SATELLITE CAPACITY DIMENSIONING FOR IN-FLIGHT INTERNET SERVICES IN THE NORTH ATLANTIC REGION

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ABSTRACT

In this paper we provide an estimation of the net satellite capacity needed to reliably offer In-Flight Internet services to aircraft flying in the North-Atlantic region. For this work we took into account the expected dynamic usage of AirCom (Aeronautical Communications) Internet services, the average aircraft' cabin configurations and the characteristics of the North Atlantic routes.

INTRODUCTION

Within some years it will become unthinkable to fly without any Internet access point onboard the aircraft. In [1] we provided realistic estimations of the revenues deriving from the aeronautical Internet services offered on North Atlantic flights, approximately the IATA zones 1, 2 and 3, and of the usage of those services. These results were presented according to the aircraft types used on these routes and to their average cabin configuration.

The acquired knowledge about the average data rates needed for AirCom Internet services was already a first important step for the system design but did not yet include information about the actual net satellite capacity needed to guarantee QoS.

In [6] we provided a statistical evaluation of the expected cumulative AirCom Internet users' behaviour and we showed which net channel capacity is required per aircraft.

In this paper we provide the net satellite link capacity for different aircraft types needed to offer AirCom Internet services, at least 99% of the time.

This link capacity per aircraft is then summed up to all fights over the North-Atlantic region, to be served e.g. through a geo-stationary satellite.

AVERAGE RATE ESTIMATION

In [1] we estimated the average data rates needed by AirCom Internet to send and receive information users during North Atlantic flights. Since this estimation was the basis of our investigations on the dynamic behaviour of this kind of Internet user, we shortly recall in the sequel our methodology and the most important results. These results will be presented in terms of expected number of users (achievable market) and consequent traffic data rates.

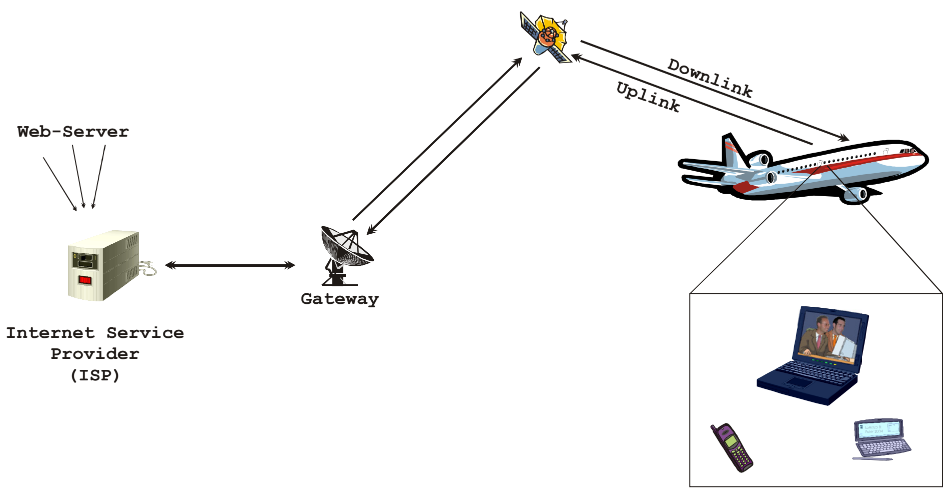


FIGURE 1: AIRCOM INTERNET: BRINGING THE INTERNET TO PASSENGERS

Due to the fact that for the tariffing and the usage of AirCom Internet services there obviously is no data available, we proceeded as follows.

As a first step we segmented the passenger market according to the class they fly (First, Business and Economy) and the purpose of their journey, i.e. we identified the passengers that have the requirement for and the economic capacity to purchase a service of the AirCom ones. The passengers which are flying First and Business or those flying Economy, but being on a business trip, are surely the ones, that have the highest need and the necessary resources to purchase AirCom services as well.

In a second step we analyzed consistent sets of usage statistics and tariffs of the terrestrial mobile Internet services (GPRS Internet services) and provided the available budgets of business and leisure users for such services.

In a further step we applied the tariffing of the terrestrial services that are regarded from passengers as equivalent to the AirCom ones, in terms of deriving benefits, and produced the revenues and traffic estimations for each user. The influences of catalysts and inhibitors were of course considered.

