DIMENSIONING OF AERONAUTICAL SATELLITE SERVICES

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ABSTRACT*—This paper addresses the traffic dimensioning for aeronautical services. Specifically, it focuses on wireless services such as UMTS and W-LAN in aircraft cabins that connect the passenger via satellite to terrestrial infrastructure. A multi-service model is presented with specific bit rate and traffic characteristics for manifold services. Furthermore it is discussed how different satellite systems can serve the traffic demand arising from the long-haul traffic over oceans and land masses. Finally, a numerical example shows the expected traffic for a geostationary satellite system.

1. INTRODUCTION

The demand for making air travelling more pleasant, secure and productive for passengers is one of the winning factors for airlines and aircraft industry. Current trends are towards high data rate communication services, in particular Internet applications. In an aeronautical scenario global coverage is essential for providing continuous service. Therefore satellite communication becomes indispensable, and together with the ever increasing data rate requirements of applications, aeronautical satellite communication meets an expansive market. According to analysts, the addressable market amounts to $70 billion through the next ten years [1].

It is anticipated that any early-to-market entry will take an evolutionary approach extending existing systems and services, or leasing currently available (mainly GEO) transponder capacity. A key issue for the success of such systems is the passenger acceptance. It is believed that the ease of access to the service can be predominantly achieved by wireless techniques as the passenger is used to from its daily life. So mobile telephony and Internet access with laptops, either wired or wireless is mandatory rather than fixed cabin installations (e.g., flat screens in backseats which are more appropriate for in-flight entertainment). The EC project WirelessCabin (IST-2001-37466) is looking into those radio access technologies to be transported via satellite to terrestrial backbones [2]. The project will provide UMTS services, W-LAN IEEE 802.11b and Bluetooth to the cabin passengers. With the advent of new services a detailed investigation of the expected traffic is necessary in order to plan the needed capacities to fulfil the QoS demands. This paper will thus describe a methodology for the planning of such systems.

The remainder of the paper is organised as follows: section 2 gives a short description of the WirelessCabin system architecture. In section 3 the services to be offered for the passengers are characterised by their traffic statistics and a multi-service model for multimedia traffic is described. In section 4 the capacity planning of the expected traffic is explained, taking into account several potential satellite constellations. Finally a numerical example is given.

2. WIRELESS CABIN SYSTEM ARCHITECTURE

The service scenario considers travellers in aircraft on the move. In the future, airliners will provide a variety of entertainment and communications equipment to the passenger. Since people are becoming more and more used to their own communications equipment, such as mobile phones and laptops with Internet connection, either through a network interface card or dial-in access through modems, business travellers will soon be demanding wireless access to communication services. So far, GSM telephony is prohibited in commercial

aircraft due to the uncertain certification situation and the expected high interference levels of the TDMA technology. With the advent of spread spectrum systems such as UMTS and W-LAN, and low power pico-cell access such as Bluetooth™, this situation is likely to change, especially if new aircraft avionics technologies are considered, or if the communications technologies are inline with aircraft development as today for the new Airbus long-haul A380 aircraft. With small business jets such as Bombadier LearJets, Gulfstream etc., individual equipment certification is already established.
When wireless access technologies in aircraft cabins are envisaged for passenger service, the most important standards for future use are considered to be: UMTS with UTRAN air interface, Bluetooth™, and W-LAN IEEE 802.11b. Of course, these access technologies will co-exist with each other, beside conventional IP fixed wired networks. The wireless access solution is compatible with other kinds of IFE, such as live TV on board or provision of Internet access with dedicated installed hardware in the cabin seats. Hence, it should not be seen as an alternative to wired architecture in an aircraft, but as a complementary service for the passengers.

