A SDN-based Aeronautical Communications Network Architecture

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***Abstract*—COMET, a Clean Sky 2 (CS2) Joint Undertaking project, addresses the challenge of designing, developing, and testing novel dual ACARS-IPS cockpit and future ground network infrastructures operating in a multi-link environment (e.g. VDL2, Swift broadband SATCOM, AeroMACS and LDACS) to enable seamless air-to-ground connectivity in support of trajectory-based ATC operations and future airline services. This paper presents SDN-based approaches in the network design and preliminary analysis that have been carried out within the project.**

***Keywords*—IPv6, IPS, SDN, Multi-link, mobility**

I. INTRODUCTION

In the past few years, software-defined networking (SDN) has attracted numerous attention from aerospace companies in its application to aeronautical or digital avionics networks. Honeywell presented potential advantages of exploiting SDN for aeronautical communications covering multiple communications domains including ground-to-ground, air-to-ground and air-to-air communications [1]; Airbus pursued a study and experiment on the application of SDN and network function virtualisation (NFV) for use in AFDX networks with OpenFlow [2]. More recently, Rockwell Collins presented a high-level airborne connectivity framework that referred to an SDN gateway platform [3]. However, none of these studies proposed any detailed network and protocol architecture. In addition, how the multi-link concept can be incorporated in such an SDN-based aeronautical communications networking environment has not been investigated.

Driven by the need to enable performance-based navigation and to reduce the aviation system impact on the environment, the EU Horizon 2020 Cleansky2 project Future Cockpit Network Communications Environment Testing (COMET) proposes to study IPv6 based future networking concepts for aeronautical communications. COMET aims to derive seamless, secured and reliable mobility and multi-links [4] solutions for future high-speed avionic platform. Future networking concepts to be explored in COMET include SDN, network coding and software-defined information-centric networking. This paper focuses on presenting preliminary studies on SDN

A part of the SDN studies is to investigate SDN-enabled mobility and multi-links solutions, where the multilink operational concept is defined as the usage of at least two air-ground datalinks simultaneously, including vertical handovers between radio links. The key issue in handling mobility and multi-links is the maintenance and optimisation of end-to-end communication in the presence of more than one radio paths to/from an aircraft. Two key challenges need to be resolved [5]: 1) the dynamic change of multiple radio paths over time due to the aircraft mobility; 2) the optimum utilisation of multiple radio paths that are available simultaneously. Two mobility protocols are considered in this paper: Mobile IPv6 and Locator ID Separation Protocol (LISP).

II. A SDN-BASED AERONAUTICAL COMMUNICATION NETWORK ARCHITECTURE

The COMET architecture is IPv6-based architecture. Fig. 1 shows a high-level SDN-based network architecture proposed in COMET. Although air passenger communications (APC) is outside the scope of COMET, it is included in the figure for completeness.

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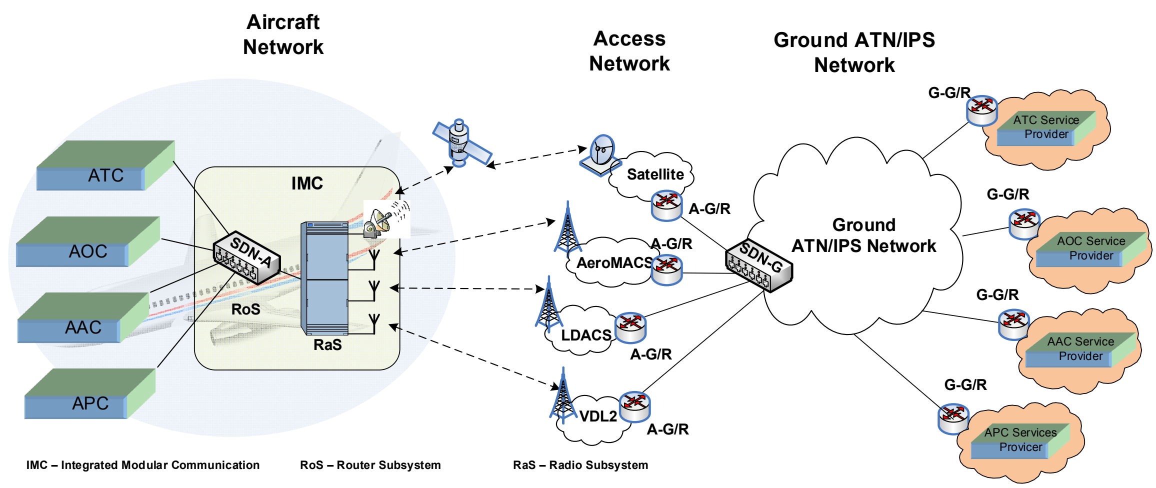

Fig. 1. COMET System Architecure

The network architecture is divided into three sub-networks: the Aircraft Network (AiN), Access Network (AcN) and Ground Aeronautical Telecommunications Network (ATN)/IPS Network.

