SESAR EXPLORATORY RESEARCH SAPIENT PROJECT OVERVIEW

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Abstract:

The SESAR (Single European Sky ATM Research) Exploratory Research project called SAPIENT (Satellite and terrestrial architectures improving performance, security and safety in ATM) is a program of the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement 699328 [1][2]. It aims at defining Satellite and Terrestrial Architectures improving performance security and Safety in ATM (Air Traffic Management) through new and innovative functionalities for future CNS (Communication, Navigation and Surveillance) and ATM systems and future European RPAS (Remotely Piloted Air System) C2/C3 satellite Data Link (DL) for governmental initiatives (C2 states for Command and Control, while C3 states Command, Control and Communications).

In this context it has been defined SAPIENT which is a novel cost-effective and performance-efficient system solution for aeronautical communications, aimed at adapting and optimizing the capacity and safety performance of aeronautical communication applications, e.g. CPDLC (Controller-Pilot Data Link Communications) and ADS-C (Automatic Dependent Surveillance – Contract), in view of the estimated 'status' of air ground ATM SoL (Safety of Life) terrestrial and satellite datalinks over actual flown trajectories. To meet these targets, SAPIENT exploits the information on actual 4D aircraft trajectories – in terms of dynamic position in space and time – and performance data of ATM Air Ground Datalinks, produced by aircraft and other elements of the ATM Communication Infrastructure [3]. The innovative aspects addressed in the SAPIENT Project are related to the TAS-I patent "System for Aeronautical Safety of Life Applications Providing Adaptation of Services and Communication Resources for Maximized Safety and Capacity Performance" [4] . Significant references for the ATM Datalink aspects are the activities undergong in SESAR on VDL2 (VHF Digital Link Mode 2) [5] and other new generation digital datalinks and in ESA on Iris [7].

The SAPIENT solution is a multilink/data link monitor and control system. It is aimed at providing information on the aircraft perception of the operational layout goodness in order to correct or operate more effectively with respect to the ATM communication goals. The main objectives are:

- Support the multilink function during the selection of the optimal data link;
- Foresee retroaction on the in-use data link, and change the resources during the flight, according to information obtained through it and according to the information collected from the other SAPIENT system actors;
- Retroact on multilink function in order to change the priority between data links (i.e. need of load balancing in a common coverage area with traffic hot spots).

The use of the SAPIENT system is expected to positively impact:

- The efficiency of the data-links management in a multilink environment, resulting in less resources needed by ATM communication system elements, with main focus on effective and efficient use of RF spectrum

- The Communication issues in the ATM air/ground links minimizing the need of tactical interventions from ATC (Air Traffic Control) and pilots to de-conflict situations
- Communication issues in the RPAS C3 satellite DL minimizing the use of RPAS safety procedure that will limit the execution of the RPAS missions
- The Air Navigation Service providing a cost saving obtained by improving the Air navigation Service productivity and the frequency band usage

The aim of this paper is to present the SAPIENT reference architecture and system boundaries, the SAPIENT protocol and the main SAPIENT simulation results.

1. SAPIENT System Introduction

The transition of the nominal interaction mechanism between ATCOs (Air Traffic Controllers) and pilots from voice to data has already started with the introduction of CPDLC/ADS-C applications in oceanic airspaces. Programmes such as European Commission's SESAR and FAA's NExtGen (Federal Aviation Administration) are on-going to continue this transition in higher density airspaces.
On long term the needs for more efficient, higher performances and reliable data exchanges will increase leading to the identification of new air/ground data-link technologies providing higher capacity throughput and better performances.

Currently three main potential new components are addressed: the AeroMACS (Aeronautical Mobile Airport Communication System) covering the airport surface communication needs; the LDACS (L-band Digital Aeronautical Communication System) for the continental airspace and a new satellite based component covering both the oceanic and continental airspace. The objective of those new links is to provide the basis for the future data-link services and FCI (Future Communication Infrastructure) needed to implement planned performance based communication services and in particular the trajectory based Air Traffic Management.

The SAPIENT project addresses a new innovative application in the field of CNS/ATM system focusing improvements to the exploitation of the synergies of Communications and Navigation technologies and the 4D trajectory management concept.

The SAPIENT innovation is based on the integration of the accurate estimation of the flights 4D trajectories with the data obtained by dynamic, accurate monitoring and measuring of the performance of ATM Air/Ground Datalinks carried out by the aircraft transceivers (satellite and terrestrial communication user terminals) relevant to the new navigation infrastructure.

