FACTS – An OMNeT++ Based Simulator for Aeronautical Communications

Felix Hoffmann
Felix.Hoffmann@DLR.de

Christian Bauer
Christian.Bauer@DLR.de

Daniel Medina
Daniel.Medina@DLR.de

Serkan Ayaz
Serkan.Ayaz@DLR.de

German Aerospace Center (DLR), Institute of Communications and Navigation
D-82234 Wessling, Germany

ABSTRACT

In this paper, we present a concept for an aeronautical communications simulator based on the discrete event simulation platform OMNeT++. In the aeronautical environment, there is a mutual dependency between the movement of the aircraft and the data traffic that is generated, making an accurate modeling particularly difficult. In addition, such a simulator requires a modular architecture due to the heterogeneous link situation and variety of application scenarios that it will have to deal with.

Categories and Subject Descriptors

J.2 [**Physical Sciences and Engineering**]: aerospace, electronics, engineering

General Terms

Algorithms, Performance, Design

1. INTRODUCTION

In the upcoming years, the amount of air traffic worldwide is expected to increase significantly. Eurocontrol, the European Organization for the Safety of Air Navigation, publishes regular forecasts of the amount of air traffic. These reports indicate that the air traffic volume will double between 2005 and 2025. In regions where air traffic is especially dense, particularly in Europe and North America, the VHF radio channels used for Air Traffic Control (ATC) are already a scarce resource, and the situation will become even worse as the number of flights increases. Until now, ATC has been largely restricted to analog voice communication between the pilot and an air traffic controller on the ground. However, increasing use is being made of data transmission in order to reduce the workload of the controller, allow for more efficient management of air traffic, and increase the number of flights that can be handled. It is envisaged that by 2020, data will have replaced voice as the primary means of communication for ATC.

To support this trend, a significant amount of work is currently being devoted to the development of new wideband or broadband data links, or to the adaptation of existing link technologies specifically to the aeronautical environment [3]. A second trend in aeronautical communications is the adoption of the Internet Protocol Suite (IPS) for use in an Aeronautical Telecommunications Network (ATN). Since an aircraft is expected to use different link technologies and access networks in different phases of flight - e.g. WiMAX while it is at the airport, a custom Air/Ground link over continental airspace, and a satellite link in oceanic or remote regions - this network will need to merge different subnetworks into one global heterogeneous network, as depicted in Fig. 1. The International Civil Aviation Authority (ICAO) is currently working towards an IPS based alternative to the existing ATN based on the ISO/OSI protocol stack [5]. An aeronautical network must support global mobility, Quality of Service provisioning for safety critical data, and seamless handovers between different link technologies, amongst other features. In [5], ICAO has presented an overview of different IP mobility solutions that may be applied to the IPS ATN. However, the true performance of these approaches in the aeronautical environment has to date not been assessed by means of simulations. Further research in this area is currently being carried out e.g. in the EU project NEWSKY [6]. To support research efforts in these fields, the Institute of Communications and Navigation at the German Aerospace Center (DLR) is currently developing a simulation platform specifically intended for use in the aeronautical environment within the project FACTS – Future Aeronautical Communications Traffic Simulator.

2. REQUIREMENTS AND APPLICATION SCENARIOS

The simulator is expected to cover a number of different application scenarios arising from current research in aeronautical communications. This may include the development of new aeronautical data links or optimization of parameters of existing links, simulation of routing or handover performance in a heterogeneous aeronautical network, including the assessment of IPS mobility solutions in aeronautics. Detailed physical layer simulations are not considered to be within the scope of this simulator. Instead, the

