connections.
3) Additional air traffic as a result of the establishment of new airport hubs.

Thus, taking an expected growth[6] of air traffic from official sources (e.g. [1] or [2]) for a specific year of reference (2015, 2020, 2025, etc.), additional air traffic can be generated according to the given percentage of increase. Applied to the three mentioned mechanisms of growth an example result could be:

1) 50% increased air traffic between existing airport relations:
   – 80% due to additional flights.
   – 20% due to larger aircraft.
2) 40% increased air traffic between new airport relations:
   – 60% due to new relations to existing hubs.
   – 40% due to new direct connections.
3) 10% increased air traffic due to new airport hubs.

These additional new airport relations and new airport hubs are generated either in a deterministic or in a stochastic way based on the above mentioned air traffic statistics and flight range categories (observing reasonable flight range restrictions based on today's statistics).

All flights in NAVSIM are generated and simulated taking common flight planning rules and practices into account (e.g. navigation along airways, etc.). In order to support future ATM/ATC concepts related to the introduction of SES additional flight routing modes (navigation along great circles, etc.) and algorithms (medium term conflict detection and resolution, self-separation, etc.) may be used in NAVSIM.

[6] In terms of percentage with regard to today's air traffic or to a reference year in the past

3.2.3.2. Topology

The second module of the simulation tool chain the topology of the NEWSKY network is derived from the mobility patterns generated in advance. Although the network topology changes constantly almost all topology changes are confined to the wireless access networks. The static core of the network comprises the permanently installed backbone routes and 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 fringe 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. FIG 6 displays an example link layer topology for a future L-band communication system computed with the enhanced radio propagation model. The application of this propagation model to SSR multilateration including a detailed description of the model itself can be found in [12]. Other more advanced models may be introduced later if necessary.

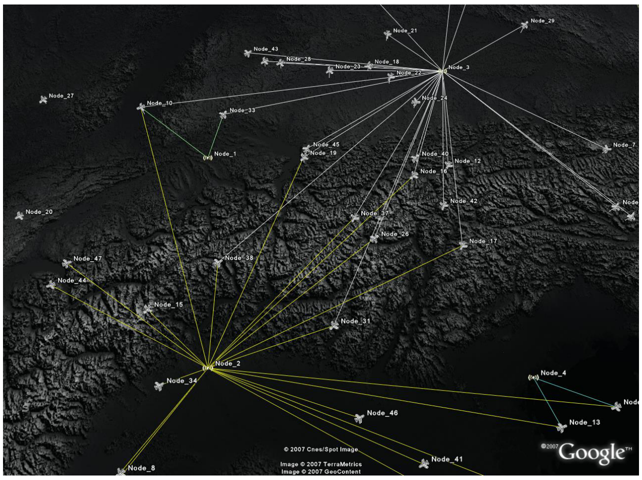

FIG 6. Effective link layer topology for a small number of ENR aircraft and four ground-stations (near Munich, Milan, Venice and Zurich) for a hypothetical L-band communication system computed with the enhanced radio propagation model. Ground-ground links are not displayed.

3.2.3.3. Data Generation

Using the modular concept for traffic, network and communication, data applications can be easily added to the simulation as prescribed by the evaluation scenario. If necessary, each data application may include its own protocol stack, thus the communication traffic properties (randomness of occurrence, etc.) depend only on the application module itself. This has the advantage that each mobility and topology model can be combined with different loading scenarios. The following data scenarios have been defined so far:

1) Data generation according to FCI scenarios [1].
2) Data generation according to the COCR study [2].
3) Static load tests (network performance approach).

In the first approach, the network load is based on the FCI scenarios published in [1]. However, by the generality of these scenarios and their openness to interpretations of the implementer the applicability of such an evaluation scenario might be arguable in some cases. 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, but did not make it into the final version. Positive aspects of the FCI scenarios are their comparatively simple implementation and the ease with which they can be combined.

In the second approach, the complexity of the simulation rises to reflect the more detailed picture of the behaviour of aeronautical communication of current and foreseen applications captured in [2]. This approach may enable a high degree of maintainability as new applications may be added quickly to (or removed from) to the simulation environment. In this approach data generation is not scenario dependent as applications are enabled and disabled according to the actual flight phase of an 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 sheer number of identified data applications.

The third 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 (e.g. the network can carry up to *x* kbps regardless of the traffic type).

All three approaches are necessary and useful for the development of a simulation environment capable to evaluate the requirements imposed on a heterogeneous aeronautical network. The first approach offers a straight forward way to create complex evaluation scenarios by the combination of appropriate FCI traffic volumes. The second method promises to be the most precise and the most complex, reflecting a detailed picture of current and future data applications. The third alternative offers a complementary evaluation of the network performance that is not based on application requirements.

Due to the modularity of the simulation concept 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.

3.2.3.4. Statistical Collections

The NEWSKY network performance is evaluated at two levels. At the higher level the user perceived network performance is evaluated. At the lower level the efficiency of the NEWSKY approach is investigated. It is clearly understood that the requirements for the user perceived performance stated in [2] must be fulfilled, while the low level validation criteria provide only a measure for the quality of the NEWSKY design. Nevertheless these values are thought to be important as they directly influence the scalability of the network. Both levels of network performance shall be evaluated using the scenarios defined in the previous section.

The user perceived performance comprises two major parameters: Delay and throughput. End-to-end delay is driven by the combined effects of the mobile and fixed network on the network path, whereas throughput is limited by the bottleneck on this path (in our case most likely the wireless component of the network). Within any network there are two types of delay an end-to-end connection can experience. For unacknowledged traffic only the one-way delay (latency) from sender to receiver and, if the connection carries real-time traffic, jitter is of importance. Acknowledged connections are seldom used for real time traffic as this type of connection has an implicit feed-back loop, which makes the experienced round-trip-time relevant. This leads to the following delay criteria: Latency (sender - receiver), jitter at the sender and the receiver, round-trip-time (sender – receiver – sender). The user perceived throughput is the average amount of data reaching the receiver per time unit. The value of this parameter is usually produced by the (implicit and explicit) traffic shaping mechanisms within the network. Values of these parameters are collected per flow, but it may be desirable to statistically aggregate them per traffic class (real-time, bulk …), node type (mobile, fixed …) and mobile-node-to-network link (wireless link, satellite link …).

The global network performance is determined by the number of delivered packets, while its efficiency is decided by the ratio of delivered packets to dropped packets. The network performance is sufficient if the number of delivered unique packets is close to the number of packets injected into the network. The number of packet drops need to be further subdivided according to their reason. Packets may be dropped due to link failures, capacity depletion, routing failures (e.g. caused by node mobility) or traffic shaping (e.g. dropped by a RED queue). The experienced network load can be derived from the instantaneous queue lengths in the intermediate nodes.

4. CONCLUSION

This document presented an overview of the concepts developed for the evaluation of the NEWSKY system. As indicated in the text, considerable parts of the different modules (and different versions of single modules) have already been implemented in the Java programming language and existing software (NAVSIM) has been used to provide input to the mobility model. Special attention has been drawn 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.). Parallelism may be used but is not intended at the moment as this approach introduces additional challenges. First versions of the evaluation environment have already been used for performance evaluations in another context [10] with very good results. Further development is expected within the NEWSKY project.

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