Requirements for Communication Systems in Future Passenger Air Transportation

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The Airports Council International (ACI) estimates that the number of global passengers will increase from over 5 billion passengers today to 12 billion by 2031. At the same time, major aircraft (A/C) manufacturers like Boeing and Airbus estimate that the worldwide commercial A/C fleet will increase 5% per year over the next 20 years, i.e. the commercial aviation market will be doubled. This growth will require not only new airports infrastructure but also investments in en-route and Air Traffic Management (ATM) systems. Part of such investments must be aimed to a growth in the capacity of the onboard communication systems. With increasing speed of Internet connections on land, passengers expect not only to be connected to the Internet but also to have good connectivity with high bandwidth to enable them the access and use of multitude applications during the flight. The need to be connected adds to the increased passenger traffic and even the implementation of new aviation standards such as: Controller-Pilot Data Link Communications (CPDLC), Future Air Navigation System (FANS), Automatic Dependent Surveillance-Broadcast (ADS-B), VHF Data Link mode 2/3/4 (VDL2/3/4), etc. Governmental initiatives such as NextGen in U.S.A. and Single European Sky ATM Research (SESAR) in Europe are forcing aviation companies to fulfill these needs to satisfy their customers while complying with regulations in different airspaces. As a result, the aviation industry faces a new paradigm in the communication system requirements, which is the subject of this paper. As a first requirement, the industry must be prepared for seamlessly adoption of future communication systems, standards, or regulation without this implying the continuous installation of new equipment, but rather the modification of the existing one. Today, any modernization of these systems represents a major change in airborne and on-land equipment, which means buying new equipment, installation of new antennas on the A/C, etc. The main repercussions of this lack of flexibility and scalability are that many of the systems currently used have become obsolete, their modernization, when possible, is highly constrained by previous limitations, and new deployments are painfully long. Therefore, the modernization of the onboard communication systems has to be flexible enough to address all these drawbacks. This paper also discusses several Requirements for Communication Systems in Future Passenger Air Transportation (RCSFPAT). Requirements like the bandwidth, which will depend on factors that cannot yet be predicted accurately (amount of increase in air traffic, capabilities of service providers, etc.). The two primary drivers for the RCSFPAT are: 1) to provide an appropriate communication infrastructure to support future air communication systems growth, and 2) to provide a consistent global solution to support the goal of fulfilling the communications requirements from passengers and communications between A/C Earth Stations (AESs) and Ground Earth Stations (GESs) thus to ensure flight safety. In order to provide worldwide coverage of the communication systems, the only current technology able to cover the oceanic regions is Satellite Communications (SatCom). Indeed, most of the airlines and A/C manufacturers have signed

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agreements with SatCom service providers and their communications systems are based on SatCom. This paper analyzes the capabilities of current SatCom services to fulfill RCSFPAT, and the requirements of future systems to meet the expectations of growth in the air transportation. However, the current capabilities of SatCom cannot support the bandwidth needs in those areas with a higher density of flights. Fortunately, these areas commonly extend over land due to the presence of domestic flights, and thus the increased communication requirements can be complemented with on-land infrastructures. The suitability of current systems such as those used in mobile communications and WiMAX is studied in this work, and some guidelines are provided for future systems to satisfy RCSFPAT. A solution with a multimode operation to accommodate different phases of flight as well as the hardware requirements to fulfill the RCSFPAT is also presented. In addition, the so-called Size, Weight, Power and Cost (SWaP-C) requirement is of crucial importance in aviation where any kilogram matters. By using Software Defined Radio (SDR), the weight of equipment is reduced. The number of radios, coax cables and antennas are reduced as well. Costly redundancies can be handled by the use of reprogrammable SDRs. The overall wiring required for navigation, communication, and surveillance systems interconnections are also minimized. As a consequence, the reduced number of parts increases the reliability and safety at the system level. By reducing the system weight and power consumption, SDRs also bring the additional benefits of reduced Greenhouse Gas (GHG) emissions and fuel cost savings. In this line, LASSENA Laboratory is currently embarked on a project to develop Software Defined Avionics (SDA) in collaboration with several industrial partners in the aviation, aerospace and embedded systems sectors. Although the aviation community is considering the requirements for operating Unmanned Aerial Vehicles (UAVs), or Systems, within the ATM infrastructure, this item is beyond the scope of this work. In conclusion, the problem addressed in this paper is not an easy one: The passengers expectations demand huge communication capabilities, the targeted coverage is worldwide, the density of flights varies in different regions, and the latency difference between different A/Cs is in the order of milliseconds. SDR appears as the only technology able to fulfill flexibility and SWaP-C requirements and Radio Frequency Unit (RFU) must be designed to meet reconfigurability scalability requirements as well. The new passenger air transportation paradigm demands an analysis of the requirements of future communication systems in a sector typically not able to satisfy the communication needs of their customers. In this globalized world, the offer of communication services may establish the difference between successful companies and the rest. Airlines not able to provide wideband communication services may be forced to transform themselves into low-cost for surviving.