Different usage profiles were obtained, according to the available passengers' budgets, which are obviously correlated to the class the passengers fly and to the purpose of their journey. Finally, based on the average number of passengers in each class, on the real flight durations, on the physiological flight times and on the actual routes, the average number of users and the mean data rates were computed.

Table 1 shows the average cabin configuration and the resulting addressable and achievable market for AirCom Mobile Phone and Internet Services of the six most operated aircraft types for North Atlantic passenger fights.

These numbers are based on OAG's Worldwide Flight database [4] and on the default aircraft' cabin configurations.

For the Internet revenues we expected the passengers working on board to buy 5 MB data packages for 35€ each. This proved to be the most convenient alternative according to the average daily business Internet usage and to its still negligible cost when compared to the daily costs of employees to a company. This led to the results summarized in Table 2.

The average Internet user on board receives during the whole flight an average data rate of about 900 bps. This knowledge was evidently not enough to dimension a whole communication system. We then proceeded with the modelling of the users' dynamic behaviour.

MODELLING THE DYNAMIC BEHAVIOUR OF AN INTERNET USER WITH THE ETSI MODEL

In [6], we estimated the dynamic behaviour of an Internet user by means of the ETSI model [2]. This model consists of three levels of detailedness called layers (see Figure 2).

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 including more than one session for the same user. 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.

	Number of Passengers in			Addressable Market		Achievable Market	
Aircraft	First	Business	Economy	Phone	Internet	Phone	Internet
A340	12	40	211	263	73	73	37
A380	22	96	437	555	162	162	81
B747	23	82	321	426	137	137	69
B767	19	48	168	235	84	84	42
B777	25	57	240	322	106	106	53
MD11	23	55	197	275	98	98	49

TABLE 1: MOST COMMON AIRCRAFT MODELS USED FOR NORTH ATLANTIC FLIGHTS.

	AirCom Internet Services		
		Mean Data Traffic in kbps	
Aircraft	**Number of Users**	**in**	**out**
A340	37	33	4
A380	81	73	8
B747	69	62	7
B767	42	38	4
B777	53	48	5
MD11	49	44	5

TABLE 2: INTERNET TRAFFIC MEAN DATA RATES.

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 [6]. Based on this, several simulations with the most operated aircraft models on North Atlantic routes were made. Table 3 shows the expected mean rates and the measured ones after a simulation time of 10^8 seconds of flight time per aircraft, i.e. for each aircraft about 3000 North Atlantic flights were simulated. The fact that, the measured mean input rates are almost identical to the expected ones, is verifying a sufficient simulation time.

Aircraft Type	Internet user number	Expected mean input rate [bps]	Simulated mean input rate [bps]
A340	37	33341	33318
A380	81	72991	73110
B747	69	62177	62073
B767	42	37847	37725
B777	53	47759	47863
MD11	49	44155	44123

TABLE 3: SIMULATION RESULTS FOR EACH AIRCRAFT TYPE

We produced then the histogram of the used data rate for AirCom Internet services for each aircraft type. The granularity of the histogram was set to 1 kbps. We measured the data rate in 60 s time windows. The results are shown in the figures below in form of PDF (Probability Density Function) and CDF (Cumulative Distribution Function) of the data rates. The graphs were limited at the largest 99.9% CDF value of all aircraft types, which is 260 kbps for the A380.

For each aircraft type we show the network capacity needed to allow the traffic to flow without losses for 99% of the time.

In Figure 3 we compare the different CDF behaviours in the aircraft types A340, B777 and A380. These types were selected, because of their significant number of expected AirCom Internet users. The A340 has the lowest number of expected users among the relevant aircraft types (37), the A380 has obviously the highest (81) and the B777 figure lies in between (53).

The CDF for the A340 increases faster than the others. This indicates that small data rate values have a higher probability compared to the other aircraft types.

The CDF for the A380 shows that high data rate values have a higher probability than for the other aircraft types.

Which net satellite link capacity is then necessary to let the required downloaded data flow over 99% of the time without loss of QoS?

The table below summarizes these results. All data rates are given in kbps.

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

It is to remark, that the ETSI model was adopted as a reference for UMTS network evaluation in 1998, for network dimensioning and performance analysis tasks. The Internet traffic is at 90%-95% elastic traffic relying on HTTP/TCP. TCP traffic is adaptive, in that it adjusts its rate to the network condition. The ETSI model is a free traffic model that does not depend on this, i.e. it has the big advantage of being a source model independent of the topology and congestion states of the rest of the network. This is of paramount importance, if one considers that for AirCom Internet services we are still in the test phase.