SAPIENT solution defines a new system to monitor and control operation and configuration of air-ground communication Datalinks (DL), including planning and dynamic allocation of their resources within a Multilink context in order to better meet the Required Communication Performance of ATM services.

This objective is achieved by measuring pre-defined DL KPIs (Key Performance Indicators) and tagging them with the 4D position..

This process will allow to achieve global knowledge of the performance and status of DLs in support to the trajectories and airspaces management.
SAPIENT is built on very simple concepts: DL communication elements perform both real-time and no-real-time measurements of the DL quality in terms of KPIs and notify the KPIs of DLs along trajectory's 4D positions of aircraft and airspace volumes to create a common knowledge of the ATM-SoL System status.

This suits to put in place actions to
- Configure DLs for performance improvement
- Allocate DL resources to aircraft in 4D space.

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2. SAPIENT System Architecture

In order to define the SAPIENT System Architecture, a segment for each type of actor has been identified in the following manner:

- **Space segment** that includes different satellite constellations, such as GNSS (Global Navigation Satellite System) for geo positioning, C2-SAT for RPA DL and so on.
- **Airborne segment** that includes the overall air traffic, both for manned and un-manned systems.
- **Ground Segment** and Network that comprise Antennas, CSPs (Communication Service Provider), SSPs (Satellite Service Provider), Solution Owners, Remote Pilot Stations for un-manned aircrafts and the IP terrestrial network that links them.
- **ANSPs** (Air Navigation Service Provider) which are the overall navigation service providers connected to the IP network.

The considered DL are:

- **Terrestrial DL for manned A/C (Aircraft) and RPA** for the direct exchange of the KPIs (Key Performance Indicators) between manned/un-manned aircraft and the terrestrial ground segment.
- **Satellite DL for A/C** for the exchange of the KPIs by way of satellite bridge, from the ground segment to the aircraft and vice versa.
- **Satellite DL for RPA** for the exchange of the KPIs by way of satellite bridge, from the ground segment to the RPA and vice versa.
- **GNSS SAT link** used to determine the exact geographical position of the manned/un-manned A/Cs and furnish the timing reference. For this reason this technology is fundamental to realize the 4D-Tagging of the KPIs.

Starting from that general reference architecture, different options have been studied in order to evaluate different modalities to exchange the KPI information and to assess at which point of the architecture position the ML (Multi-Link) functions. As output of the trade-off activity, a reference SAPIENT system scenario both for Manned Aircraft and for Unmanned Aircraft has been identified. It has been named as “Active Solution Owner” scenario.

2.1. SAPIENT Reference Scenario

In the following figures the SAPIENT reference system architectures for manned and unmanned A/C scenario are shown. These pictures describe KPIs exchange and where the SAPIENT solution and multilink capabilities are implemented.
In this scheme a centralized Solution Owner collects the overall KPIs from A/Cs and Service Providers and produces a KPI Summary that reports the QoS (Quality of Service) of the data links.
In this reference scenario are represented two traffic types:

- ATS/AOC (Air Traffic Services/ Air Operator's Certificate) traffic: that is the common exchanged traffic to monitor and control the flight in various application: ATS between the A/Cs and the controllers and AOC between the A/Cs and the airlines companies. This term is not strictly bound to this types of application’s traffic and it’s valid for any type of messages application exchanged on a DL
- SAPIENT traffic: that is the traffic of the exchanged KPIs, strictly bound on the proposed SAPIENT solution.

Both in Figure 1 and Figure 2, the yellow box “SAP” is used to indicates where the SAPIENT solution is deployed, while the green “ML” (Multi Link) box indicated where the multilink functionalities (as defined by SESAR) are deployed.

The main positive features of the selected architecture are:

- The A/C router implements SAPIENT solution and the ML functionalities, therefore the A/C is part of the decision making for the data link selection. This solution will increase the complexity of the airborne SW, but will leave to the A/C the possibility to quickly re-act in emergency or no-routine cases
- The Service Providers (CSP and SSP) implement the SAPIENT solution, but not the ML functionalities
- There is a centralized entities in charge of the overall coordination of the KPI collection and sharing. The will assure the complete collection and processing of the KPI data and the homogenous sharing of processed KPI summaries
- No need of coordination policies between different Service Providers (Communication or Satellite)
- Optimization of exchanged KPIs through the different satellite and terrestrial data links
- The use of the terrestrial network for the extended SAPIENT traffic exchanges, reducing the need to the A/G traffic exchanges and the related bandwidth occupation

