

CAPACITY DIMENSIONING FOR LONG-HAUL INFLIGHT ENTERTAINMENT STREAMING SERVICES

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Abstract

This paper reports about the work of the 2003/2004 MSK2 project [1] at Ilmenau Technical University on streaming satellite services for In-Flight Entertainment (IFE). A simulation model was developed for planning, performance estimation and capacity dimensioning of satellite systems offering streaming services in long-haul aircraft flight scenarios. We focus on simulation aspect and describe in detail streaming source, handover mechanism and channel allocation of each satellite at the satellite system. We present a tool set which is capable to simulate satellite system, the North-Atlantic flight scenario, and data traffic in a real time simulation at day time scale.

Introduction

Streaming satellite services is a candidate for replacement and/or supplement for current taped in-flight entertainment, particularly on long-haul routes. This paper describes modeling and simulation design for planning, performance estimation and capacity dimensioning of satellite systems offering streaming services in long-haul aircraft flight scenarios. User behavior for streaming services and their capacity usage of various satellite systems and various flight scenarios are investigated. Long-Haul flight scenarios for the North Atlantic region where selected, since this

region is one of the major markets offering In-flight Entertainment (IFE).

Simulating global communication scenarios using satellite systems to offer services for highly mobile users (e.g. passengers within aircraft) yield high system complexity.

On the one hand, it has to be possible to determine the current positions of each satellite of the constellation and of each aircraft at any simulation time. On the other hand, the communication data packet flow and the behavior of each communication node have to be integrated into the simulation.

Therefore, a powerful, reliable and flexible simulation tool set is needed, in whose environment these two levels of simulation can run in parallel.

Our simulation results are based on the real flight routes and schedules taken from the OAG's Worldwide Flight database [3].

Simulation Tool Set

The modelling, system design and simulation of aeronautical communication systems are indeed no trivial issues. Mobility of users, e.g. passengers within aircraft, the satellite system and the data packet flow have to be implemented easily and simulated efficiently.

MLDesigner® [4] and *SatLab*® [2] support the prementioned 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 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. [5]

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 and satellites). SatLab is used to simulate the spatial and temporal distribution of aircraft. Satellite constellation parameters for LEO, MEO, and GEO satellite systems and all flight routes are specified as input files for the software system SatLab.

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.

A multi user avionic streaming model was developed using the discrete event (DE) domain of the Mission Level Design tool MLDesigner. SatLab is used to simulate the communication nodes, providing current positions and velocities of all satellites and aircraft as a function of time.

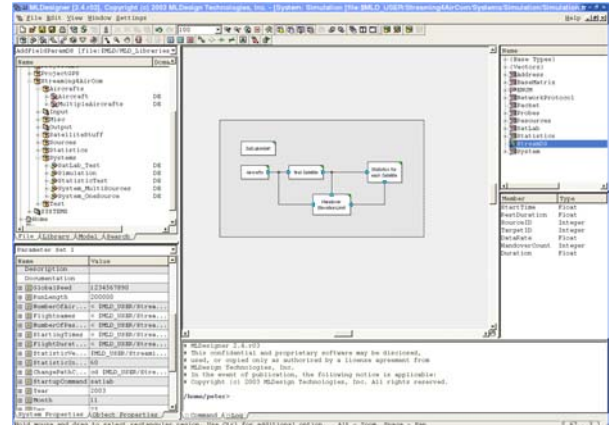


FIGURE 1: MLDESIGNER WORKSPACE

Figure 1 shows the top-level view of the avionic streaming model in the MLDesigner workspace (center of the GUI).

Other GUI windows show (clockwise from lower left) the model properties editor, the file manager, the data structure editor, the data structure member editor and, at the right bottom, the command window. The model properties window (lower left) is used to set parameters for the model shown in the design window. The data structure member editor (center right window) shows the some of the members/fields of the stream data structure including amongst other things: *time of initiation*, *duration*, and *data rate*.

Parameters of the simulation can be given as input files to exchange for other parameter sets and extern simulations. It is also possible to run several iterations in a simulation.

Screenshots of SatLab's map view of satellite system and flight routes are shown in figures below (Figure 4, Figure 5, and Figure 6).

System modeling

Figure 2 shows the top level of the system model. It is subdivided into parts streaming source (all aircraft including passengers), satellite selection, handover test, statistic collection, and SatLab connectivity.