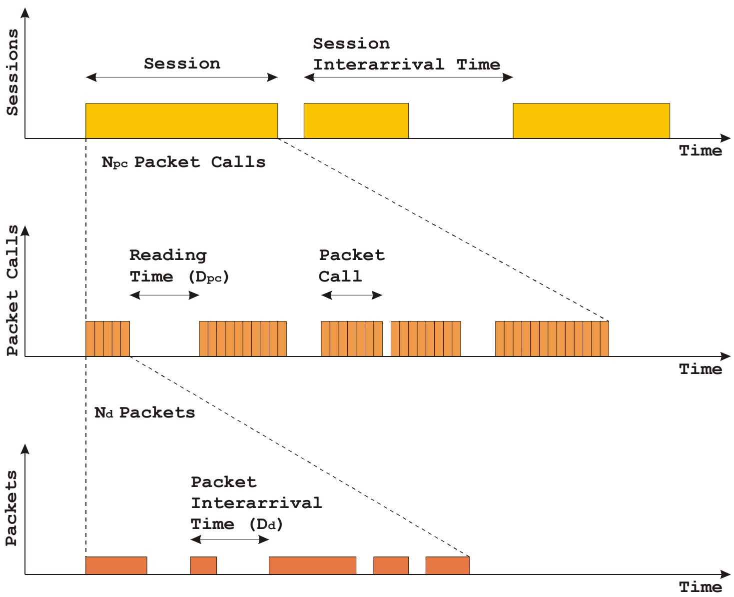
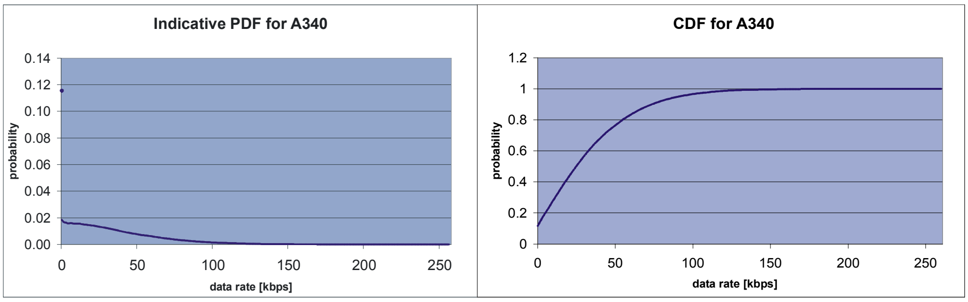
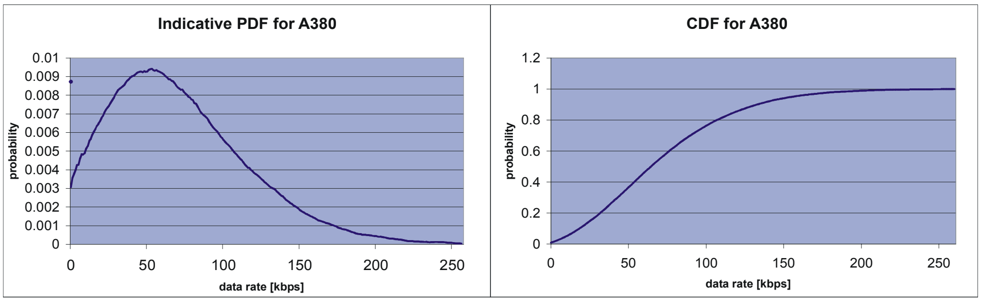