Nomenclature

A/A = Air-To-Air
A/C = Aircraft
A/G = Air-To-Ground
ACARS = Aircraft Communications Addressing and Reporting System
ACI = Airports Council International
ADS-B = Automatic Dependent Surveillance-Broadcast
AES = Aircraft Earth Station
AMSS = Airborne mobile satellite system
AOC = A/C Operator Communications
APC = Airline Passenger Communications
ARC = Aviation Rulemaking Committee
ATC = Air Traffic Control
ATIS = Automatic Terminal Information Service
ATM = Air Traffic Management
ATN = Aeronautical Telecommunication Network
ATS = Air Traffic Services
ATSC = Air Traffic Security Coordinator
BW = Bandwidth
CAN = Collaborative Avionic Network
CBB = Connexion by Boeing
CMC = Central Maintenance Computer
CPDLC = Controller-Pilot Data Link Communications
CSMA = Carrier Sense Multiple Access
D8PSK = Differentially Encoded 8-Phase Shift Keying
EFB = Electronic Flight Bags
ELB = Electronic Log Book
ENR = En Route
ETSI = European Telecommunications Standards Institute
FAA = Federal Aviation Administration
FANS = Future Air Navigation System
G/G = Ground-To-Ground
GEO = Geostationary Earth Orbit
GES = Ground Earth Station
GFSK = Gaussian-Filtered Frequency Shift Keying
GHG = GreenHouse Gas
GLSR = Geographic Load Share Routing
HFDL = High Frequency Data Link
ICAO = International Civil Aviation Organization
LASSEN = Laboratory of Specialized Embedded System, Navigation and Avionic
LEO = Low Earth Orbit
LTE = Long Term Evolution
PCD = Personal Communication Devices
PL = Power Level
QoS = Quality of Service
RCSFPAT = Requirements for Communication Systems in Future Passenger Air Transportation
RFU = Radio Frequency Unit
SatCom = Satellite Communication
SDA = Software Defined Avionics
SDR = Software Defined Radio
SDWR = Software Defined Wideband Radio
SESAR = Single European Sky ATM Research
STDMA = Space-Time Division Multiple Access
SWaP-C = Size, Weight, Power and Cost
TDMA = Time Division Multiple Access
UAV = Unmanned Aerial Vehicles
VDL2 = VHF Data Link mode 2
VHF = Very High Frequency
VPN = Virtual Private Network
$\alpha$ = shape parameter
$\beta$ = probability for the maximum packet size
$C_{ij}$ = maximum instantaneous per-node throughput
$D_d$ = mean value of gap time between two consecutive packets
$D_{pc}$ = interarrival time between web pages
$i$ = node in the network
$j$ = neighbour node
$k$ = positive constant
$L_G$ = total of Air-To-Ground and Ground Earth Station links
$m$ = maximum allowed packet size
$N$ = mobile nodes
$N_d$ = mean packet number of packets per page
$N_{pc}$ = number of pages per session
$P$ = normal Pareto distributed random variable
I. Introduction

Before October 2013, when an A/C was ready to take off, passengers knew that in few minutes their smartphones and other Personal Communication Devices (PCD) would stop working. There would be no way to read emails, or status updates on Facebook, or Google. In few words, there would not be any phone service or Internet connection. Not until that date, that the airlines would have require to passengers to turn off all devices during take offs and landings; “that rule was changed to allow the use of Wi-Fi, while still prohibiting sending or receiving emails and text messages below 10,000 feet to prevent interference with critical A/C systems” 1.

Although many airlines currently offer Internet and telephony services via satellite link during the flight, the technology is far from being available on all A/C. With increasing speed of Internet connections on land, passengers expect not only to be connected to the Internet but also to have good connectivity with high bandwidth to enable them the access and use of multitude applications during the flight.

A first step was in 2000, with the appearance of Connexion by Boeing (CBB); airlines like Scandinavian Airlines, Japan Airlines, Lufthansa, British Airways, etc. offer their passengers a service called Airborne mobile satellite system (AMSS) for high-speed communications in long distance travels (CBB is not available anymore). In order to provide worldwide coverage of the communication systems, the only current technology able to cover the oceanic regions is SatCom. Indeed, most of the airlines and A/C manufactures have signed agreements with SatCom service providers and their communications systems are based on SatCom.

Many airlines and government agencies, as the Federal Aviation Administration (FAA), recognize that consumers are intensely interested in the use of PCDs aboard on-flight. That is why FAA tasked a government-industry group to examine the safety issues and the feasibility of changing the current restrictions. Previously in 2012, FAA updated its guidance for approving airlines to allow pilots to use Electronic Flight Bags (EFB) in the cockpit, requiring that they demonstrate that the device does not interfere with an A/Cs electronic systems, according to Aviation Rulemaking Committee (ARC) 2.

In addition, the ACI estimates that the number of global passengers will increase from over 5 billion passengers today to 12 billion by 2031 3. At the same time, major A/C manufacturers like Boeing and Airbus estimate that the worldwide commercial A/C fleet will increase 5% per year over the next 20 years 4, i.e. the commercial aviation market will be doubled. This growth will require not only new airports infrastructure but also investments in en-route and ATM systems.

The need to be connected is added to the increase in passenger traffic and even to the implementation of new aviation standards such as: CPDLC, FANS, ADS-B, VDL2/3/4, etc. Governmental initiatives such as NextGen in U.S.A. and SESAR in Europe are forcing aviation companies to fulfill these needs to satisfy their customers while complying with regulations in different airspaces.

As a result, the aviation industry faces a new paradigm in the communication system requirements, which is the subject of this paper. As a first requirement, the industry must be prepared for seamlessly adoption of future communication systems, standards, or regulation without this implying the continuous installation of new equipment, but rather the modification of the existing one. Today, any modernization of these systems represents a major change in airborne and on-land equipment, which means buying new equipment, installation of new antennas on the A/C, etc. The main repercussions of this lack of flexibility and scalability are that many of current equipment has become obsolete; its modernization, when possible, is highly constrained by previous limitations; and new deployments are painfully long. Therefore, the modernization of the onboard communication systems has to be flexible enough to address all these drawbacks.