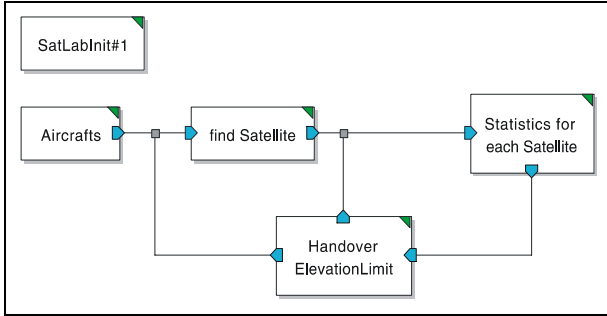


FIGURE 2: TOP-LEVEL OF SIMULATION MODEL

First SatLab is initialized; satellite ephemerides data and aircraft flight information are loaded from input files. The module “Aircraft” symbolizes all aircraft nodes as instances of an aircraft module. Within each aircraft module, multiple users generate stream requests. A stream request creates a data structure “StreamDS”, which contains information about start time, duration, data rate, source ID, and target ID of the current stream. The target ID symbolizes the satellite number for transmitting the stream, which is determined at module “find Satellite” using source ID (aircraft number) and the SatLab’s *RelPosition* function.

After initiate the stream the nearest (highest) satellite and therefore the best connection is selected for transmission.

The mechanism of handover process and statistic collection will be described in detail in the following sections.

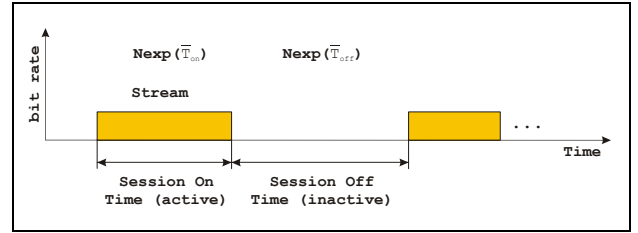


FIGURE 3: ON-OFF MODEL FOR STREAMING User

Streaming Source

Each user streaming session is represented by an On-Off model (Figure 3). A negative exponential distribution characterizes a stream active time, with a mean value of \bar{T}_{on} . The stream off time is represented by a negative exponential distribution, with the mean value \bar{T}_{off} . Their mean values are system parameters. Equal parameters are assumed for all users. The mean traffic load of each user can be calculated

with $A = \frac{\bar{T}_{on}}{\bar{T}_{on} + \bar{T}_{off}}$ [Erl]. The mean arrival rate

of a stream is calculated with $\lambda_{call} = \frac{1}{\bar{T}_{on} + \bar{T}_{off}} \left[\frac{1}{\text{sec}} \right]$.

Each aircraft transports a certain number of passengers given by the OAG database. An activity parameter a can be set to define the ratio of streaming service users to overall passengers within an aircraft.

The mean number of used channels is calculated with $\bar{N}_{channel} = A \cdot N_{pax} \cdot a$, where N_{pax} is the number of passengers of the aircraft and a is the activity ratio.

At simulation start, each source is set to active or not active with a given probability. Thus we start the simulation in steady state having the mean number of sources active.

Handover Strategies

Inter-satellite Handover can occur due to either the movement of the mobile nodes, and/or the movement of satellites. In the aeronautical case both communication nodes move quickly.

A handover is needed if the elevation angle ε is running below a certain given limit ε_{limit} . As assumption for our simulation an aircraft is equipped with a 70° steerable antenna at the top and has a maximum roll angle of 25° , therefore a elevation limit of $\varepsilon_{limit} = 45^\circ$ was set as parameter.

The simulation uses a simple approach for handover mechanism. At stream initiation, the satellite at highest elevation is selected for the communication link. During active time of a stream it is tested with a given period time whether the current elevation angle is fallen below the elevation limit. In this case a new best satellite will be selected. The process time for handovers is unattended. It is assumed that such delays can be avoided by buffering of the stream data.

The simulation is modular (as seen in Figure 2) and makes it easy to exchange the handover concept. The selection of satellites at initiation of a stream is described in module "find Satellite". According to the handover concept it can be modified or exchanged.

Further concepts could select the longest visible satellite at stream initiation to reduce the number of handovers.

Collecting Statistics

The statistic module collects cumulative data rate usage values for each satellite and stores the information periodically in an output file according to a given period time.

The measurement of number of handovers is performed at the "handover" module, where a data structure member "Handover-Count" of

each stream data structure is increased during a handover process.

After expiration of a stream the total number of handovers, the mean number of handovers and the ratio of handovers to stream duration time is determined and stored in an output file.

OAG Based Flight Routes

We are focusing on the North-Atlantic long-haul flight scenario; it is definitely one of the most important markets for In-Flight Entertainment (IFE). For this purpose we used the OAG flight route data [3].