For instance, access to VPN or the possibility of being reachable under the user's telephone number while flying, will become real with the network architecture.
The WirelessCabin architecture and its components are conceptually depicted in Figure 1. Such an infrastructure comprises:

- Several wireless access segments in the aircraft cabin, namely a wireless LAN according to IEEE 802.11b standard for IP services, an UMTS pico-cell for personal and data communications, and Bluetooth™ 1.1, as well as a standard wired IP LAN.
- A satellite segment for interconnection of the cabin with the terrestrial telecom networks. The different cabin services must be integrated and interconnected using a *service integrator,* that allows the separation and transportation of the services over a single or several satellite bearers. Peculiarities, such as limited bandwidth, asymmetric data rates on satellite up- and down-link, and dynamic traffic demand between the different services and handover between satellite bearers need to be addressed. In order

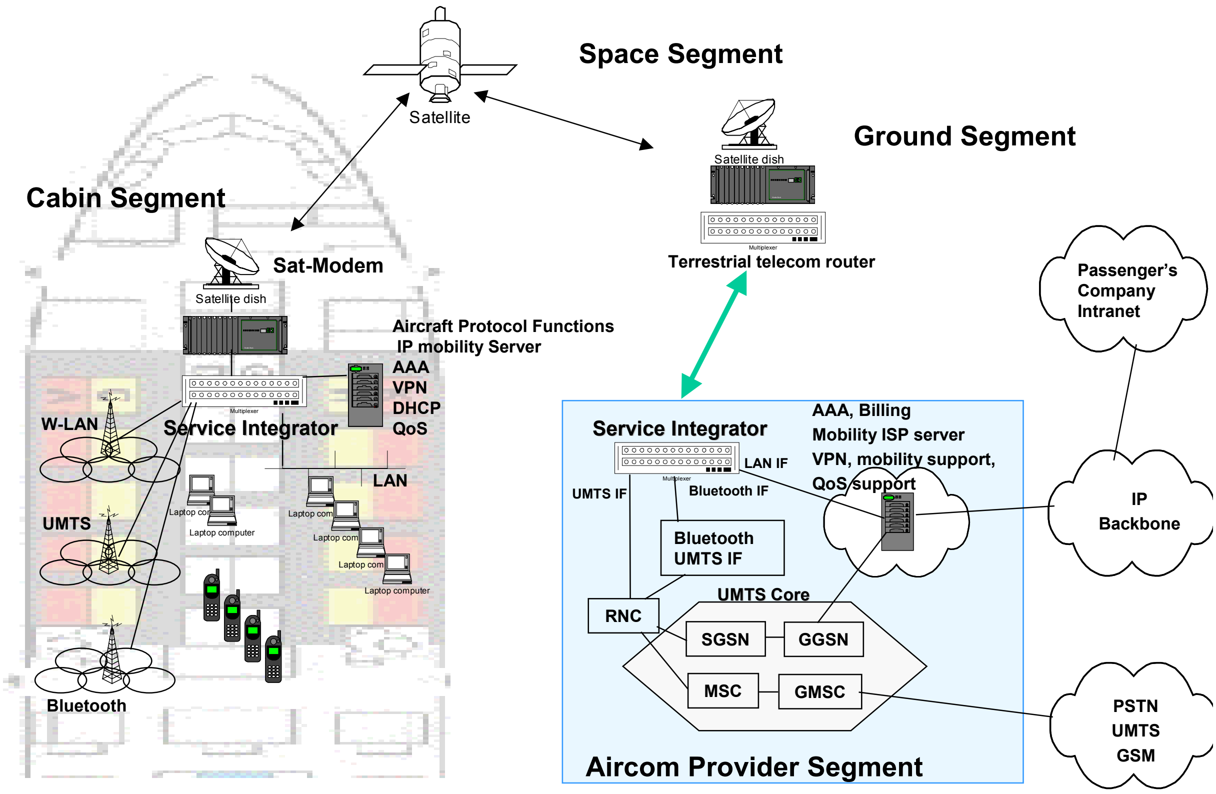


Figure 1: WirelessCabin network architecture

to minimize the cost (satellite resources) for a given QoS efficient interworking between the service integrator and the satellite segment will be required.

- An aircom service provider segment supporting the integrated cabin services. The aircom provider segment provides the interconnection to the terrestrial personal and data networks as well as the Internet backbone. For the UMTS cabin service, a subset of the UMTS core network must be available.

