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MISSON LEVEL SYSTEM DESIGN FOR COCKPIT AND PASSENGERS AERONAUTICAL SERVICES

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Abstract

Satellite based Air Traffic Management (ATM) and In-Flight Internet (IFI) services surely are among the most important ones that will be offered to airlines in the long term. In the design of any communication and security system, high performance must be paid for with high system costs. It is then clearly important, under the business case and technical perspective, to have fairly realistic estimates of the network resources that have to be provided, in order to guarantee the desired Quality of Service (QoS) and Security.

Introduction

To fairly estimate resources is already a non-trivial task for any terrestrial communication system. Yet, anytime a satellite constellation (of GEOs and/or non-GEO satellites) is envisaged to offer services to mobile users even bigger efforts are needed, since the analysis and the simulation of the communication network has to be coordinated with the analysis and the simulation of the satellite constellation. A powerful, reliable and flexible simulation tool set is then needed, in whose environment these two levels of simulation can run in parallel.

In this paper we shortly present MLDesigner and SatLab, a tool set including a mission level design tool and a constellation simulator that proved to be well suited for the aforementioned requirements. We model then the real case scenarios of ATM and IFI services offered in the North Atlantic region and finally present the performance results of these tools. All our simulation results are based on

a) the real flight routes and schedules taken from the OAG's Worldwide Flight database [OAG03],
b) the information transfer during a flight for ATM services, in terms of contents, sources, drains (e.g. the pilots) and the time constraints [ODI01, EM01],
c) the expected usage of In-Flight Internet services based on our previous market analyses [BWH03] and the expected dynamic behaviour of Internet users during a flight, as in [UBWH04],
d) the default aircraft' cabin configurations of the most relevant aircraft types flying in the North Atlantic region (A340, B747, B767, B777 and MD11) and the data of the A380.

About the Used Tool Set

The modelling, system design and simulation of cockpit and passenger aeronautical communication systems are indeed no trivial issues. On the one hand a satellite system, ground station network and the time variant aircraft scenario has to be integrated. On the other hand the communication packet data transport has to be implemented easily and simulated efficiently.

MLDesigner and SatLab could support us in these tasks.

MLDesigner is a system-level simulation modelling platform that integrates both major system-level modelling areas (architecture and function), and most simulation modelling domains, all in a single tool. MLDesigner models are defined graphically as hierarchical block diagrams. Blocks have defined inputs and outputs that are connected via visible links or via shared memories. Control and information is passed between blocks via particles (called tokens) that consist of either a simple trigger particle or a hierarchical data structure. Bottom level blocks contain primitives written in a form of C++ code. Higher-level blocks contain block diagrams. All blocks can be parameterized for easy "what if" analysis and to maximize block reusability. [USeal03]

We modeled our system using the discrete event domain (DE).

SatLab is a design environment for mission and system level design, animation, and analysis of wireless mobile communication and navigation systems. SatLab supplies every MLDesigner model with satellite and aircraft position information needed to calculate transmission delays and to determine links between mobile communication nodes (e.g. aircraft, satellites and ground stations).

SatLab was used to simulate the spatial and temporal distribution of aircraft.

MLDesigner and SatLab are dynamically connected via an IP socket interface. SatLab runs as server. When MLDesigner starts, it commands SatLab to execute a predefined script, provides initialization data (e.g. time and date) and then periodically requests position data from SatLab during the simulation.

Simulation of the Air Traffic Management Scenario

ATM services include Air Traffic Services, Airline Operation Control, Airline Administrative Communications, Airline Passenger Correspondence, Controller-Pilot Data Link, Datalink-Flight Information Services, and automated position reporting.

In a satellite based ATM Network aircraft use relay satellites to communicate with the ground control stations. As relay satellite we used for our simulations the Inmarsat AOR-W and AOR-E.

The figure below shows in short the interactions between aircraft, satellites, satellite ground stations and ground control stations.