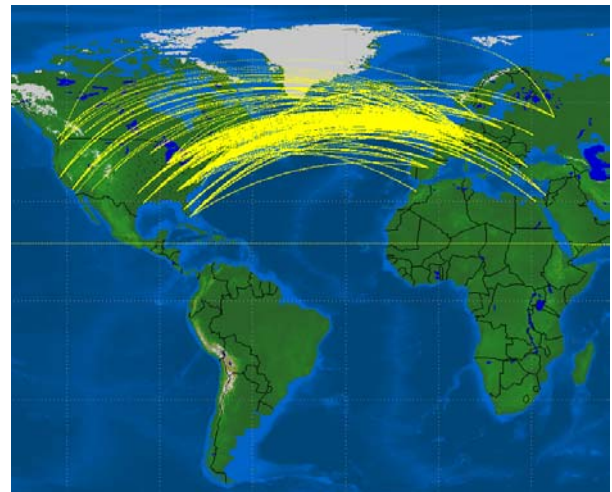


FIGURE 4: NORTH ATLANTIC FLIGHT ROUTES OF ONE DAY

Figure 4 shows a North Atlantic flight routes snapshot of a one day simulation.

Figure 5 shows a temporal distribution of 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.

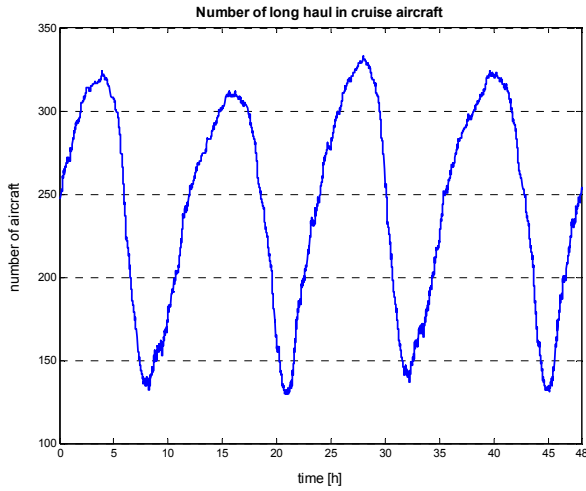


FIGURE 5: NUMBER OF AIRCRAFT EN ROUTE DURING A 48 HOURS SIMULATION

Satellite System

For our simulations we have chosen a MEO satellite system. It consists of 27 satellites in 3 orbit planes; each satellite has an altitude of about 24 km. Figure 6 shows the coverage of this selected constellation with a minimum elevation angle of about 35° to reach global coverage.

The satellite scenario is variable and can easily be exchanged by using another SatLab input file.

More than one satellite could be used to transmit streams from/to an aircraft. Therefore an advanced handover concept by selecting the longest visible satellite can be implemented.

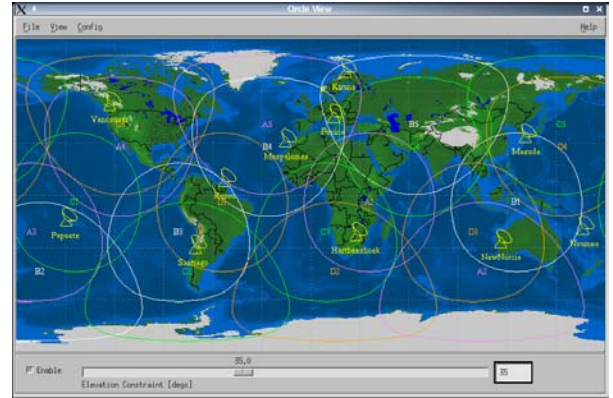


FIGURE 6: MEO SATELLITE SYSTEM OF 27 SATELLITES

Streaming Simulation Results

It could be possible to provide a certain data rates for different stream service classes respectively. As an assumption for the simulation the data rate of a stream was set to 1 to estimate the number of necessary channels. By knowing the maximum and mean number of used channels, one can determine the total data rate by using a distribution of stream service classes.

Table 1 shows a summary of the most important simulation parameters.

Parameter	Value
Elevation limit \mathcal{E}_{limit}	45 [°]
Mean stream off time \bar{T}_{off}	7200 [sec]
Mean stream holding time \bar{T}_{on}	1800 [sec]
Activity ratio a	0.1
Handover test period	60 [sec]
Statistic period	60 [sec]
Data rate	1

TABLE 1: SUMMARY OF SIMULATION PARAMETERS

To prove our simulation results we can compare the selected stream duration distribution and the overall mean value with the set mean values of the negative exponential distribution for stream holding time \bar{T}_{on} . Figure 7 shows a histogram of stream duration. The mean value of about 1795 seconds is close to the set parameter \bar{T}_{on} . About 140000 random stream duration values were selected.

The mean number allocated channel of the whole flight scenario can be calculated by multiplying the total number of users with the mean traffic load per user.