OMNET++ 2008, March 03, Marseille, France

DOI 10.4108/ICST.SIMUTOOLS2008.3004

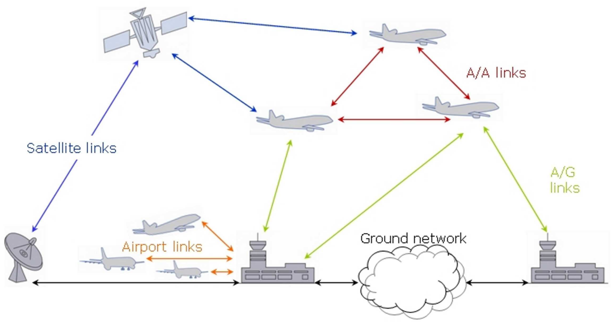

Figure 1: The heterogeneous aeronautical networking environment

physical layer is to be characterized in a more abstract fashion by a set of typical parameters, such as bit error rate and delay. In order to provide meaningful results, the simulator must be able to model the aeronautical environment with sufficient level of detail. In particular, this covers the following aspects:

- The simulator will need to provide a realistic model of air traffic, both for the current situation, as well as for future scenarios that feature a higher amount of air traffic.
- The simulator will need to generate realistic data traffic. As far as ATC is concerned, this can be achieved by modeling those data applications that have been defined e.g. in [4].
- The infrastructure, i.e. the distribution of base stations, ATC sectors, and airports, also needs to be modeled realistically, since we are focusing specifically on the aeronautical environment and its peculiarities.

These three aspects of the simulation environment will be discussed in more detail in Section 3. Due to the wide range of application scenarios, the simulator should be based on a modular, extendable architecture that allows the simulator to be easily adapted to the current purpose. It should scale well with the number of nodes, since simulations of the air traffic worldwide may include up to 75,000 aircraft, plus ground stations. Based upon these last requirements, the OMNeT++ simulation environment [2] along with the INET framework seems to provide a suitable platform for an aeronautical communications simulator.

3. THE AERONAUTICAL ENVIRONMENT

The aeronautical context poses a number of difficulties for a simulation platform that are typically not present in other fields of communications. This is due to the mutual dependencies between the data traffic that is generated, the current position and situation of the aircraft, and the movement of the aircraft. For example, upon entering the controlled airspace around an airport, the pilot contacts the responsible ATC controller, thereby generating data traffic. The controller will notify the pilot of his approach route, or - depending on the traffic density around the airport - may instruct the pilot to fly a holding pattern and wait until he can be cleared for landing. Thus, communication may influence the mobility pattern of the aircraft, in turn potentially leading to a further increase in the amount of data traffic. However, taking this circular dependency into account would require the implementation of true air traffic control procedures as well, greatly increasing the complexity of the simulator. Therefore, we only consider a linear dependency, where the mobile nodes generate data traffic, which appears as load for the communication network. As was mentioned above, an aircraft is expected to make use of different link technologies during different phases of flight. To assess the performance of issues such as mobility or resource management in such a heterogeneous network, it appears to be sufficient for the beginning to assume generic physical and link layers rather than detailed implementations of standards such as WiMAX, also to keep the computational complexity to a minimum.

3.1 Modeling of Air Traffic

Since the generation of data traffic is closely dependent on the position and movement of the aircraft, the air traffic must also be modeled realistically in order to arrive at a realistic data traffic load for the communications network. We are considering three different approaches to air traffic generation, which will be used in different cases, depending on the scenario to be simulated:

Generation of aircraft trajectories by means of a dedicated air traffic simulator: In case a simulation focuses on a relatively small area, e.g. containing only the arrival and departure flights for a certain airport, the trajectories of the aircraft need to be particularly exact. For this purpose, we make use of an air traffic simulator developed at DLR's Institute of Flight Guidance, which generates very detailed aircraft trajectories for Frankfurt International Airport, including separation rules and holding patterns. These trajectories are calculated in advance, saved to a file, and then read in by the OMNeT++ based communications simulator.