At first, this paper presents the current scenario wherein the communication systems for passenger air transportation are developed, as well as the services that are available at each phase of flight. The following section presents the capacity requirements in order to provide an appropriate communication infrastructure supporting future

\[
\begin{align*}
Q_{ij} &= \text{transmission queue} \\
R_s &= \text{mean input rate during of an active session} \\
R_{user} &= \text{mean rate per user} \\
S_d &= \text{size of each packet} \\
T_{OFF} &= \text{session inactive time} \\
T_{ON} &= \text{session active time} \\
\mu_{max} &= \text{maximum instantaneous per-node throughput} \\
\mu_n &= \text{mean packet size} \\
x &= \text{scale parameter}
\end{align*}
\]
air communication systems growth, as well as to provide a consistent global solution fulfilling air passenger communications, air traffic security coordinator service and operational communications requirements between AESs and GESs. Section IV proposes a solution with multimode operation in order to accommodate different phases of flight as well as hardware requirements to fulfill the RCSFPAT. Finally, benefits and conclusions are presented Section V.

II. Current scenario

As explained in section 7.1.1 of Annex 6 to the Convention on International Civil Aviation\(^4\), an aircraft shall be provided with radio communication equipment capable of:

1) Conducting two-way communication for aerodrome control purposes;
2) Receiving meteorological information at any time during flight; and
3) Conducting two-way communication at any time during flight with at least one aeronautical station and with such other aeronautical stations and on such frequencies as may be prescribed by the appropriate authority.

A. A/C Communications Addressing and Reporting System (ACARS)

Currently, the continuous communication between A/C - aeronautical station is assured with the standard ACARS cockpit data link avionics. This data link service provides air-ground communications via VHF radio stations and satellites to the airline industry. The ACARS system was first introduced to enable A/C to send their take-off and landing reports automatically to airline computers; today the system is installed in almost all commercial A/C and is being used for applications that require a very reliable service\(^5\).

![ACARS messages during flight phases](image)

**Figure 1.** ACARS messages during flight phases

With increasing speed of Internet connections on land, the emergence of new technologies and the continuous development of the satellite network, the current scenario in A/C communication systems has changed over the last years. Once on the A/C, passengers expect not only to be connected to the Internet but also to have good connectivity with high bandwidth to enable them the access and use of multitude applications during the flight. The increase in supply and demand passenger air transportation market, forces the airlines to offer more and more onboard and in-flight services. Regardless the type of passenger or its purchasing power, the necessity of being online today is growing. In Table 1, we have identified the services that are offered by airlines and some service providers.

<table>
<thead>
<tr>
<th>Taxi</th>
<th>Take-Off</th>
<th>Departure</th>
<th>En Route (ENR)</th>
<th>Approach</th>
<th>Land</th>
<th>Taxi</th>
</tr>
</thead>
<tbody>
<tr>
<td>From A/C</td>
<td>From A/C</td>
<td>From A/C</td>
<td>From A/C</td>
<td>From A/C</td>
<td>From A/C</td>
<td>From A/C</td>
</tr>
<tr>
<td>OUT</td>
<td>OFF</td>
<td>Engine Data</td>
<td>Position Reports</td>
<td>Provisioning Gate</td>
<td>ON</td>
<td></td>
</tr>
<tr>
<td>Link Test</td>
<td>Weather Reports</td>
<td>Weather Requests ETA</td>
<td>Requests ETA</td>
<td>Fuel Information</td>
<td>IN</td>
<td></td>
</tr>
<tr>
<td>Clock Update</td>
<td>Delay Info/ETA</td>
<td>Special Requests</td>
<td>Special Requests</td>
<td>Crew Information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay Reports</td>
<td>Voice Request</td>
<td>Engine Information</td>
<td>Engine Information</td>
<td>Fault Data from</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To A/C</td>
<td>To A/C</td>
<td>To A/C</td>
<td>To A/C</td>
<td>To A/C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDC and ATIS</td>
<td>Flight Plan Update</td>
<td>A/C Oceanic</td>
<td>A/D Assignment</td>
<td>Gate Assignment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight and</td>
<td>Weather Reports</td>
<td>Clearance</td>
<td>Connecting Gates</td>
<td>Connecting Gates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance</td>
<td></td>
<td></td>
<td>Passengers and</td>
<td>Passengers and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airport Analysis</td>
<td></td>
<td></td>
<td>Crew ATIS</td>
<td>Crew ATIS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V-Speeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight-Plan, Leaf FMC</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

APT : Automatic Terminal Information Service
TMA : Terminal Maneuvering Area
ENR/ORP : Oceanic Remote Polar

ATIS : Automatic Terminal Information Service
ATC : Air Traffic Control
CMC : Central Maintenance Computer
PDC : Pre Departure Clearance

V-Speed : Standard terms used to define airspeeds
FMC : Flight Management Computer
ETA : Estimated Time of Arrival

American Institute of Aeronautics and Astronautics
## Table 1. SatCom service providers and services offered

<table>
<thead>
<tr>
<th>Service provider</th>
<th>Infotainment</th>
<th>Office (in-flight)</th>
<th>Telemedicine</th>
<th>Flight security</th>
<th>Logistic &amp; maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satcom1</td>
<td>Mobile phone inflight (Available on iPhone, iPad, iPod, Android) Fax Voice VoIP Email Text Messaging (SMS). Mobile Data. Multimedia content wirelessly. Internet over Wi-Fi. Apps for passengers In-Flight Television</td>
<td>Office in the sky Virtual Private Network (VPN)</td>
<td>Ground-to-air voice calling service. A/C Position</td>
<td>Apps for the Crew Data Link</td>
<td>Data Link</td>
</tr>
</tbody>
</table>
In its most basic form, these services are sub-leased to companies, such as, Gogo Inc. in U.S.A., which uses an Air-To-Ground (A/G) technology currently operating in the 800 MHz band. The A/G (bands around 2.4 GHz and 5.8 GHz) is based in a cellular network that allows cockpit and passengers connecting to the Internet above 30,000 feet while traveling at speeds greater than 500 miles-per-hour. In this case radio frequency signal travels directly between the A/C and the ground (today, more than 1,500 commercial and 5,000 business A/C are equipped with this technology). These services are also offered by companies such as Inmarsat, Iridium, ViaSat, Row44, etc., which provide several services in SatCom with a global coverage, based on satellite networks in C-, L-, Ku- and recently in Ka-band.