The aircraft network hosts the Integrated Modular Communication (IMC) system, which consists of two functional components: a Router Subsystem (RoS) and a Radio Subsystem (RaS).

The RoS functionally consists of a communication manager (CM), a router, and a media and data gateway (MDG). The CM and MDG can be physically co-located. Packets from the four application domains, namely air traffic control (ATC), air operation control (AOC), airline administrative control (AAC) and air passenger communications (APC), will be intercepted by the MDG. The MDG will on the one hand extract and pass the IPv6 packet header information in the packet through the signalling interface to the CM, and on the other pass the data packets to the router. The MDG will also perform voice transcoding functions for voice applications and data conversion functions, when necessary. The CM, acting as an on-board SDN controller in the aircraft (SDN-A), is responsible for all control and management (C&M) functions. It will make decisions on how packets should be scheduled, which radio links should be used to transmit the packets from the aircraft to the ground, etc. according to the packet header information, the required quality of service and security policy, and control redundancy for both nodes and link. Hence SDN-A will have a global view of the aircraft communication system. All decisions will then be communicated to the router, which functions like a packet forwarder, from the CM through the signalling interface. After receiving the decision from the CM, the router will forward the packets to the appropriate radio links in the RaS as instructed by the CM. The RaS consists of four radio links enabled by software defined radios including satellite, LDACS, AeroMACS and VDL2 and their transceivers for transmitting and receiving packets to/from the ground.

The access network consists of the four radio access networks to provide data transport functions for COMET air traffic management (ATM) services between the AiN and ATN networks. Simultaneous connection from the aircraft to more than one radio transport networks and handover between different radios are supported to increase coverage and capacity.

The ground ATN network consists of a ground SDN (SDN-G) controller, which inter-operates with the onboard SDN-A controller in a client-server mode through the gateways/routers of the radio transport networks. The top level functional splits between SDN-G and SDN-A controllers are as follows: *(i)* SDN-G controller is responsible for performing configuration, resource allocation, routing and switching related tasks and *(ii)* SDN-A controller is responsible for radio link selection and packet scheduling. The two SDN controllers' functions are performed through SDN applications for handling network resources, controlling mobility procedures as well as other necessary network operations. The ground ATN network also consists of other key components that would enable ATM services to be supported such as security functions, mobility and multi-link operations.

III. Mobility and Multi-link Operations

Future aviation networks will move towards an IP-based paradigm in order to increase operational efficiency [6]. The ATN/IPS standard [7] defined by the International Civil Aviation Organisation (ICAO) based on IPv6 will be deployed for ground-ground and air-ground communications.

The multi-link operational concept as defined in SESAR P15.2.4 requires that an aircraft should be capable of multi-homing for routing data simultaneously over different radio interfaces or radio paths from the aircraft to the ground to provide support for mobility. Currently, two major mobility protocols are being considered for the support of aircraft mobility and multi-link operations: IETF Mobile IPv6 (MIPv6) and CISCO Locator/Identifier Separation Protocol (LISP) [8].

Mobile IP is a location-independent protocol that relies on two IP addresses to enable mobility: the *home address*, which is a permanent IP address used to identify the mobile node (MN) regardless of its current location, and a *care-of-address* (CoA) with which the MN is associated to identify its current location when it moves to a foreign or visited network as described in Fig. 2. A mobility anchor at the MN's home network maintains

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the relationship between the two addresses. One of the biggest drawback of MIPv6 [9] is its incapability to support multi-link operations (or multi-homing). Communication is only available over one subnet at a time even if the aircraft has multiple connections. To overcome this shortcoming, Shim6 [9] was proposed to supplement IPv6 with multi-homing capability.