Simplified generation of aircraft trajectories according to flight database: For larger-scale simulations across a wider geographical area, the trajectories do not require the same level of detail, as long as the general distribution of air traffic is still related to true traffic patterns. In this case, we generate files containing the aircraft trajectories from a database containing the starting and destination airports for all scheduled flights worldwide by interpolating along the great circle route connecting these airports. Especially for long distance flights, this is a reasonable approximation of the true route.

Dynamic generation of air traffic according to statistical model: In some cases, true flight data as is used for the two approaches above may not be required or available. In particular, much of the current work in aeronautical communications addresses the years 2020, so that some assumptions must be made about the amount and distribution of air traffic in the future. First, the frequency of flights between each pair of airports according to current information will need to be determined. Then, this traffic can be scaled according to the increase in air traffic that is expected for the year to be simulated.

3.2 Modeling of Infrastructure

In contrast to the modeling of the air traffic, the modeling of the ground infrastructure is relatively straightforward. The positions of all base stations in service in Europe that are used for VDL Mode 2 - the digital communications technology currently being deployed in aviation - have been provided by the two major communications service providers worldwide, ARINC and SITA. In addition, the simulator reads in the position of all ATC sectors in European airspace and keeps track of the current sector of each aircraft. This information is required e.g. to trigger the transmission of data by an aircraft or to determine the ground station with which an aircraft should communicate. Since our focus lies on the aspects that are specific to aeronautical communications, a detailed representation of the ground network itself is outside the scope of our work. In any case, it can be assumed that the bottleneck of any communications path will be the wireless link to the aircraft, and not within the ground network.

3.3 Modeling of Data Traffic

Modeling of data traffic is simplified by the fact that the applications used by ATC are well defined by the aviation community. For example, [4] provides a list of services that are foreseen for use in the future. Such an application can be characterized by the sequence of messages sent between a controller and an aircraft, the size of each of these messages, as well as the event that triggers this application. Some applications are triggered in a deterministic manner, based on the aircraft's situation. For example when an aircraft enters a new ATC sector, it must register with the controller. Other applications may be periodic in nature, such as regular position reports, or occur randomly, in which case they can be modeled as a Poisson process. Data traffic generated by passengers using in-flight internet access must be generated by an appropriate statistical model. If the purpose of a simulation is to analyze the maximum throughput of a certain link, an exact representation of the actual applications is not necessary. Instead, a constant load can be generated by each aircraft or ground station.

4. CHANGES TO THE INET FRAMEWORK

Our implementation is based on the INET framework, which adds support for simulating communications networks to OMNeT++. Implementations of common protocols such as IPv4, IPv6, TCP, UDP, etc. are available, as well as support for mobile wireless nodes, including an implementation of the IEEE 802.11 standard. Still, some modifications or extensions to INET were necessary in order to fulfill our requirements for simulating the aeronautical environment. The most notable modifications are listed below.

- *Modification of Coord.h*: The 2-dimensional Cartesian coordinates of the INET Framework are not suitable for dealing with air traffic. Therefore, the existing class within INET has been extended to spherical coordinates. Unfortunately, this increases the computational overhead of dealing with mobile nodes, since computations in spherical coordinates, e.g. determining the distance between two points, are typically more complex than their equivalent in Cartesian coordinates.

- *BasicMobilitySpherical*, *LineSegmentsMobilitySpherical*, *AircraftMobility*: With the design principle based on the existing BasicMobility and BonnMotionMobility modules, we have implemented additional mobility modules that read trajectory input files and provide the appropriate mobility functionality based on spherical coordinates. These trajectory files are produced in advance, taking into account navigational waypoints interpolated by great circle routes.

- *ChannelControlSpherical*: As of now, INETs ChannelControl module, which is manages the connectivity of wireless nodes, does not provide support for a host making use of several wireless channels, and therefore several radio technologies, at the same time. Our new ChannelControlSpherical class extends the existing ChannelControl while staying backwards compatible to the existing INET implementation.