In September 2013, the FAA, through its document entitled “Recommendations on Expanding the Use of Portable Electronic Devices During Flight”, has determined that airlines could safely expand passengers use of PCDs during all phases of flight, and was immediately providing the airlines with guidelines. However, FAA was not considering the use of cell phones for voice communications during flight because Federal Communications Commission (FCC) regulations prohibited any airborne calls using cell phones.

Consequently, the permission to use PCDs on board, the annual increase in air traffic, as well as the new aeronautical passenger services will require new models and architectures with higher bandwidth into communication systems A/G, Air-to-Air (A/A) including SatCom systems and equipment’s.

B. Aeronautical Telecommunication Network (ATN)

At the present time, the typical scenario in aeronautical communications is the ATN and sub-network. ATN and sub-networks are operated between three principal segments: Ground Segment, User Segment and Space Segment (Fig.3). According to the International Civil Aviation Organization (ICAO), the international aeronautical telecommunication service shall be divided into four parts: aeronautical fixed service, aeronautical mobile service, aeronautical radio navigation service and aeronautical broadcasting service as specified in Ref. 8. The ATN, however, is not limited to operational traffic: As a global infrastructure, it is also intended to carry general communications. General communications include Airline Passenger Communications (APC), which is defined as communications related to non-safety voice and data services for passengers and crewmembers for personal communication.
The objective of the ATN is to provide mobility, that is, to maintain transparent connectivity among A/G, GES and Ground-To-Ground (G/G) applications. This connectivity is accomplished over multiple sub-network types. The ATN currently recognizes a limited set of sub-networks like: AOC, AMSS, Air Traffic Security Coordinator (ATSC), High Frequency Data Link (HFDL), Mode S and Very High Frequency (VHF) Data Link 2/3/4 (VDL2, VDL3 or VDL4). However, the standard makes provisions to add next generation aviation sub-networks for NextGen in U.S.A. and SESAR in Europe. These sub-networks include enhanced SatCom networks, CPDLC, FANS, ADS-C, AIRCOM, etc.

### III. Capacity requirements

The estimation of future capacity requirements for a single A/C is based on the European Telecommunications Standards Institute (ETSI) packet model for Internet traffic\(^{10}\) (Fig. 3). This study shows an approach to estimate the channel capacities needed to guarantee the desired QoS.

In Fig. 3: \(N_{pc}\) is the mean number of pages per session, \(D_{pc}\) is the interarrival time between web pages, \(N_d\) is the the mean packet number of packets per page, \(D_d\) is the mean value of gap time between two consecutive packets with an interarrival time geometrically distributed, \(T_{SOFF}\) is the session active time and \(T_{SOFF}\) is the session inactive time. Another important factor into consideration is \(S_d\), which stands for the size of each packet (datagram). In order to calculate this factor ETSI uses the Pareto distribution with cut-off defining it as follows:

\[
S_d = \min (P, m) \tag{1}
\]

Where \(P\) is normal Pareto distributed random variable \((\alpha = 1.1, k = 81.5 \text{ bytes})\) and \(m\) is maximum allowed packet size, \(m = 66,666\) bytes\(^{10}\). The probability density function (PDF) of the datagram becomes:

\[
f_n(x) = \begin{cases} \frac{\alpha k^\alpha}{x^{\alpha+1}}, & k \leq x < m \\ \beta, & x = m \end{cases} \tag{2}
\]

Where \(\beta\) is the probability that \(S_d > m\):

\[
\beta = \int_{m}^{\infty} f_n(x)dx = \left(\frac{k}{m}\right)^{\alpha}, \alpha > 1 \tag{3}
\]

Then the mean packet size can be calculated as:

\[
\mu_n = \int_{-\infty}^{\infty} x f_n(x)dx = \int_{k}^{m} x \frac{\alpha k^\alpha}{x^{\alpha+1}}dx + m \left(\frac{k}{m}\right)^{\alpha} = \frac{ak - m \left(\frac{k}{m}\right)^{\alpha}}{\alpha - 1} \tag{4}
\]
With the parameters above the average size is:

$$\mu_n = 480 \text{ bytes}$$

(5)

In Ref. 10, the mean web page size taken into account is about 120 Kb. However, current trend of the size of a website is increasing today, even if websites are visited using PCDs, as we can see in Fig. 4:

According to the HTTP Archive\(^\text{11}\) (which collects and permanently stores the Web’s digitized content), today’s average web page has surpassed the 1.5 MB mark, arriving to 1.71 MB in February 2014. At this rate (average increase of 32% per year), the average page size will reach 8 or 9 MB by 2020. It should be emphasized that the greater amount of data contained corresponds to images in different formats (Fig. 5).

Therefore, we can use these values to calculate a mean rate per user ($\bar{R}_{\text{user}}$), after computing the mean input rate during an active session ($\bar{R}_n$) as follows (Ref.10):

With the parameters above, the average size is:

![Figure 4. Total transfer size and total request (Feb 2011 – Feb 2014)\(^\text{11}\)]

![Figure 5. Average bytes per page by content type (Feb 2014)\(^\text{11}\)]
The factor \( N_{pc} \) can be neglected because it is eliminated with the factorization. In our calculations, we take into account that the mean page size in 2020 will be 9MB, the average number of packets, \( N_d \), is 18,750 packets per page, and the time between arrivals of web pages, \( D_{pc} \), is 206 s (Ref. 10). This yields a mean input rate of \( R_s = 349,515 \text{ bps} \). Then, the mean rate per user can be computed as:

\[
R_{\text{user}} = \frac{T_{\text{SON}}}{T_{\text{SON}} + T_{\text{OFF}}} R_s
\]

(7)

For calculating the mean session active time (\( T_{\text{SON}} \)) we use the average time value spent per interaction for laptops from Table 2 as follow:

**Table 2. Average time spent per device\(^{12}\)**

<table>
<thead>
<tr>
<th>Device</th>
<th>Average time spent per interaction (Minutes)</th>
<th>Average time spent per interaction (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphone</td>
<td>17</td>
<td>1,020</td>
</tr>
<tr>
<td>Tablet</td>
<td>30</td>
<td>1,800</td>
</tr>
<tr>
<td>PC/Laptop</td>
<td>39</td>
<td>2,340</td>
</tr>
<tr>
<td>TV</td>
<td>43</td>
<td>2,580</td>
</tr>
</tbody>
</table>

\( T_{\text{SON}} = 2,340 \text{ s} \)

For estimating the mean session inactive time, \( T_{\text{OFF}} \), we use the statistics of Global Mobile Data Traffic Forecast Update, 2012-2017 and 2013-2018 (average traffic per mobile device type) by Cisco Visual Networking\(^{13,14}\):

**Table 3. Mobile broadband average usage (MB/month) for device categories\(^{13,14}\)**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphones</td>
<td>55</td>
<td>150</td>
<td>342</td>
<td>529</td>
<td>1,272</td>
<td>2,576</td>
<td>2,660</td>
<td>5,371</td>
</tr>
<tr>
<td>Tablets</td>
<td>405</td>
<td>517</td>
<td>820</td>
<td>1,374</td>
<td>2,311</td>
<td>4,223</td>
<td>5,378</td>
<td>9,183</td>
</tr>
<tr>
<td>Laptop, netbook</td>
<td>1,460</td>
<td>2,131</td>
<td>2,503</td>
<td>2,455</td>
<td>6,522</td>
<td>6,942</td>
<td>5,731</td>
<td>5,095</td>
</tr>
</tbody>
</table>

This is a key data consumption trends for RCSFPAT. Here, we consider a pessimistic estimate (10 GB/month due to the impact of 4G networks\(^{15}\)) of mobile broadband average usage to determine a mean rate per user. The calculated value results \( R_{\text{user}} = 30,864 \text{ bps} \) or 13.9MB/hour and the mean pause between sessions is \( T_{\text{OFF}} = 24,158 \text{ s} \).

**Table 4. Number of passengers, minimum and maximum expected mean data rate per A/C type**

<table>
<thead>
<tr>
<th>A/C</th>
<th>Number of passengers</th>
<th>Minimum expected mean data rate (Mbps)</th>
<th>Minimum expected mean data rate (MB)</th>
<th>Maximum expected mean data rate (Mbps)</th>
<th>Maximum expected mean data rate (MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320</td>
<td>150 - 180</td>
<td>52.43</td>
<td>6.55</td>
<td>62.91</td>
<td>7.86</td>
</tr>
<tr>
<td>A330</td>
<td>253 - 440</td>
<td>88.43</td>
<td>11.05</td>
<td>153.79</td>
<td>19.22</td>
</tr>
<tr>
<td>A350</td>
<td>270 - 550</td>
<td>94.37</td>
<td>11.80</td>
<td>192.23</td>
<td>24.03</td>
</tr>
<tr>
<td>A380</td>
<td>555 - 853</td>
<td>193.98</td>
<td>24.25</td>
<td>298.14</td>
<td>37.27</td>
</tr>
<tr>
<td>B737</td>
<td>85 - 215</td>
<td>29.71</td>
<td>3.71</td>
<td>75.15</td>
<td>9.39</td>
</tr>
<tr>
<td>B777</td>
<td>301 - 550</td>
<td>105.20</td>
<td>13.15</td>
<td>192.23</td>
<td>24.03</td>
</tr>
<tr>
<td>B787</td>
<td>210 - 330</td>
<td>73.40</td>
<td>9.18</td>
<td>115.34</td>
<td>14.42</td>
</tr>
<tr>
<td>B747</td>
<td>467 - 605</td>
<td>163.22</td>
<td>20.40</td>
<td>211.46</td>
<td>26.43</td>
</tr>
</tbody>
</table>
In Table 4 we present the minimum and maximum expected mean data rate per A/C type and the number of passengers. As it can be seen, in terms of data rate RCSFPAT for APC ranges from 29.71 Mbps up to 300 Mbps approximately. In order to satisfy the growing of bandwidth on flight, the evolution of 4G technologies (4th generation mobile networks or 4th generation wireless systems) such as WiMax, Long Term Evolution (LTE), Evolved High-Speed Packet Access (HSPA+), etc., and the development of 5G standards seem promising future solutions not only for A/G communications, but also for SatCom.

Another aspect to take into account is the evolution of ACARS. The data rate of ACARS system is limited to 2.4 Kbps (220 character user data; due to its use of VHF voice radios). At a higher data rate, the rate of errors in decoding the received signal will increase and communications will become impossible. To support ACARS traffic growth, the capacity constraints as well as the Air Traffic Services (ATS), the use of data link and A/C equipage with EFB/ELB (Electronic Flight Bags/Electronic Log Books), ACARS will be replaced by AIRCOM by SITA (Fig. 6).

The key challenge to A/C transition from ACARS to new generation communications systems is the cost of modifying A/C systems. This practically means that A/C will continue to use ACARs until at least 2020 but will begin to increasingly use other data communications links in parallel. AIRCOM is implementing new generation services that will initially complement, and over the next 5 to 10 years progressively replace ACARS. At the same time, the FAA and EUROCONTROL have plans to add an additional zone called Autonomous Operations Area (AOA) where ATC is not used (A/C self-separate). AIRCOM next generation services will follow two parallel paths: ICAO-defined VDL (VHF Digital Link) and ATN links for ATS, and IP links for A/C Operator Communications (AOC)\(^5\).