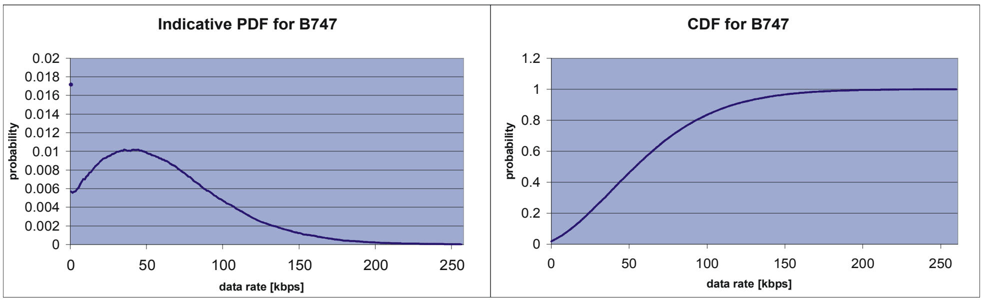
FIGURE 2: ETSI PACKET MODEL FOR INTERNET TRAFFIC



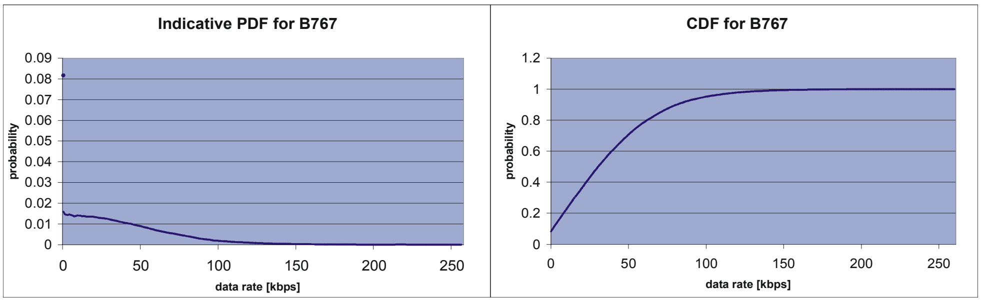
The analysis of the A340 with 37 internet users gave a mean input rate of 33318 bps. The expected input rate was 33341 bps. The CDF cut at 99% gives a rate of 130 kbps.



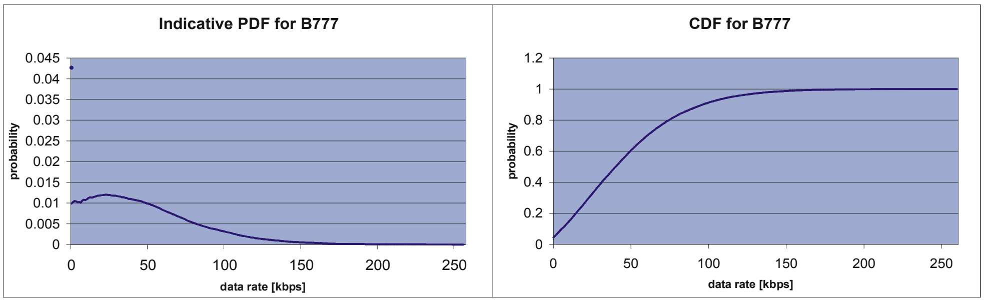
The analysis of the A380 with 81 internet users gave a mean input rate of 73110 bps. The expected input rate was 72991 bps. The CDF cut at 99% gives a rate of 204 kbps.



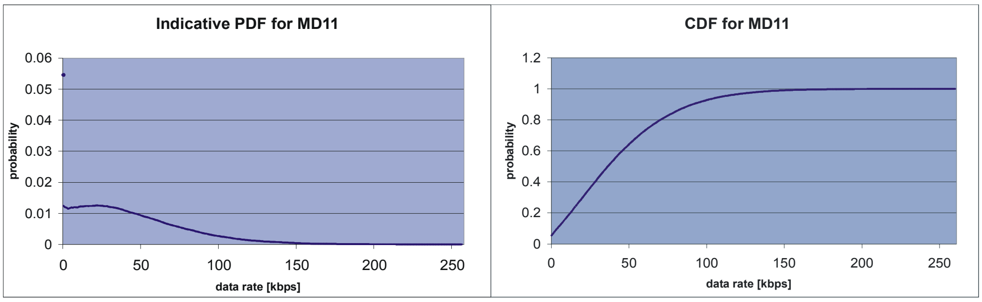
The analysis of the B747 with 69 internet users gave a mean input rate of 62073 bps. The expected input rate was 62177 bps. The CDF cut at 99% gives a rate of 185 kbps.



The analysis of the B767 with 42 internet users gave a mean input rate of 37725 bps. The expected input rate was 37847 bps. The CDF cut at 99% gives a rate of 139 kbps.



The analysis of the B777 with 53 internet users gave a mean input rate of 47863 bps. The expected input rate was 47759 bps. The CDF cut at 99% gives a rate of 159 kbps.



The analysis of the MD11 with 49 internet users gave a mean input rate of 44123 bps. The expected input rate was 44155 bps. The CDF cut at 99% gives a rate of 151 kbps.