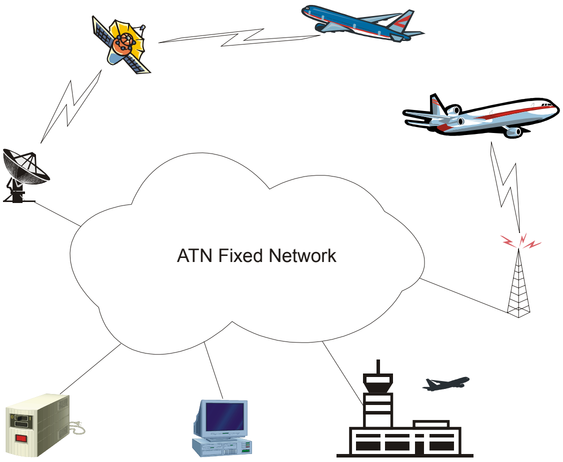

FIGURE 1: SCHEMATIC OF ATM SYSTEM

Out of all ATM services we focused on the most important ones: the Air Traffic Services (ATS).

Table 1 shows the selected services and the sizes of the packets sent. The data flow for each service is described in detail in [ODI01].

For our purposes it is relevant to recall that each flight is divided into phases such as Strategic Planning, Ground, Climb out, En Route, and Arrival.

Each phase has a fixed duration, with the clear exception of the En Route phase, and defined service message profiles.

We developed at first a simulation environment to evaluate the capacity needed by a single aircraft during a long haul North Atlantic flight and then extended our results to the global scenario of all aircraft flying on North-Atlantic routes during a whole day. For this purpose we used the OAG flight route data [OAG03].

MLDesigner and SatLab were used in conjunction in order to render the spatial position of the aircraft and at the same time simulate the data transfers between communication nodes (i.e. aircraft, satellite and ground station). The transport of service messages was implemented by sending packet data structures. All network nodes in our model are freely settable by input files.

Flights were defined by using a data structure that includes flight name, departure and destination's longitude and latitude, altitude, start time, flight duration, takeoff time, route sectors and reporting interval.

ATS Class	Service	Packet size [byte]
CPDLC	ACM	264
	ACL	227
	DCL	360
	DSC	257
D-FIS	D-OTIS	203
	D-RVR	152
	D-SIGMENT	178
ADAP	CAP	56
	FLIPCY	872

TABLE 1: SELECTIVE ATM SERVICE CHARACTERISTICS

Figure 2 shows the implemented MLDesigner simulation model. In order to feasibly handle all data, the aircraft modules are linked dynamically. The satellite ground stations and the satellites themselves are statically loaded. The transmission delays are computed according to the mutual distance between satellites and aircraft.

The block at the upper right hand side handles statistics collection and reporting for each aircraft.

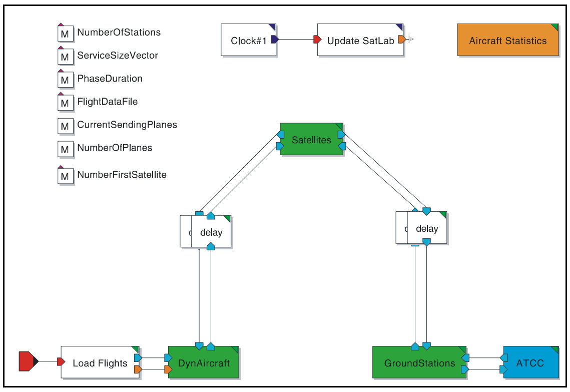

FIGURE 2: MODELING STRUCTURE OF ATM SYSTEM

Figure 3 shows the typical traffic profile of data sent by an aircraft. Typical is the 872 bytes peak, which indicates the FLIPCY service (FLIght Plan ConsistencY) before departure. During the En/Route phase the 50 Bytes packets of the APR (Automatic Positioning Reporting) service are sent each 60 seconds.