The provision of such a heterogeneous access network with collectively mobile users requires the development of new protocol concepts to support

- the integrated services with dynamic bandwidth sharing among the services and asymmetrical data rate;
- IP mobility and virtual private networks (VPN) for the individual passengers in the mobile network;
- authentication, admission and accounting (AAA) in the mobile network, especially taking into account the necessity to support different pricing concepts for each passenger in the mobile network and the interaction of airline, satellite provider, aircom service provider and terrestrial service providers.

Satellite Connection

Connection to telecom networks is considered to be achieved by satellites with large coverage areas [3], especially over oceanic regions during long-haul flights. The service concept needs to take into account today's peculiarities of satellite communications, thus it must cope with the available or in near future available satellite technology, and interworking must be performed at aircraft interface level with the satellite segment, cf. Figure 2:

- Only restricted satellite data rates will be available in the near future; thus the bandwidth that is requested by standard interfaces of the wireless standards needs to be adapted to the available bandwidth (typically: 432 kb/s in down-link, 144 kb/s up-link (Inmarsat B-GAN™), or 5 Mb/s in down-link, 1.5 Mb/s in up-link (Connexion™ by Boeing)). Furthermore, dynamic bandwidth management is needed to allocate higher bit rates from temporarily unused services to other service.
- Currently, few geostationary satellites such as the Inmarsat fleet are available for two-way communications, that cover the land masses and the oceans. Ku-band may be used on a secondary

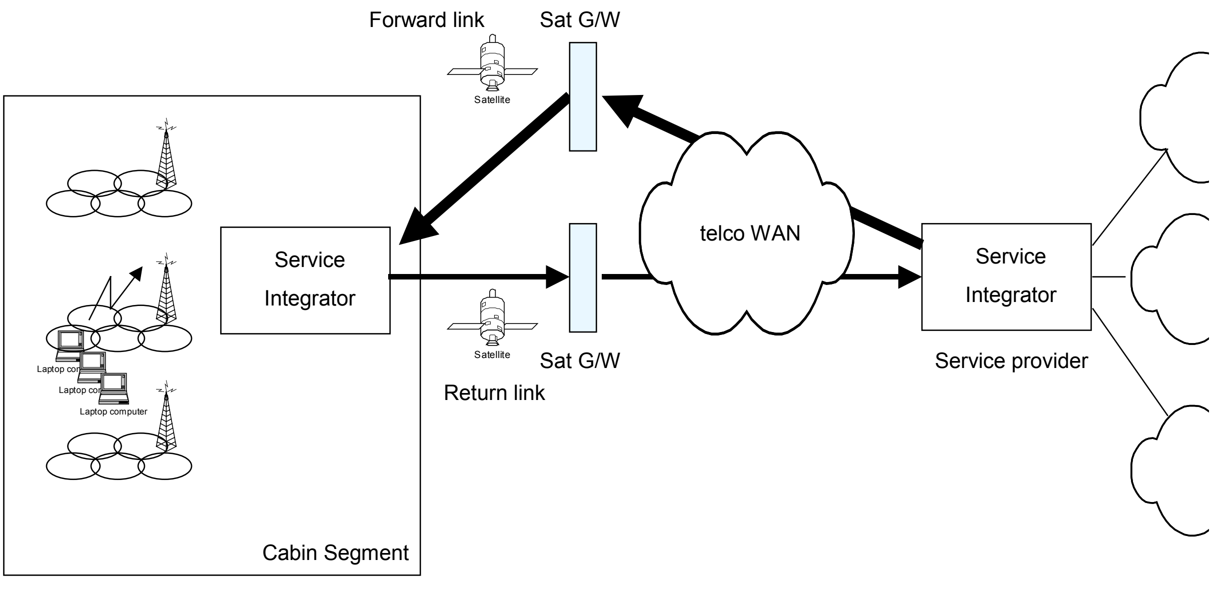


Figure 2: Satellite connection scenario

allocation basis for aeronautical mobile satellite services (AMSS) but bandwidth is scarce and coverage is mostly provided over continents. K/Ka-band satellites will be launched in the near future, again here continental coverage is mainly intended. The scenario must thus consider

- the use of different satellite systems, which will probably force the support of different service bearers, and
- **handover** between satellite systems.