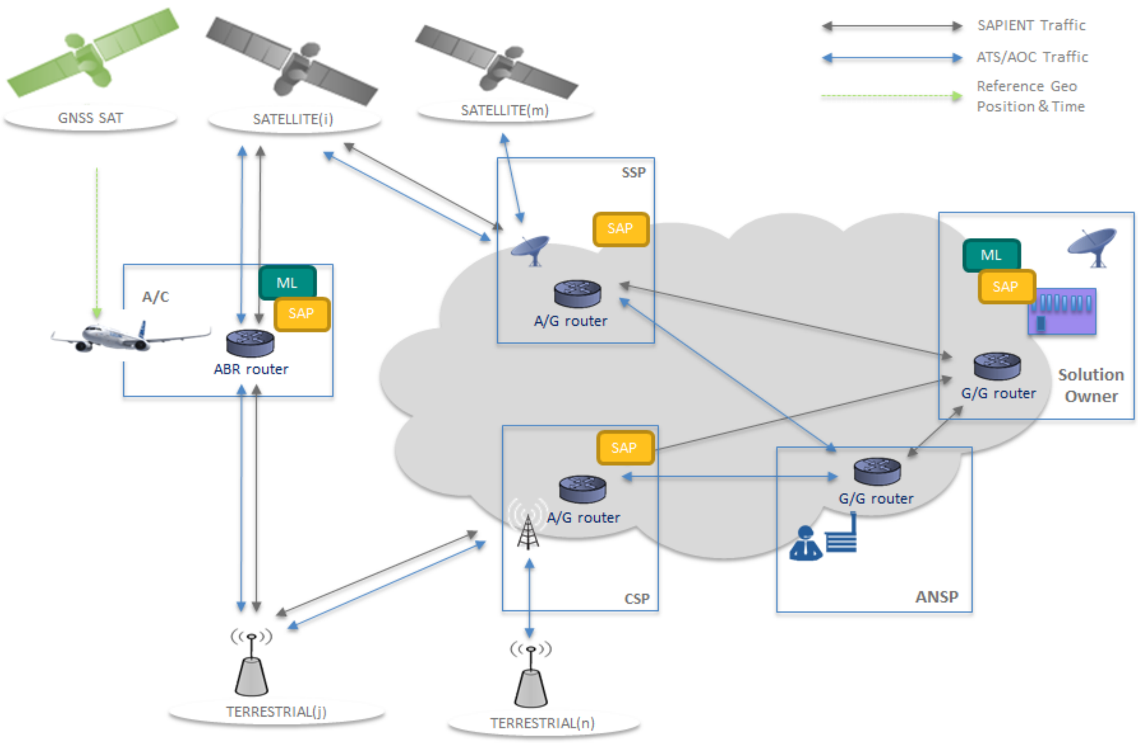

Figure 1: SAPIENT Reference architecture for Manned A/Cs

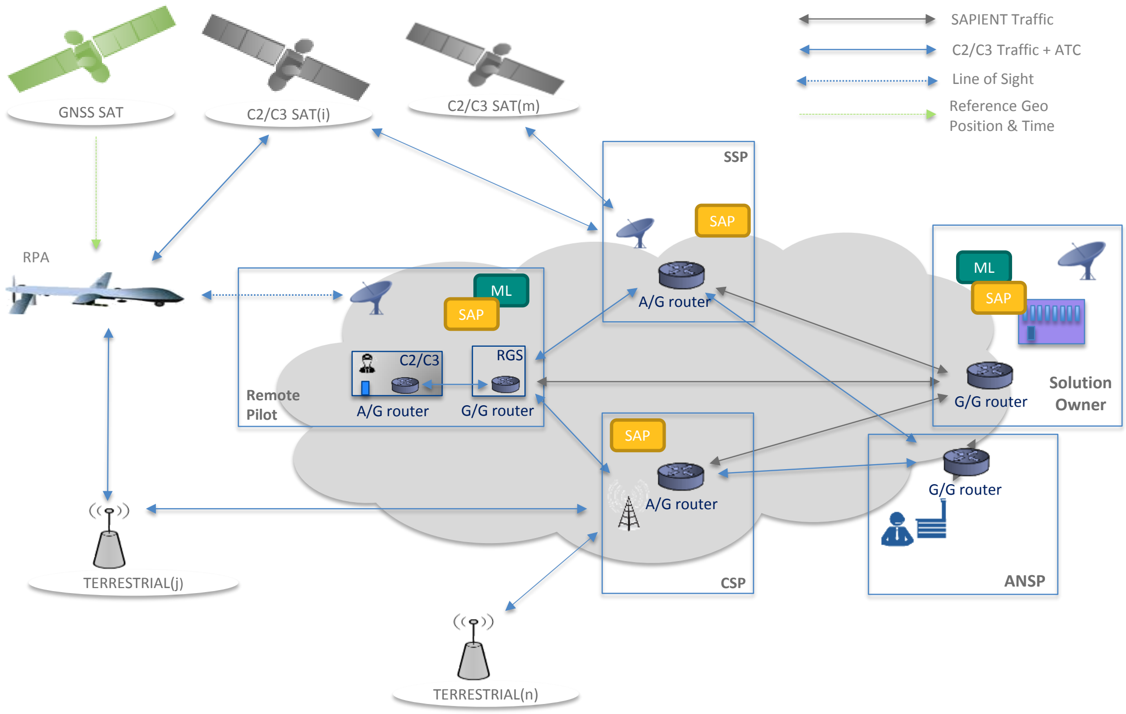

Figure 2: SAPIENT Reference architecture for RPA

3. SAPIENT KPI definition

The Key Performance Indicators (KPI) are data and metrics suitable to quantify the quality of the terrestrial and the satellite ATM air/ground datalink. The following KPIs have been defined and considered for the Terrestrial and the SATCOM (SATellite COMmunications) links:

- **Real-time KPI:** They are the real time KPIs relevant to the SATCOM data link status during the flight. They are collected and shared with high frequency. That KPI (e.g.: Carrier to Noise Ratio) are originated and shared by the aircraft (manned or un-manned).
- **Periodic KPI:** they are the periodic KPIs collected or shared with a certain periodicity in the range form few minutes up to hours or days. This class identifies KPI (e.g.: Latency) that are originated and shared by the ground domain (CSP, SSP, ANSP).
- **Statistical KPI:** they are the statistical KPIs calculated over long periods (months or years) of time. This class identifies the KPI (e.g.: Link Availability) that are originated and shared by the ground domain and, in particular from Solution Owner or CSP/SSP that have a noteworthy KPIs database and an elaborator to process big data.

4. SAPIENT Protocol Overview