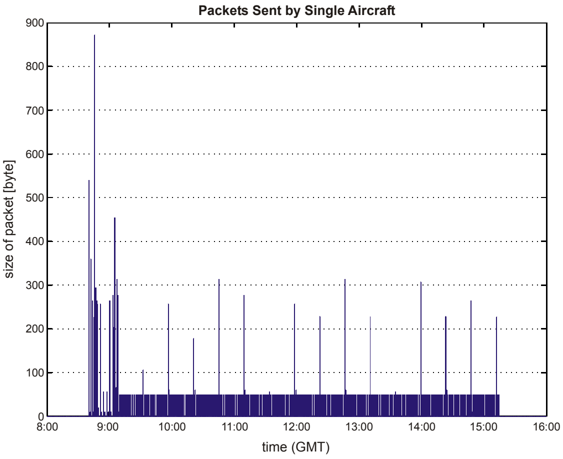

FIGURE 3: PACKETS SENT BY SINGLE AIRCRAFT

Going up in this logical scale from aircraft up to the whole North-Atlantic scenario, Figure 4 shows the actual number of aircraft en route during 48 hours. Base time is GMT. Even maxima are due to the aircraft flying from Europe to North America, the odd ones are due to those flying from North America to Europe.

Note the obvious one day periodicity of the curve. Maxima are of about 330 aircraft, minima of about 130.

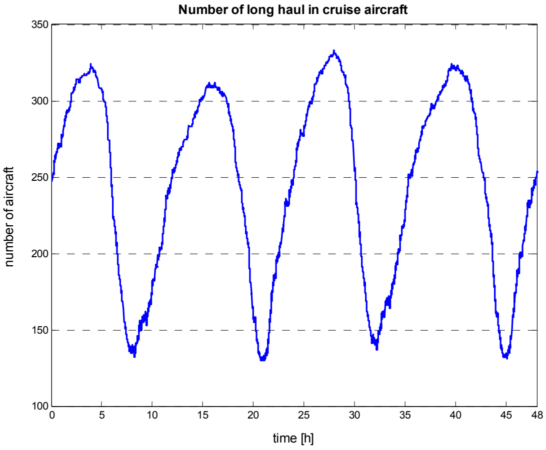

FIGURE 4: NUMBER OF AIRCRAFT EN ROUTE DURING A 48 HOURS SIMULATION

Using the model for the traffic received by and sent from each aircraft, the number of aircraft in the North Atlantic region and their type distribution we could estimate the uplink and downlink data rates for the chosen Inmarsat satellites. The AOR-E was used as relay for all flights from Europe to the USA, the AOR-W for all others.

For each satellite the amount of data packet sizes were accumulated for downlink and uplink separately within a time window of 20 seconds. The simulation was made in 66 steps with about 21 aircraft each. The results were later superposed. The aircraft scenario proved to be too complex for being simulated in one run. The total simulation CPU runtime was of about 35 hours.

Figure 5 shows the downlink traffic load of both satellites with the highest peak of capacity usage (9486 bps). Figure 6 shows the uplink traffic load for each satellite. The correlation between the number of active planes and the maxima of ATM data traffic appear there evidently. Table 2 summarizes the most important simulation results.