It is assumed that each satellite segment is connected via terrestrial wide area networks or via the IP backbone to the aircom service provider.

- Asymmetrical data rates in satellite up- and down-links, that may also be caused to operate in conjunction with different satellites systems for up- and down-link. The service portfolio in the cabin and the service integration needs to cope with this possibility.

The different wireless access services of UMTS, W-LAN and Bluetooth require an integration of the services over the satellite. The central part of the service portfolio provisioning is the service integrator (SI), cf. Figure 3. The service integrator will provide the interfaces for the wireless and wired service access points in the cabin, as well as the interface to the terrestrial networks at aircom provider site. All services will be bundled and transported between a pair of Service Integrators. It performs the encapsulation of the services and the adaptation of the protocols.

The SI multiplexer is envisaged to assign variable capacities to the streams, controlled by a bandwidth manager that monitors also the QoS requirements of the different service connections. Changes in capacity assignment must be signalled to the SI at the other communication end. The heterogeneous traffic stream is then sent to streaming splitter/combiner. This unit is envisaged to support several satellite segments and to perform handover between them. Asymmetrical data rates in inbound and outbound directions can be managed here. Adaptation to the supported satellite segments are done by medium access controllers (MAC) in a modular manner. Towards the terminal side, the interfaces of the wireless access standards need to interwork with the transport streaming of the SI by specific adaptation layers (AL). These ALs have to be designed according to the analysis of the impact of delay, jitter and restricted / variable bandwidth on the protocol stack. Buffering (to compensate delay jumps at handover) and jitter compensation for real-time services (e.g., voice) must be also provided here. Above scheme was submitted for patenting in [4].

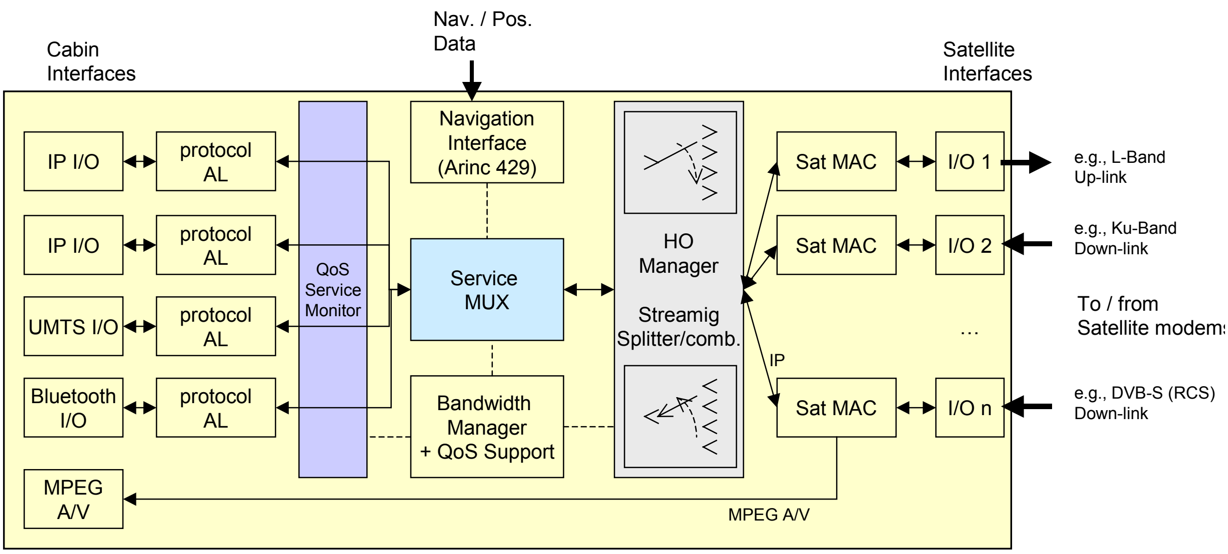


Figure 3: Service Integrator

3. CABIN SERVICES AND MULTI-SERVICE TRAFFIC MODEL

A central issue affecting the addressable market(s) is in how far the underlying business case combines separate market segments which are potentially closely related to the *aeronautical broadband satellite communications (AirCom)* segment in a narrow, i.e. "communication-only", sense. Concerning *AirCom*-specific services we propose a classification into five categories with their particular service profiles as summarized in Table I. A more detailed discussion of AirCom services and the rationale for this classification can be found in [5], as well as an overview of the state-of-the-art in terms of existing and planned systems and services.