In order to support the SAPIENT solution, it's fundamental to introduce and define a new set of protocols and processes that will allow to integrate the data obtained by dynamic monitoring and measuring of the performance of the ATM Air/Ground data links with the estimation of the 4D trajectory of the aircraft. The objectives are, thanks to the information collected, to support the multilink function during the selection of the next data link and generate a retroaction mechanism to ensure a continue and secure communication between the aircraft and the flight controller.

4.1. 4D-Tagging process

The 4D-Tagging process is a set of functions that has the objective to associate a time, position and validity tag to the KPI information generated from the system's elements.

The rationale behind the 4D-Tagging process is to classify the KPIs measured or monitored from the aircraft and the ground segments in terms of time, geographical position and validity. In addition, the 4D-Tagging will allow the synchronization of the data exchanges aimed at optimizing the use of the available data link resources.

Taking into account the need of retrieving the information mentioned before, it is necessary to consider within the system's requirements the need of:

- A GNSS infrastructure, in order to associate to each element a tag with an only one reference point for time and position
- A system to check the synchronism between the timestamps of the tagged information received
- A system to ensure security and the definition of a security policy

In the following figure a possible scenario for the 4D-Tagged information is depicted. In the picture is represented the same airplane in different instants that exchanges data with the ground segment through satellite or terrestrial data link.