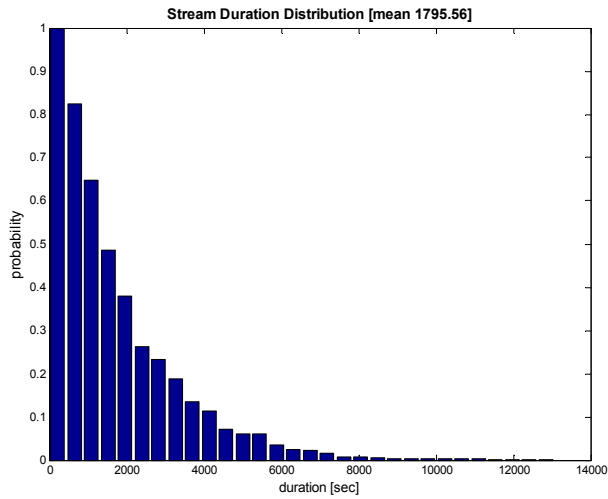


FIGURE 7: STREAM DURATION DISTRIBUTION

Figure 8 shows a plot of channel allocation for all satellites over the simulation time. The measurement period was 60 seconds; therefore the time is given in minute scale. One can see the rotation of the highest satellites over the North-Atlantic region. Maxima occur correlated to the peaks of OAG flight scenario (compare Figure 5).

In Figure 9 the peak values of all satellites are shown in a front view. The maximum value of about 1800 channel allocations occurs at about hour 5, which is also a peak value of in cruise aircraft (compare Figure 5).

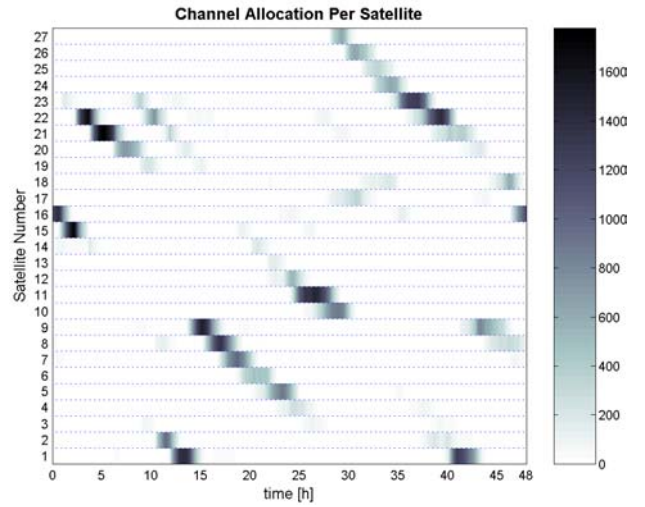


FIGURE 8: NUMBER OF USED CHANNELS PER SATELLITE OVER TIME

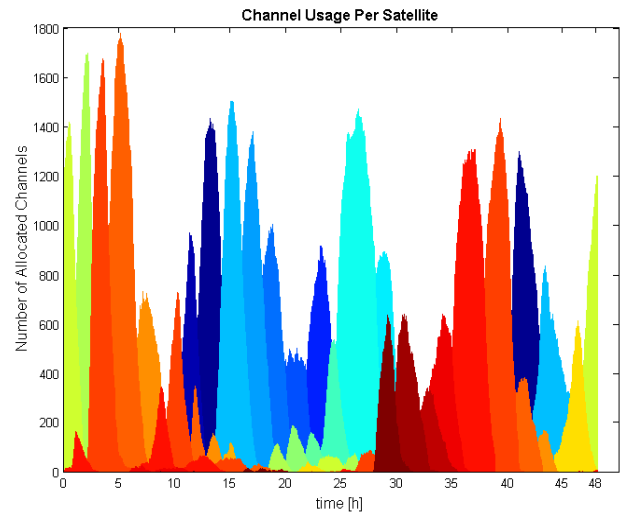


FIGURE 9: CHANNEL USAGE FRONT VIEW

To prove these results, we can calculate the mean active streams at this time. Using the following equation the mean number of active streams can be calculated.

$$\bar{N}_{channel} = A \cdot N_{pax} \cdot a$$

A is the mean traffic load of one user, using the parameter of Table 1 $A = \frac{1800}{9000} = 0.2$.

The number of passengers can be determined by the mean number of passengers within an aircraft and the current number of aircraft ($N_{pax} = \bar{N}_{pax} \cdot N_{aircraft}$). With a mean passenger number of about 227 and a peak value of 330 aircraft resulting about 1450 allocated channels in mean for the time of 5th hour for the whole flight scenario.

Using an elevation limit of 45° handover occur relatively rare. At about 140000 transmitted streams about 4500 handovers occurred during the simulation time.

If we use an 80° elevation limit for the same scenario about 20 handovers per flight occurred.

Conclusion

We have shown the feasibility of the simulation of the whole In-Flight Streaming services 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.

Our simulation model is extendable and variable. Streaming source and handover mechanism can be exchanged easily.

It is to be mentioned, that these results are worst cases. This model implies no buffering.

References

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- [2] SatLab® Manual v4.2, <http://www.mldesigner.com>
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- [5] 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