The next step is now to derive the individual traffic statistics for the identified service categories. Table II contains a list of traffic parameters for possible aircom communication services. Note that the usage parameters are estimated currently and will be refined by passenger interviews in the WirelessCabin project. The second column shows how frequently an application may be used. The numbers apply for business travellers. It is assumed that the video conferencing services will only apply to dedicated corporate aircraft. The third column shows the average duration of the usage of an application. The fourth and fifth columns show the bit rates required by the applications. Here, forward link means the direction towards the aircraft. The last column indicates the burstiness which is defined here as peak bit rate divided by the average bit rate. If more than one value is given for the burstiness, they refer to the different service components of a multimedia service.

In particular, for modelling the multi-service traffic generated and received on-board the aircraft, an earlier developed linear scalable multi-service traffic model is currently being adapted to the aeronautical scenario. Figure 4 provides an overview and details of the original traffic model as it has been used for the dimensioning of the EuroSkyWay satellite system and its particular terminal types [6].

TABLE I. CATEGORIZED AIRCOM SERVICES

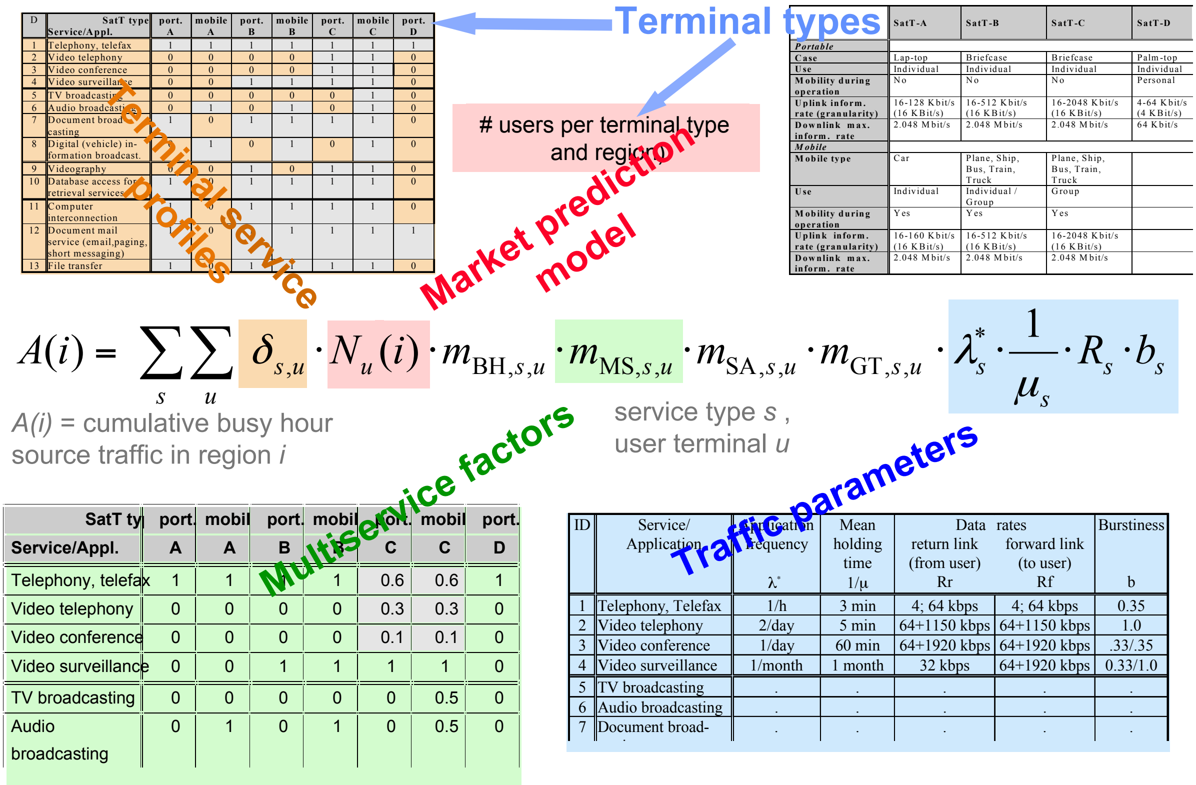
Category	Services
Infotainment	www, email, live TV, gambling, phone, intelligent travel information
Office	email, www, phone, fax, video-conferencing, file transfer
Telemedicine	video conferencing, vital data trans-mission
Flight security	cabin & cockpit survey, flight recorder data transmission
Logistics & maintenance	video and audio server upload, aircraft maintenance data