- *MobileNodeManager*, *InfrastructureManager*, *SectorManager*: These top-level modules (like ChannelControl) are responsible for reading in trajectory files and for generating aircraft nodes at the appropriate time, generating the infrastructure, and maintaining a database of ATC sectors, respectively. Whenever an aircraft moves, the SectorManager checks if the aircraft has moved into a new ATC sector. Upon initialization of an aircraft node, a brute force search over all sectors must be performed to find the valid sector. Subsequently, only those sectors that are adjacent to the sector of the previous step need to be checked.

The Graphical User Interface (GUI) of OMNeT++ is based on two-dimensional Cartesian coordinates. To better be able to display the air traffic as well as ATC sectors, we have integrated NASA WorldWind [1] with OMNeT++ to create a custom GUI. Fig. 2 is a screenshot of this GUI, showing flights coming from North America, arriving at the coast of the UK around 6:20 UTC. Connections are displayed between aircraft closer than 150 nmi, demonstrating the potential for an aeronautical ad hoc network over oceanic regions. The transmission ranges of base stations are drawn as circles with a radius of 200nmi.

The Tcl/Tk-based OMNeT++ GUI has been extended via the Java Native Interface (JNI) to make use of the NASA WorldWind Java SDK for graphical representation of aeronautical networks on a virtual globe. WorldWind uses the Java Bindings for OpenGL (JOGL).

Most changes have been made in tkapp.cc and modinsp.cc, which are both part of the tkenv environment, to be able to inspect the "system module" (i.e., the whole network) in the WorldWindow. During tkapp initialization, a Java Virtual Machine (JVM) is created with the JNI_CreateJavaVM function.

A new TInspector subclass named TGraphicalWorldWindow, similar to TGraphicalModWindow, uses the JVM to create a WorldWindow and display the compound modules, connections and message animation on the virtual globe, using available WorldWind Java objects, such as WorldWindowGLCanvas, WWIcon to draw aircraft, Polyline to draw connections, etc. At the same time, the original Tcl/Tk-based inspector windows are still available to display the internal structure of compound modules.

In general, we have tried to stay compatible to the existing INET framework, which is shown by the fact that we already have the original INET IPv6 protocols running on top of our current implementation.

5. ONGOING AND FUTURE WORK

In this paper, we have presented our concept for a simulation platform for aeronautical communications, which is based on the discrete event simulator OMNeT++. Due to the close relationship between mobility and generated data, the aircraft trajectories must be calculated with sufficient level of detail. The modular architecture of the simulator allows additional components to be easily added. In partic-

Figure 2: Screenshot of WorldWind based GUI

ular, this may include newly developed data links or protocols that need to be assessed with respect to their suitability for aeronautical communications.

To the best of our knowledge, there is no freely available simulator for aeronautical communications. Therefore, cross validation with results from other simulators is poses a problem. However, simulation results have been published for the performance of the VDL Mode 2 datalink, which is currently being deployed. Within FACTS, the VDL Mode 2 standard will also be implemented, and results will be compared to those that have been published. While this is not a formal validation of our simulator, and will largely compare the implementation of the datalink itself, good correlation between the results will increase our confidence in our simulation platform.

6. REFERENCES

[1] NASA World Wind. Website. Available online at http://worldwind.arc.nasa.gov/index.html.

[2] OMNeT++ Discrete Event Simulation System. Website. Available online at http://www.omnetpp.org.

[3] Identification of Technologies for the Provision of Future Aeronautical Communications. NASA/CR 2006-214451, NASA, October 2006.

[4] Communications Operating Concept and Requirements for the Future Radio System. Future Communications Study Report, Eurocontrol / FAA, May 2007.

[5] Use of Internet Protocols Suite (IPS) as a Provision for Aeronatical Networking. Working group n report, ICAO, May 2007.

[6] M. Schnell and S. Scalise. Newsky - A Concept for Networking the Sky for Civil Aeronautical Communications. In *Proc. 25th Digital Avionics System Conference*, October 2006.