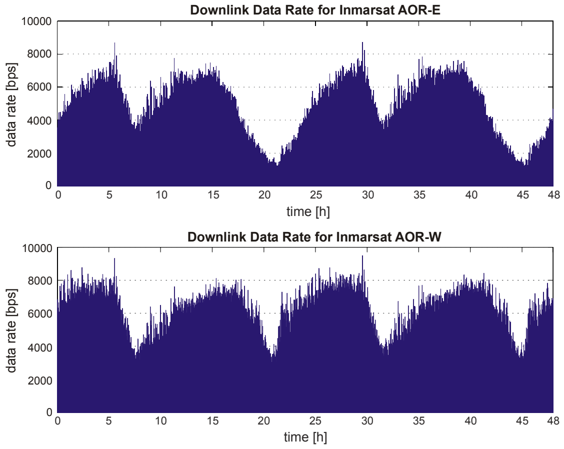

FIGURE 5: 48 HOURS' SNAPSHOT OF DOWNLINK TRAFFIC LOAD FOR BOTH INMARSAT SATELLTES

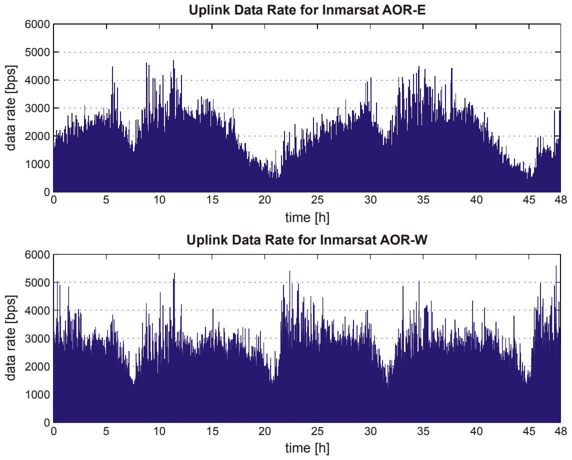

FIGURE 6: 48 HOURS' SNAPSHOT OF UPLINK TRAFFIC LOAD FOR BOTH INMARSAT SATELLITES

	Satellite	Rate [bps]		Total Traffic [MByte]
		Maximum	Average	
Down-link	AOR-W	9486	2280	46.96
	AOR-E	8718	1769	36.45
Uplink	AOR-W	5590	1601	32.97
	AOR-E	4718	1175	24.20

TABLE 2: SIMULATION RESULTS OF 48 HOURS SNAPSHOT FOR BOTH INMARSAT SATELLITES

In order to offer ATS services in the North-Atlantic region a GEO satellite shall offer a net satellite capacity of about 9 kbps.

Simulation of In-Flight Internet

In [UBWH04] we modelled the dynamic behaviour of the aggregate Internet traffic generated by In-Flight-Internet users. The source model is based on the ETIS model [ETSI98] shown in Figure 7.

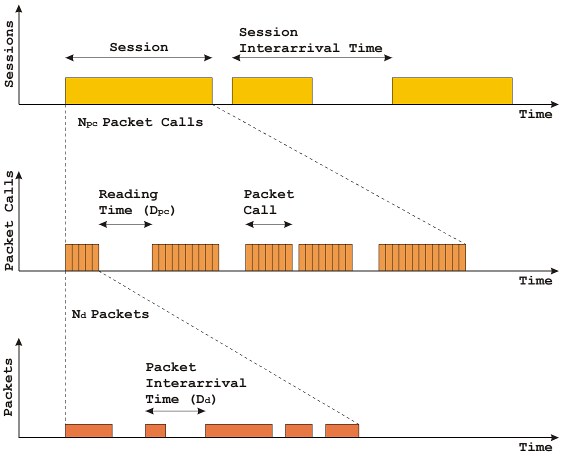

Figure 7: ETSI Packet Model for Internet Traffic

At the top level there is the session layer, which describes a typical Internet session. The start of a session is characterized by a Poisson arrival process. The value for the mean session arrival rate is left open as a parameter for setting the average data rate in time intervals. The session holding time derives from the settings of the lower layers.

Within a session several packet calls may occur. The number of packet calls within a session is described by means of a geometrically distributed random variable. Each packet call can easily be interpreted as the download request for a single page.

Between two packet calls, the user takes a certain time to interpret the received information. This time is called reading time and is described through a geometrical distribution.

A packet call initiates a sequence of packets, whose number is modelled again by a geometrical distribution. The gap between two consecutive packets is described by a negative exponentially distributed interarrival time and the size of each packet is Pareto distributed with a cut-off to limit its maximum size.

A detailed description of fitting the ETSI parameters to the AirCom Internet case can be found in [UBWH04].

The Internet source modeled in MLDesigner is shown in Figure 8. The “WWWClient” part generates sessions and triggers packet calls. Whenever the “WWWServer” part receives a packet call it generates the page consisting of single packets sent by a data structure.