The traffic generated and received by a single aircraft is a function of

- the distribution of passengers among first, business and economy class, (obviously passengers in first and business class are more keen on using AirCom services)
- the duration of the flight, (it seems reasonable that passengers of short flights will use virtually no AirCom services, it is thinkable to introduce a threshold in the AirCom traffic analysis for the flight duration, flights taking less than 1.5 hours could be neglected)
- the physiological flight time (it is more likely that passengers flying from East to West on long haul flights will make use of AirCom than passengers flying from

TABLE II. AIRCOM TRAFFIC CHARACTERISTICS

Service, Application	Application frequency	Mean holding time	Data rate return link	Data rate forward link	Burstiness
Telephony	2/h	3 min	9.6 kb/s	9.6 kb/s	2.857
Video telephony	0.01/flight	5 min	16+64 kb/s	16+64 kb/s	1.0
Video conference	0.01/flight	15 min	16+384 kb/s	16+384 kb/s	3
Shared Applications	0.01/flight	15 min	384 kb/s	384 kb/s	2.5
Video surveillance	permanent	unlimited	64 kb/s	-	1.0
Document mail service (email, short messaging, paging)	5/h	0.25 s	16 kb/s	16 kb/s	1.0
File transfer	5/h	4 s	144 kb/s	144 kb/s	20
WWW	2/h	30 min	16 kb/s	144 kb/s	20



$$A(i) = \sum_{s}\sum_{u} \delta_{s,u} \cdot N_u(i) \cdot m_{\mathrm{BH},s,u} \cdot m_{\mathrm{MS},s,u} \cdot m_{\mathrm{SA},s,u} \cdot m_{\mathrm{GT},s,u} \cdot \lambda_s^* \cdot \frac{1}{\mu_s} \cdot R_s \cdot b_s$$

Figure 4: Components of the linear scalable multi-service traffic model for capacity dimensioning of broadband satellite systems.

West to East, who should sleep to minimize the jetlag effects),

- the set of available services.

The traffic should be described as superposition of the traffic generated by each passenger according to the characteristics of the desired services in terms of

- data rate: symmetric, asymmetric, peak rate, sustainable rate,
- QoS parameters: delay, delay variation, loss rate.

4. SERVICE DIMENSIONING

This section provides an overview of key issues and steps for the systematic system dimensioning of WirelessCabin aircom satellite communications system. We will tackle the satellite constellations as potential candidates for aircom services as well as the gross traffic calculation and assignment process.

Different market entry options and reference business cases must be taken into account in an initial stage of a system design. The evolutionary path leads from existing L-band systems such as Inmarsat GAN (see Figure 5) or B-GAN in few years up to C/Ku band and existing GEO transponders, whereas the "revolutionary" path may target from the beginning at advanced K/Ka band technology and the design of a tailor-made, potentially non-GEO system.