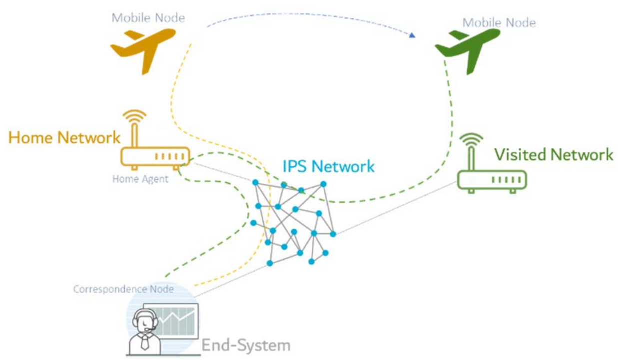

Fig. 2. MIPv6 mobility concept

In contrast, LISP does not have the concept of a home network and the IP address of the MN remains fixed regardless of its location. In addition, LISP naturally supports multi-link operations.

A. Shim6 and Mobile IP

SHIM6 is an IPv6 based multi-homing protocol proposed by IETF and was originally designed to provide IPv6 with failover and load-sharing capabilities. The SHIM6 protocol provides a mechanism to append the active connection with a newly acquired IP address over different radio access networks. This is achieved by the exchange of Update Request (UR) and Update Acknowledgment (UA) SHIM6 control messages between the mobile host and the correspondent node (CN). However, SHIM6 does not provide mobility support. To support mobility with multi-link operations in COMET, MIPv6 and SHIM6 protocols are coupled together to achieve route optimization and multi-homing. In addition, COMET also exploits the IEEE 802.21 Media Independent Handover (MIH) protocol to enable the support of seamless vertical handovers between different network access technologies.

In this section, the signalling exchanges for handover between BGAN and AeroMAC radio links in the forward direction using MIPv6/SHIM6 over a non-SDN based and a SDN-based COMET network architecture are presented respectively. It is assumed that handover is initiated by the RoS onboard the aircraft.

1) Non-SDN Architecture: Fig. 3[1] the AiN is composed of an end-system and different IMC entities including the RoS, an adaptation manager and the two radios links. The AcN is composed of the BGAN and AeroMACS radio access networks, and on the ground the ATN network where ATN Ground-Ground router, Media Independent Information Service (MIIS) and the CN is located. It is assumed that aircraft has an active connection with the CN on the ground initially over the BGAN radio.

In step-1, the aircraft initiates the handover process and decides to handover the BGAN active connection to AeroMACS. Step-2 performs resource preparation in AeroMACS. In step-3, the RoS sends a COMET specific message using the IEEE 802.21 MIH primitive to the AeroMACS radio via the adaptation manager onboard the aircraft. Step-4 involves AeroMACS specific signalling messages for the creation of new AeroMACS service. Step-5 is the response to the COMET specific MIH message sent in step-3. In step-6, the aircraft configures new IP address over the AeroMACS network. In step-7, the RoS sends SHIM6 *"Update Request"* (UR) message to the CN, which then updates the locator list of aircraft in step-8. In step-9, the CN sends back a response as *"Update Acknowledgement"* (UA) message to the RoS. In step-10 the aircraft, initiates *"Reap Explore"* signalling towards the CN using a new IP address over AeroMACS. In step-11, the CN responds back with *"Reap Inbound OK"* message to both IP addresses of the aircraft. Upon reception of this message over the AeroMACS radio, the RoS sends a *"Reap Operational"* message to the CN in step-12 once it receives *"Reap Inbound OK"* message over AeroMACS interface onboard the aircraft. The CN starts using the new IP address of aircraft after receiving *"Reap Operational"* message from aircraft. The handover is complete by releasing the BGAN resource in step-13.

[1] In Fig 3, PoS=Point of Service, PoA=Point of Attachment, MIIS=Media Independent Information Services.