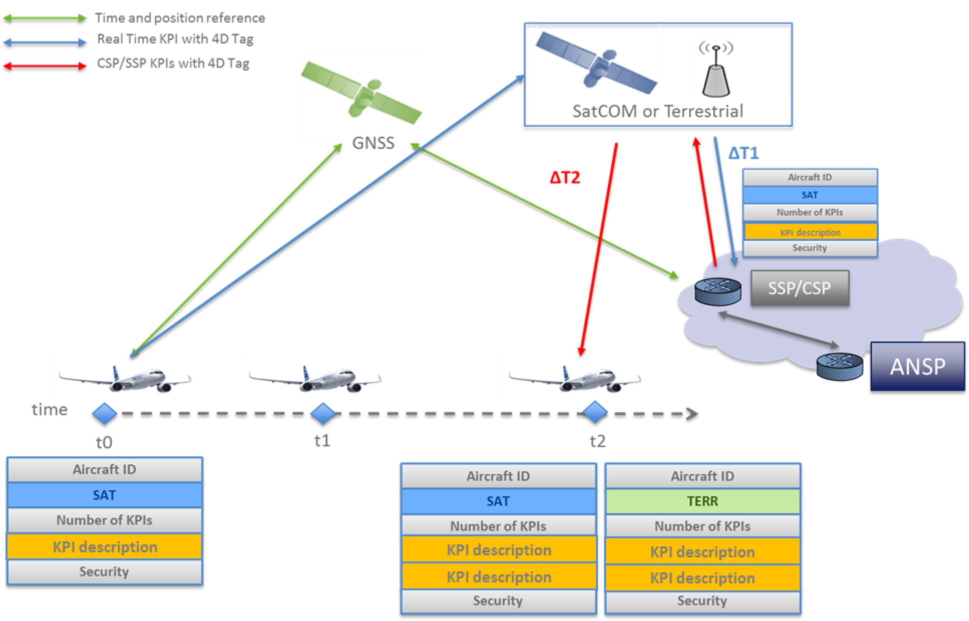

Figure 3: Candidate scenario for 4D-Tagging

4.2. 4D MAP protocol principles

The 4D MAP (Multilink Administration Protocol) protocol aims to generate a four Dimensions Map of the area of interest that characterizes each point with the information needed by the aircraft to choose the most proper data link and to define how the information is exchanged. Moreover the 4D MAP protocol is in charge of the methodology implemented to select the optimal data link and to setup the connection, according to the information collected from the 4D Tagging process.

The 4D MAP protocol has to implement all the functionalities needed to perform the 4D-Tagging process and to enable the link selection logic.

In particular, in the aircraft there are the functionalities related to:

- The KPI process (monitoring, measuring and elaboration) that are the input for the 4D MAP function

- The link selection logic, supported by the Navigation Function and the 4D Trajectory Management

The Navigation Function comprises the relations with the GNSS infrastructure and the aircraft monitoring (position, banking, etc.).
Similarly, on the ground segment the 4D MAP functionalities are implemented from the service providers: in this case their responsibility foresees to tag the generated KPI and to collect all the other tagged KPIs belonging to the same technology in order to generate a database that will be elaborated and summarized with the aim of allowing the aircraft to perform the correct data link choice and establish the retroaction mechanism for possible corrections.

5. Evaluation of the SAPIENT system benefits

The evaluation of the SAPIENT system benefits was done using the SAPIENT system-level simulator. More detail about the SAPIENT simulator and the verification results can be found in [7]. This section of the present paper aims at presenting some major results of the performed verification activities.

The first picture reports the frame loss for high-priority traffic on the forward link. Frames are considered lost if they are either dropped (e.g., due to decoding errors) or they arrive at their destination later than a predefined (end-to-end) delay threshold. The following figure reports the loss rate, assuming a threshold equal to 485ms, with an increasing number of A/Cs (10 to 40).

Figure 4: Average Frame Loss in case of a delay threshold equal to 485ms

The figure clearly shows that the baseline (i.e., a solution not employing SAPIENT) has high loss rates with more than a few A/Cs. On the other hand, using the SAPIENT solution reduces the loss rate. The SAPIENT-enabled solution is tested with several reporting periods, from a very short one (1s) to a very large one (60s). While activating SAPIENT provides benefits, whichever the period, a trend is clearly visible: too long a period implies that the reaction to an overload condition is delayed, and frames may get lost in the meantime. A shorter period, instead, guarantees faster reaction, but increases the load on the forward link as well (due to the reporting traffic). This last effect starts showing up when the period is particularly short (1s in the simulation). This hints at the fact that an optimum reporting period can, and should be configured based on the load of the DL.

The picture reported hereafter shows the simulation results in terms of availability of the system.
The performance is compared against three baselines. In the first two, the A/C remains connected to the same DL, namely LDACS and SATCOM, regardless of its connection status. In the third one, labelled as base SAPIENT, the A/C exploits the SAPIENT handover capabilities, choosing the DL with the best SNR (Signal to Noise Ratio) with a 30s period. A full SAPIENT solution, instead, exploits context information on possible performance drops: more specifically, it receives information regarding

the performance drop in a nearby area, and performs a pre-emptive vertical handover before entering that area.
The figure clearly shows that SAPIENT increases availability considerably.