The system dimensioning process can be structured in several steps:

- Determination of gross traffic per aircraft using the multi-service model as

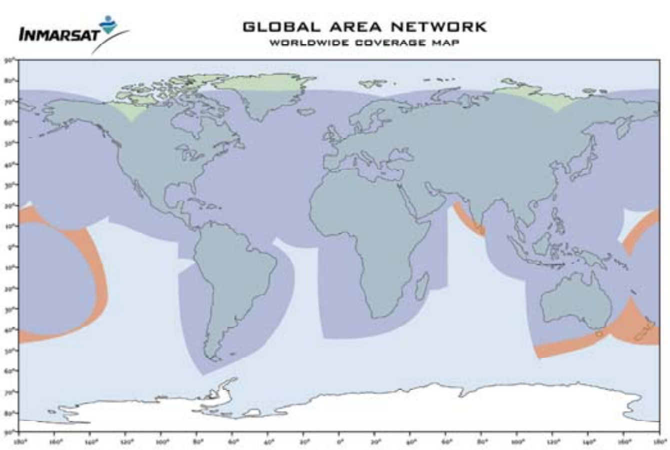


Figure 5: Inmarsat L-band coverage

described in section 3.

- Determination of the timely and locally varying traffic, depending on the flight path and flight schedule, assuming also a service roll-out scenario for different airlines and aircraft types.
- Identification of potential serving satellites and their coverage areas.
- Mapping and traffic allocation of the aircom traffic to the satellite systems.

Two key observations concerning the "geographic market" are (i) the pronounced asymmetry of market opportunities between northern and southern hemisphere (partly just a result of our earth's "continental layout"), and (ii) the fact that a significant share of the addressable market is at higher (northern) latitudes, especially with the important long-haul intercontinental flight routes between the European, North American and East Asian regions. Both observations are illustrated in Figure 6, although its view is Europe-centric; the underlying flight route investigations have been performed within the European ACTS project ABATE and have been used for design and dimensioning studies of an aeronautical subsystem of the EuroSkyWay satellite communications system [6].

Flight route statistics/data are relevant to get (series of) snapshots of airplane distribution in the service coverage area, which are essential input information for satellite antenna spot beam design and overall system capacity dimensioning. Usually, the latter will be based on some worst case situation extracted from the snapshots. A simplified minimum set of data describing a global or regional flight scenario can be based on

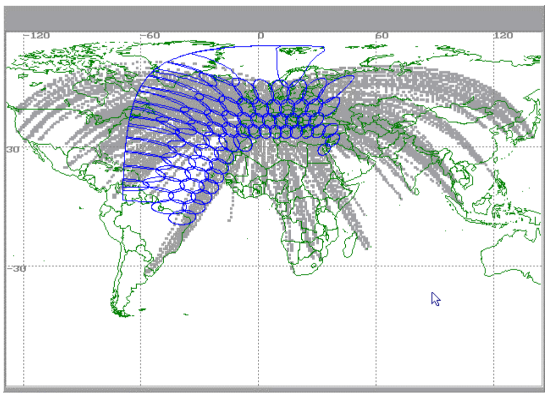


Figure 6: ABATE coverage and flight route density [6].

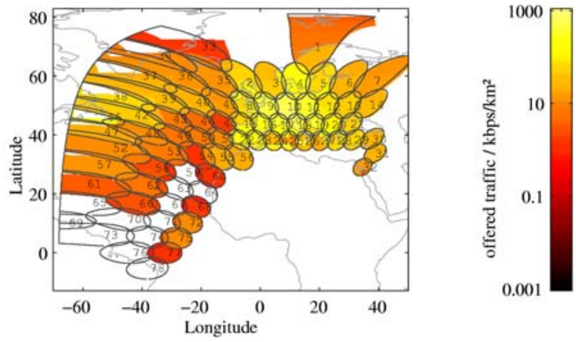


Figure 7: ABATE traffic density

- departure and destination airport locations,
- related departure and arrival times (either from exact time tables, or as a flight frequency model),
- a simple model for cruising speed (e.g., simply a constant speed derived from the flight distance divided by the flight duration, neglecting any influences from other flight phases),
- a simple model for geographic flight routes (e.g., each flight following a great circle between start and destination).