In particular, ICAO-defined VDL is capable of operating with the following modes:

1) ICAO VDL mode 2 uses the Differentially Encoded 8-Phase Shift Keying (D8PSK) modulation scheme. This scheme has a data rate of 31.5 Kbps compared to the VHF ACARS rate of 2.4 Kbps and 25 KHz channel spacing and Carrier Sense Multiple Access (CSMA) channel access policy.

2) ICAO VDL mode 3 uses the D8PSK modulation scheme. This scheme has a data rate of 31.5 Kbps and 25 KHz channel spacing and Time Division Multiple Access (TDMA) channel access policy.

3) ICAO VDL4 standard uses the Gaussian-Filtered Frequency Shift Keying (GFSK) modulation scheme. This scheme has a data rate of 19.2 Kbps and 25 KHz channel spacing and Time Division Multiple Access (STDMA) channel access policy, and/or D8PSK modulation with a data rate of 31.5 Kbps on 25 KHz channel spacing, for ICAO VDL 2 – like operations\(^6\).

Between ATSSs we can find several services\(^7\) which can be classified according to Table 5:

![Figure 6. AIRCOM Data Link System Architecture](http://arc.aiaa.org/doi/pdf/10.2514/6.2014-2862)

**Figure 6. AIRCOM Data Link System Architecture**

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The main problems of ATS are related to the lack of availability of a service when it is required, and the hazardously misleading information such as undetected mis-delivered messages, undetected corrupted messages, undetected late or missing messages and undetected out-of-sequence messages. All these represent a high risk for the operational and safety requirements particularly for ATC. That is why EUROCONTROL and the FAA, in their study entitled “Communications operating concept and requirements for the future radio system”, provide a table with Service Level Operational Assessment to make the service usable for each ATS service in the future.

### Table 5. ATS Service Groups\(^7\)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Link Logon (DLL)</td>
<td>ATC Clearance (ACL)</td>
<td>Data Link Automatic Terminal Information Service (D-ATIS)</td>
<td>Arrival Manager Information Delivery (ARMAND)</td>
<td>Surveillance (SURV)</td>
<td>Data Link Alert (D-ALERT)</td>
<td>In-Trail Procedures (ITP)</td>
<td>Air-to-Air Self Separation (AIRSEP)</td>
</tr>
<tr>
<td></td>
<td>ATC Communication Management (ACM)</td>
<td>Data Link Operational Terminal Information Service (D-OTIS)</td>
<td>Dynamic Route Availability (DYNAV)</td>
<td>Flight Plan Consistency (FLIPCY)</td>
<td>Flight Path Intent (FLIPINT)</td>
<td>Urgent Contact (URCO)</td>
<td>Auto Execute (A-EXEC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data Link Operational En Route Information Service (D-ORIS)</td>
<td>Data Link Flight Update (D-FLUP)</td>
<td>System Access Parameters (SAP)</td>
<td>Wake Broadcast (WAKE)</td>
<td>Pilot Preferences Downlink (PPD)</td>
<td>Paired Approach (PAIRAPP)</td>
</tr>
<tr>
<td>Data Link Taxi (D-TAXI)</td>
<td>ATC Microphone Check (AMC)</td>
<td>Data Link Significant Meteorological Information (D-SIGMET)</td>
<td></td>
<td>Traffic Information Service-Broadcast (TIS-B)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Trajectory Coordination (COTRAC)</td>
<td></td>
<td>Data Link Runway Visual Range (D-RVR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data Link Surface Information and Guidance (D-SIG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 6. Future Operational Assessment for ATS\(^7\)

<table>
<thead>
<tr>
<th>Service</th>
<th>Continuity</th>
<th>Integrity</th>
<th>Availability of Provision</th>
<th>Availability of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL</td>
<td>0.9995</td>
<td>10^-6</td>
<td>0.99995</td>
<td>0.9995</td>
</tr>
<tr>
<td>ACM</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>A-EXEC</td>
<td>0.99999</td>
<td>10^-6</td>
<td>0.9999995</td>
<td>0.999999</td>
</tr>
<tr>
<td>AIRSEP</td>
<td>0.9995</td>
<td>10^-6</td>
<td>0.99995</td>
<td>0.99995</td>
</tr>
<tr>
<td>AIRSEP SURV</td>
<td>0.9995</td>
<td>10^-6</td>
<td>0.99995</td>
<td>0.99995</td>
</tr>
<tr>
<td>AMC</td>
<td>0.995</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.993</td>
</tr>
<tr>
<td>ARMAND</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>C&amp;P ACL</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>C&amp;P SURV</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>COTRAC</td>
<td>0.9995</td>
<td>10^-6</td>
<td>0.99995</td>
<td>0.99995</td>
</tr>
<tr>
<td>D-ALERT</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>D-ATIS</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>DCL</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>D-FLUP</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>DLL</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>D-ORIS</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>D-OTIS</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>D-RVR</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
<tr>
<td>DSC</td>
<td>0.999</td>
<td>10^-6</td>
<td>0.9995</td>
<td>0.999</td>
</tr>
</tbody>
</table>

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Therefore, A/G and SatCom links allowing data rates from at least 30 Mbps up to 300 Mbps traffic are critical to provide an appropriate communication infrastructure supporting future air communication systems growth, as well as to provide a consistent global solution fulfilling APC, ATSC and AOC requirements between AESs and GESs (to ensure flight safety). All of that depending on the maximum expected mean data rate of A/C (Table 4).

### IV. Multimode operation approach

Having defined the RCSFPAT in terms of data rate needs in the previous section, at this point we propose an alternative solution capable of supporting the continued growth of RCSFPAT. In this regard, SDRs are an ideal platform for prototyping and evaluating airborne platforms. Software routines (the software is loaded and controlled through proprietary mechanisms and each radio manufacturer typically employs a unique infrastructure or architecture) are perfectly suited for: switching to other wireless protocols, integrate new standards in A/Cs without substantial cost, developing monitoring tools to guarantee QoS, processing signals for more efficiently use of spectrum, and ensuring the scalability and reconfigurability of system. According to its operation mode, an SDR can be:

1. **Multiband**: Supports multiple frequency bands;
2. **Multi-Pattern**: Supports multiple standards or between different networks;
3. **Multiservice**: Provides different services (e.g., telephony, data, video streaming);
4. **Multichannel**: Allows two or more transmissions and receptions simultaneously on different channels.