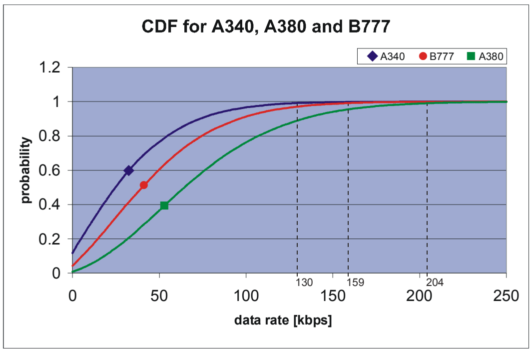


FIGURE 3: COMPARISON OF THE CDF'S FOR A340, B777 AND A380.

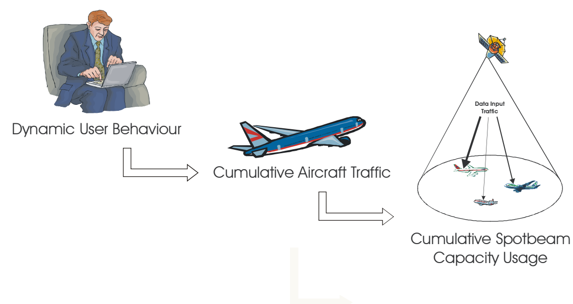


FIGURE 4: STEPWISE APPROACH FROM THE BEHAVIOUR OF A SINGLE AIRCOM INTERNET USER TO THE NEEDED CUMULATIVE SPOTBEAM CAPACITY.

CAPACITY DIMENSIONING FOR A GEO SATELLITE

Summing up the 'per aircraft capacity' over a footprint, leads to satellite capacity dimensioning.

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 4 shows the distribution of the aircraft operating inside the footprint.

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

Figure **5** shows the indicative CDF of data rate required by all aircraft flying in the North-Atlantic area.

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 4: DISTRIBUTION OF THE AIRCRAFT TYPES USED FOR NORTH-ATLANTIC FLIGHTS.

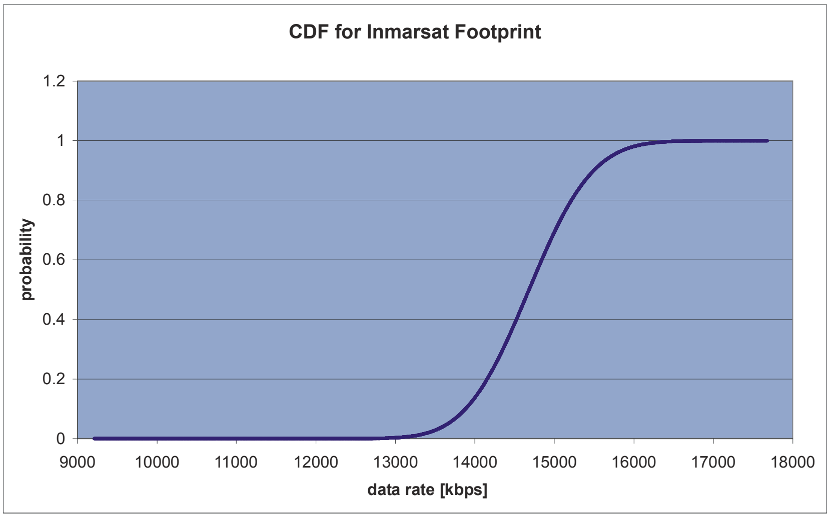


FIGURE 5: INMARSAT FOOTPRINT DATA RATE REQUIREMENTS TO OFFER 99% OF THE TIME AIRCOM INTERNET SERVICES OVER THE NORTH-ATLANTIC REGION WITH THE EXPECTED QOS.

We want to highlight here that the simulations do not account the impact of buffering, in order to remain independent of different buffering strategies. By introducing a buffer, and thus delay, would lead to lower capacity requirements and open the analysis to a trade-off between link utilization and achieved QoS.

Our results have to be understood under this point of view as worst case.

CONCLUSIONS

We have presented the expected dynamic behaviour of AirCom Internet users during long-haul North Atlantic flights and provided per aircraft type and for the whole North-Atlantic region the net satellite channel capacity required to guarantee for 99% of the time a surfing experience with a QoS comparable to that of a business Internet connection.

QoS for AirCom Internet services can be guaranteed on an A380 for 99% of the time by offering a net satellite link capacity of 204 kbps. QoS for AirCom Internet services can be guaranteed on in the North-Atlantic region for 99% of the time by offering a net satellite channel capacity of about 18 Mbps.

ACKNOWLEDGMENT

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