Using MLDesigner’s map functionality multiple independent instances of Internet source are generated according to the number of passengers within an aircraft.

For measuring the necessary data rate the packet sizes are accumulated in time windows and divided by the time window size.

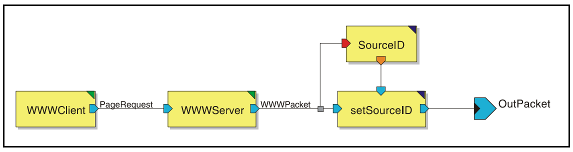

Figure 8: Internet Source Modeled in MLDesigner

The results were presented in form of PDF’s (probability density function) and CDF’s (cumulative density function) of the used data rate. Base for our estimations were the aircraft types A340, B747, B767, B777, MD11 and A380 and our previous market analyses [BHW03]. Table 3 shows the simulation results for the expected number of users, mean data rates and the capacity required to offer, according to the chosen aircraft type, for 99% of the time the necessary QoS. The data rates are in kbps. These results were obtained by simulating for each aircraft type about 3000 intercontinental North-Atlantic flights.

AirCom Internet Services

Model	No. Users	Mean Rate	Required Capacity	Capacity to mean ratio
A340	37	33	130	3.99
A380	81	73	204	2.79
B747	69	62	185	2.98
B767	42	38	139	3.66
B777	53	48	159	3.31
MD11	49	44	151	3.43

TABLE 3: SIMULATION RESULTS FOR EACH AIRCRAFT TYPE (IN KBPS)

A sheer extension of these results to the aggregate traffic of a satellite spotbeam, or footprint, was not possible using the same model, due to the high number of aircraft and passengers to consider. Another model was necessary in order to perform simulations whose run length was independent of the number of passengers.

The CDF of the dynamic data rate usage for each aircraft type was rebuilt through a random data rate generator (RDG) Figure 9 shows the principle of this generator.

A random number uniformly distributed between 0 and 1 is used as input on the y-axis of the desired CDF. The resulting value on the x-axis is the desired random data rate of the airplane, for the chosen smallest time unit (time granularity).
Clearly the random variable generated in such a way has the desired PDF and CDF.

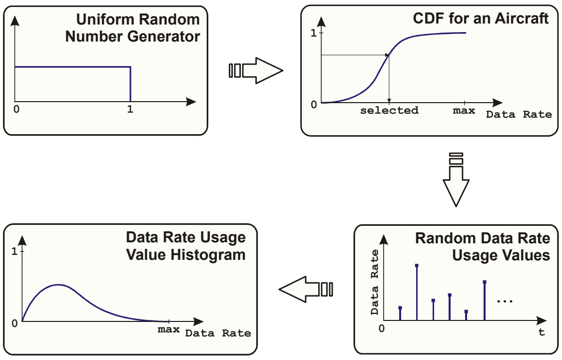

FIGURE 9: RANDOM DATA RATE GENERATOR

The big advantage of this solution is that all simulation runs are independent of the number of users.

Table 4 shows an example of the measured speed-up. As a rule of thumb it came out

$$K_{speedup} \approx 20 \cdot N_{user} .$$

It is further to remark that the generated data rate usage values cause no loss of detail for the whole simulation, since for every aircraft type the bandwidth CDF results out of the simulation of 3000 (!) intercontinental flights.

With this optimization, a simulation run of IFI services for one day of flights between Europe and America took only minutes instead of days.

Aircraft Type	*Simulation running time* [s]		$K_{speedup}$	*Speed-up factor to user number ratio*
	ETSI source	*RDG*		
A340	531.0	0.7	759	20.5
B777	778.5	0.7	1112	20.9
A380	1168.0	0.7	1669	20.6

TABLE 4: COMPARING RANDOM DATA RATE GENERATOR TO ETSI MODEL SIMULATION

Based on OAG's data of worldwide scheduled passenger flights, the number and type of aircraft flying the North-Atlantic routes per day were simulated and mapped the into the footprint of Inmarsat's AOR-W satellite. Table 5 shows an estimation of the distribution of the aircraft operating inside the footprint.