On the other hand, providers of satellite networks are enormously orienting to utilization of Ka-band for your next generation of satellites. This would reduce greatly the development of the RFU onboard in a promising multisatellite network approach.

### Table 7: SatCom network providers’ features

<table>
<thead>
<tr>
<th>Inmarsat</th>
<th>Iridium</th>
<th>ViaSat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orbit</strong></td>
<td>GEO - Geostationary Earth Orbit (35,786 Km)</td>
<td>LEO- Low Earth Orbit (780 Km)</td>
</tr>
<tr>
<td><strong>Multiple-access scheme</strong></td>
<td>FDMA / TDMA</td>
<td>FDMA / TDMA</td>
</tr>
<tr>
<td><strong>Modulation types</strong></td>
<td>O-QPSK / pi/4-QPSK / 16-QAM</td>
<td>QPSK / DE-QPSK / DE-BPSK</td>
</tr>
<tr>
<td><strong>Latency</strong></td>
<td>1.2 – 3.5 sec</td>
<td>427 ms – 1.7 sec</td>
</tr>
<tr>
<td><strong>Service link</strong></td>
<td>L-Band / Ku-Band /Ka-Band (Global Xpress, 2014)</td>
<td>L-Band / Ka-Band (Iridium Next, 2015)</td>
</tr>
<tr>
<td><strong>Feeder links</strong></td>
<td>C-Band / Ku-Band</td>
<td>Up: Ka-Band Down: K-band</td>
</tr>
<tr>
<td><strong>Services</strong></td>
<td>Voice / Fax / Low-speed and high-speed data / VoIP / Flight Tracking / Safety services</td>
<td>Voice / Fax / Low data / Flight Tracking / Safety services</td>
</tr>
</tbody>
</table>
“Ka-band is the next generation of high-bandwidth satellite technology, with eight times more bandwidth than Ku-band. Ka-band satellites are better suited to support high-throughput capacity that cannot be met by more congested Ku-band frequencies. Ka-band also allows smaller end-user antennas.”

To cite some examples in Ka-Band:
1) ViaSat has a satellite in North America, which can support up to 50 Mbps or more.
2) Inmarsat has plans to launch three Ka-band satellites to offer the new Global Xpress service and to achieve full global coverage by the end of 2014 or early 2015. They plan to offer up to 30 Mbps for business aircraft (with a 30 cm planar antenna) up to 50 or 60 Mbps for commercial aircraft (with a big and heavy antenna). Coverage will be global, except of Polar Regions.
3) Iridium for its part will launch in 2015, Iridium NEXT, a second-generation worldwide network of telecommunications satellites. The constellation will provide L-band data speeds of up to 1.5 Mbps and High-speed Ka-Band service of up to 8 Mbps.

A. Cognitive radio SatCom system approach

Considering that in a near future the bulk of the satellite network will work in Ka-band, we can propose an approach using SDRs, cognitive techniques and collaborative avionic network, in order to fulfill RCSFPAT (future SatCom market) demand. The targeted SDR will be able, in its most basic form, to:

1) Switch between different modulation types (Modulation / Adaptive modulation).
2) Switch between different SatCom networks (Reconfigurable).
3) Demodulate the down converted signals (Reprogrammable).
4) Simulate reception scenarios (Flight phases).
5) Cognitive radio capabilities (Resource arbitration)
6) Scalable design and implementation.

In Fig. 7, we present the flow chart of the operation of the airborne SDR unit for all phases of flight, considering Iridium, Inmarsat and ViaSat as SatCom providers. Hereinafter, the airborne SDR unit will be referred to as Software Defined Wideband Radio (SDWR). At first, SDWR is off because the A/C is receiving an acceptable Power Level (PL) (in terms of SNR 107 or -70 dB approx.) from ground infrastructure, which means that the A/C is connected via an ATN A/G router to different services including APC, ATC, AOC, ATSC and other subnets.

Once the link to the ATN A/G router is unreliable in terms of received power, the SDWR is activated and immediately seeks to connect to a satellite network; the connection criterion for these networks (Iridium, Inmarsat and ViaSat) has been determined:

1) By latency. In this case Iridium provides the lowest latency as indicated in Table 7.
2) By coverage area. In the same way SDWR will seek a connection with Iridium, since the coverage it provides is global. The next choice is Inmarsat network, Inmarsat offers coverage in 85% of the planet and with a much higher latency time due to the nature of the constellation as shown in Table 7.
3) By services offered. Since all operators work in Ka-band, we can assume that they all offer the same services as shown in Table 1. In this case our third option would be ViaSat network.

Once connected to a satellite network, SDWR will monitor network traffic as well as bandwidth allocation and QoS (to monitoring performance and use, fault, and security aspects of a link, network, or network component). If these parameters are acceptable, the connection with the satellite operator is maintained, otherwise SDWR switches to the next satellite network in the order provided.

Figure 7. SDWR on board an A/C Flowchart

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B. Collaborative Avionic Network (CAN)

In RCSFSPAT, it is possible that at some point in flight phases, either by weather or for some other reason, connection to satellite networks does not provide adequate QoS for a remote connection to an ATN A/G router. In this case, the SDWR seeks a connection (inter-node connectivity) with a neighboring A/C in an established range to use another SDWR as an A/A Router for connection to a satellite network or to the ATN A/G router or GES. At this point, the A/C connects as a guest to one (Fig. 8.a) or more neighboring A/C (Fig. 8.b) and distributes traffic between them with an overlay cognitive approach.