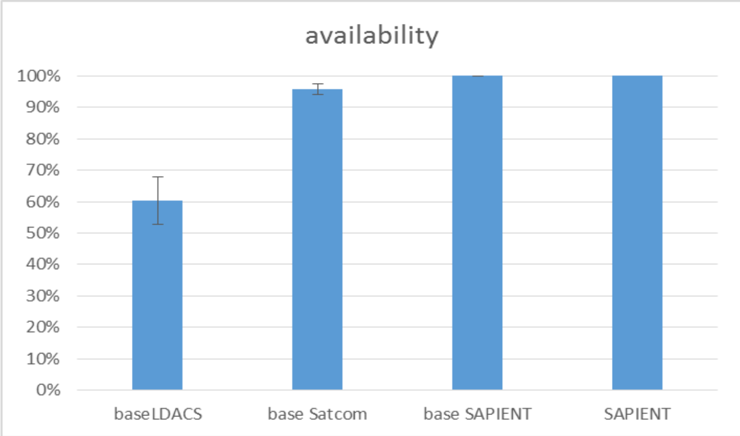

Figure 5: Connection availability

The next figure shows the simulation results in terms of average frame delay. The two versions of SAPIENT exhibit the same delay, since the fraction of frames that are lost due to the lack of context information is comparatively small. The average frame delay is a weighted average of LDACS's and SATCOM's, the weights being given by the fraction of time the A/C spends using either DL.

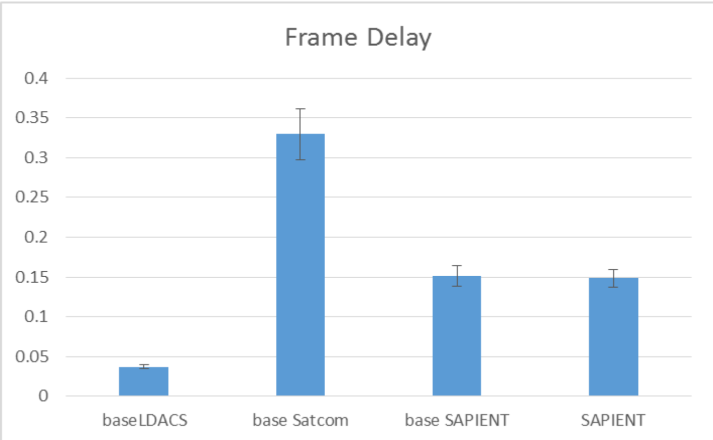

Figure 6: Average frame delay

6. Conclusions

This paper provides an overviews the SESAR Exploratory Research project called SAPIENT. It is a SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement 699328. The innovative concept to manage the terrestrial and satellite links is presented. The aspects addressed in the SAPIENT Project are related to the TAS-I patent "System for Aeronautical Safety of Life Applications Providing Adaptation of Services and Communication Resources for Maximized Safety and Capacity Performance".

This paper has presented the main SAPIENT project achievements with special focus on the main SAPIENT solution verification results obtained through a dedicated SW simulator.

The main outcomes of the simulation activity are as following [7]:

- using local information only (i.e. the Real Time KPIs) an A/C is able to implement a make-before-break approach. This is beneficial with both a single DL, since it allows one to bring forward a horizontal handover, and multiple DLs, since it allows an A/C to place a vertical handover at the right point in time. In both cases, the increase in availability is remarkable
- using global information (i.e. the KPI-summaries) an A/C is able to react to critical situations, such as temporary overload or performance drop, by switching to a less loaded or more performing DL, performing a horizontal or vertical handover at the right point in time. This may increase the service availability and also service continuity if one of the DLs is underperforming unexpectedly. On the other hand, SAPIENT can help an A/C make decisions that drive the system towards a load-balanced state, reducing the congestion, hence the delay and the ensuing frame losses

The SAPIENT simulation activity has demonstrated that the SAPIENT solution implementation will allow to:

- improve the service integrity, by reduction of data losses (bit, packet or frame).
- improve the service continuity with respect to an ATM baseline environment where SAPIENT is not implemented
- improve the service availability with respect to an ATM baseline environment where SAPIENT is not implemented

A dedicated SAPIENT website has been set for dissemination purpose: http://sapient-project.eu/sju/ [8]

7. References

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