Actual flight routes are very variable due to the needed adaptation to the jet streams. Variations of plus minus 1000 km with respect to the expected position on the geometric shortest route are normal. This could then mean variations in latitude/longitude of up to $\pm 9°$ with respect to the expected position on the shortest route.

The results of the traffic calculation with overlaying spotbeam coverage from the ABATE system are depicted in Figure 7. In the figure the density is shown for the time 17:00 h.

The capacity planning is here important. The goal is to minimize the peak capacity per spotbeam in order to reduce the requirements for the satellite payload. Several algorithms have been proposed in [7]. After distributing the traffic to the spotbeams using the HomFlow graph algorithm, a carrier assignment has been performed using impairment graphs and graph colouring. The result of this process can be seen in Figure 8. One can easily see that adjacent spotbeams must be decoupled by separate frequencies. In general, three frequencies would suffice. However, spotbeam #47 and #53 are coupled through large overlapping. Thus, at least

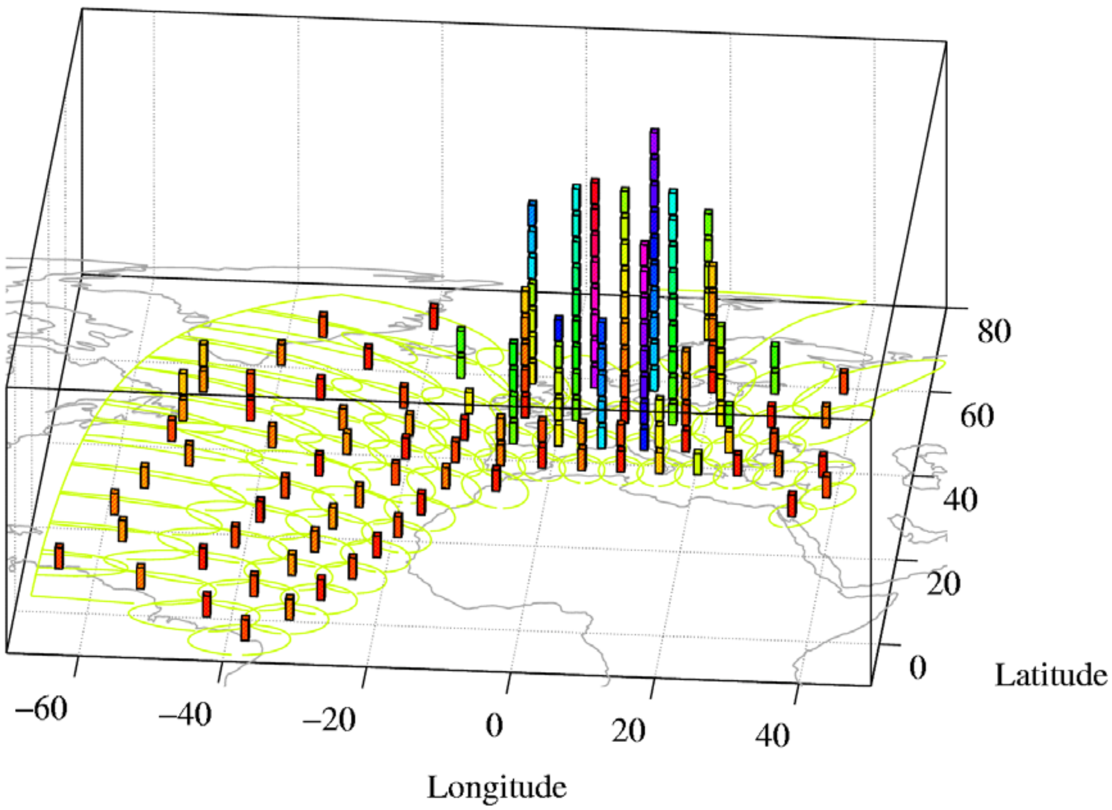


Figure 8: Optimized aircom traffic and carrier assignment for the ABATE scenario

four frequencies are required. The highest traffic density in Europe is caused by medium haul air flights in the evening busy hour while transatlantic flights require fewer capacity.

5. ACKNOWLEDGEMENT

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