![Flowchart](Image)

**Figure 8:** a) Communication link A/C-ATN A/G router via A/A router, b) Communication link A/C-ATN A/G router via two A/A routers

The communication paths used to establish the connections between an A/C and ATN A/G router or GES are shown in Fig. 8.a. They can be asymmetric regarding the bandwidth, and bidirectional or unidirectional (including receive only). Also, this connection could take different paths through the system. The routing information of communications must be preset to A/A routers of the same or concerted airlines for CAN. A/A routers can be deployed on the same SDWR. The topology to be used is that of a Mesh Network.

SDWR must be capable of establishing connections to relay, translate and/or gateway information, as needed. In fact, they must be capable of: receive and transmit with the same data formats and on the same frequency, receive and transmit with the same data formats but on different frequencies and receive and transmit with different data formats and on different frequencies or modulations.

C. A/A routers

In the case of A/A routers, the operation model of CAN is shown in Fig. 9. Therefore, the A/C that receives a request connection: First, it verifies availability in terms of traffic, bandwidth (BW) and QoS, in order to not compromise its own connection. If the A/A link is not available or if it compromises QoS, the connection request to router A/A is rejected. Otherwise, a Guest-A/A router connection is established and a specific BW is assigned through a bandwidth allocation algorithm. While the A/A link is active, the SDWR monitors that this established connection does not compromise QoS of the gateway A/C. If it is detected that the Guest-A/A router connection compromises the QoS, the connection is rejected, otherwise the connection is maintained for the required time.

The flow chart of CAN is shown in Fig. 10 and is based on the already mentioned in Fig. 9. It incorporates the ability to forward the connection request to another A/C, establishing a Gateway mode. When in this mode, it should be ensured that this connection does not compromise the QoS, otherwise the connection is rejected.

The CAN consists of a variable number \( N \) of mobile nodes (A/C), also it consists of a fixed number \( M \) of GES (via satellite link) and A/G stations distributed geographically, assumed to be operated by an A/G communications provider. A particular node in the network is uniquely identified by its number \( i \in \{1, \ldots, N + M\} \).
A connection to a GEO or LEO network always has latency as indicated in Table 7. In the case of a CAN based in the principle of Mesh Network\textsuperscript{24}, there is a latency attached; however this would be much smaller. Theoretically, the maximum instantaneous throughput achievable per node is given by:

$$\mu_{max} = \frac{1}{N} \sum_{(i,j) \in L_G} C_{ij}$$ \hspace{1cm} (8)$$

Where $L_G$ denote the set of all A/G and GES links $(i,j)$, and $C_{ij}$ denotes the capacity of link $(i,j)$.

As shown in Fig. 11, each node $i$ has an outgoing link $(i,j)$ with each neighbor $j \in N_i$ with a $Q_{ij}$ associated transmission queue where arriving packets are temporarily stored while waiting for transmission over the link $(i,j)^{24}$.

We remark that the use of a CAN would be made only in case that the communication between the A/C and ground services do not meet the required QoS. In order to leverage the available A/G full capacity at any given time, the traffic load between all A/G links must be balanced, including links via GES. To accomplish this, Ref. 23 proposes combining geographic information together with information about the size of the buffer. The authors call this approach Geographic Load Share Routing (GLSR) (in Ref. 24).

### D. Others aspects

We remark that the so-called Size, Weight, Power and Cost (SWaP-C) requirement is of crucial importance in aviation, where any kilogram matters. That is why until now the approach SDR appears as the only technology able to fulfill flexibility and SWaP-C requirements and RFU must be designed to meet reconfigurability scalability requirements as well.

In addition to the benefits\textsuperscript{5} offered to RCSFPAT, a multimode operation approach it has some benefits and contributions to other fields such as:

1) Environmental:
   a) Solution based on industry environmental needs by reducing the weight of the A/C.
   b) Reduces the need for fuel which contributes to a significant reduction of GHG emissions
   c) Minimum hardware replacement and recycling via software applications upgrades for improved or new functionalities

2) Original Equipment Manufacturer (OEM):
   a) Reduction of costs and development time of new equipment via a single platform that is innovative and reconfigurable
   b) Reduction of certification and integration efforts for new applications
   c) Simplified repair and maintenance

\textsuperscript{5} This benefits are aligned with the objectives of LASSENA Laboratory, who currently develop Software Defined Avionics (SDA) in collaboration with several industrial partners in the aviation, aerospace and embedded systems sectors

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Figure 10. Guest-A/A router connection for CAN

Figure 11. A node’s transmission queues\textsuperscript{24}
3) Retrofit Applications:
   a) Replace expensive legacy avionics with additional applications
   b) Provide a low-cost growth path for future upgrades

4) Regulatory Evolution:
   a) Addresses new operational standards such as NextGen and SESAR
   b) Supports the automated airspace concept based on Automated Airspace Computer System (AACS)

V. Conclusion

In this paper, we have presented the RCSFPAT based on current data and several forecast. To respond the increase in air traffic volume (5% per year), operational efficiency and environmental issues as well as enhancing safety, we have presented a solution based on SDR multimode capable of complementing the services provided by SatCom network providers in Ka-Band. We have also provided a review of current scenarios and services offered in aeronautical communication and SatCom.

The most important factors showed in this paper have been the minimum and maximum expected mean data rate per A/C. In future works, these values (29.71 – 300 Mbps) will be useful for design of avionics communication cognitive networks in terms of QoS, capacity and data rate.

Finally, we have showed that to support the rapid growth in future air communication systems and the goal of fulfilling the communications requirements from passengers and communications between AESs and GESs (thus to ensure flight safety), SDR technology with cognitive techniques is the most appropriate technology providing a consistent global solution.

Acknowledgments

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References


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