A worst case scenario was selected when all aircraft flying from Europe to North America are within the footprint. For each aircraft an RDG with the appropriate CDF was inserted into the modeling environment.

The mean data rate value after a $5 \cdot 10^7$ seconds simulation time resulted in about 14.7 Mbps, the maximum data rate in about 17.7 Mbps.

Figure 10 shows the indicative CDF of data rate required by all aircraft flying in the North-Atlantic area during a whole day.

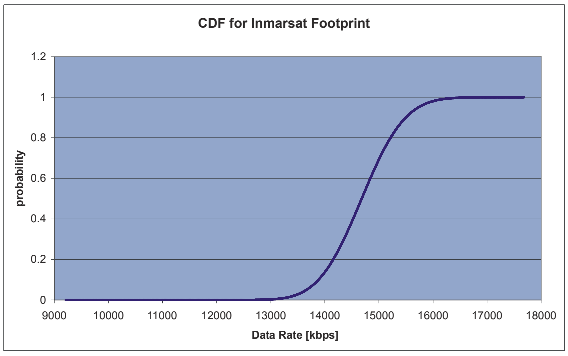

FIGURE 10: EXAMPLE OF NETWORK DATA RATE ESTIMATION RESULTS FOR IN-FLIGHT INTERNET SERVICES OFFERED DURING NORTH ATLANTIC FLIGHTS

Aircraft Type	Total Number	Distribution [%]
A340	68	19.83
A380	0	0.00
B747	57	16.62
B767	110	32.07
B777	79	23.03
MD11	29	8.45
	343	100.00

TABLE 5: DISTRIBUTION OF THE AIRCRAFT TYPES USED FOR NORTH-ATLANTIC FLIGHTS

Conclusions

We have shown the feasibility of the simulation of the whole In-Flight Internet and ATM traffic in the North-Atlantic area in day time scales.

SatLab and MLDesigner proved to be a stable and extensible platform. Our results could be extended to arbitrary scenarios on all scales, starting from the user behaviour up to aircraft types and constellations. Even a terrestrial telecommunication network to offer aeronautical services could be simulated by using the environment we developed.

Last but not least the results we presented are based on very general assumptions and, when available, on real data.

In order to offer In-Flight Internet services during North Atlantic long haul flights a GEO satellite shall offer a net capacity of about 18 Mbps.

In order to offer ATM services about 9 kbps are necessary.

References

[BWH03] L. Battaglia, M. Werner, M. Holzbock, "Revenues and Performance of Global Satellite Aeronautical Communications", 21st AIAA ICSSC, International Communications Satellite Systems Conference, Yokohama, Japan, 2003.

[EM01] EMERTA-Study (March 2001) EMERTA consortium; EMERging Technologies opportunities, issues and impact on ATM

[ETSI98] Universal Mobile Telecommunication Systems (UMTS); "Selection procedures for the choice of radio transmission technologies of the UMTS", Technical Report TR 101 112 v3.2.0, ETSI, 1998

[OAG03] www.oag.com, 2003.

[ODI01] Eurocontrol, "Operational Requirements for Air/Ground Co-operative Air Traffic Services", 2001

[UBWH04] P. Unger, L. Battaglia, M. Werner, M. Holzbock, “Dynamic Behaviour of AirCom Internet Users on Long-Haul North Atlantic Flights”, in Proceedings ICC 2004, Paris, France, 20-24 June 2004.

[USeal03] P. Unger, H. Salzwedel et al., "System-Level Simulation Modeling with MLDesigner", IEEE ACM MASCOTS 2003, 11th International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems, Orlando, Florida, 2003

[WHB02] M. Werner, M. Holzbock, L. Battaglia, “Potential of non-GEO satellite constellations in the future AirCom market,” 20th AIAA ICSSC International Communications Satellite Systems Conference, Montreal, Canada, 2002.