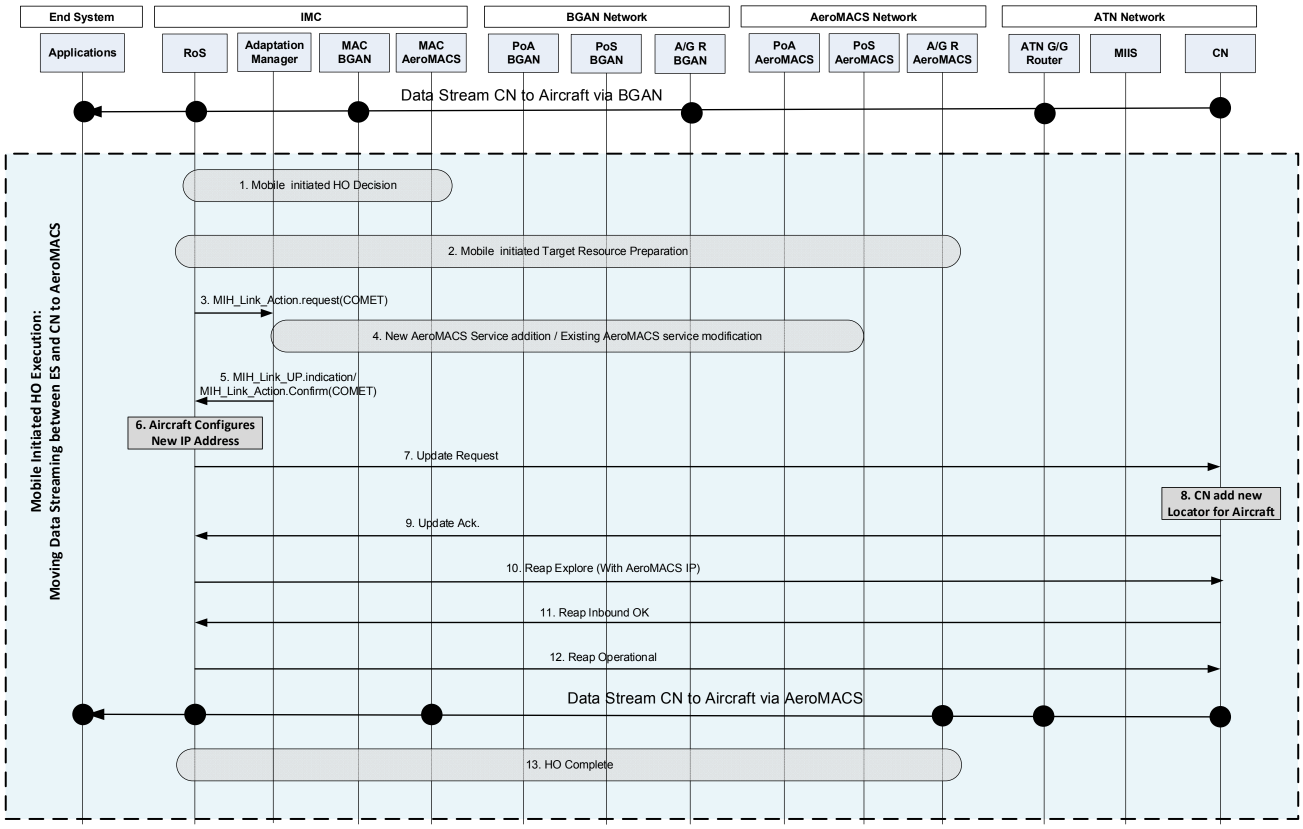

Fig. 3. Forward Link Mobile Initiated HO from BGAN to AeroMACS using MIPv6/SHIM6/MIH (non-SDN based)

2) SDN Architecture: The signalling flow shown in Fig. 4, represents the message exchange for handover from BGAN to AeroMACS in a SDN-based COMET network using MIPv6/SHIM6 protocol. In this case, the aircraft network again has an end-system and IMC entities consisting of the RoS, SDN-A controller and the two radio links. The AiN consists of the same radio access networks as in the non-SDN case, and on the ground the ATN network where the SDN-G and the CN are located. Again, it is assumed that aircraft has an active connection with CN on the ground over BGAN radio and handover is initiated by the aircraft. It has to be noted that the onboard SDN-A controller acts as the CM and the SDN-G performs functions MIIS on the ground in the ATN network.. Step-1 to Step-6 represent the signalling for handover initiation, decision and resource preparation on the target network and configuring new IP address on aircraft over target network (AeroMACS) interface. From step-7 onwards, most of the control messages are being exchanged over the east/westbound SDN interface between the SDN-A and SDN-G. Step-7 combines *"Update Request"* and *"Reap Explore"* messages in *"Update Explore Request"* message and send it to SDN-G. The SDN-G then sends *"Update Request"* message towards CN in step-8. The CN adds new IP address/Locator for aircraft and sends *"Update Ack"* back to SDN-G in step-9 and step-10. In step-11, SDN-G sends *"Reap Explore"* message to CN. The CN responds back with *"Reap InboundOk"* message to SDN-G in step-12, which is forwarded by SDN-G towards the aircraft over AeroMACS radio. In step-13, RoS in aircraft sends *"Reap Operational"* message to signals the CN on the ground to start sending data over AeroMACS. Finally, step-14 in Fig. 4 represents the release of resources from the BGAN network after successful handover from BGAN to AeroMACS.

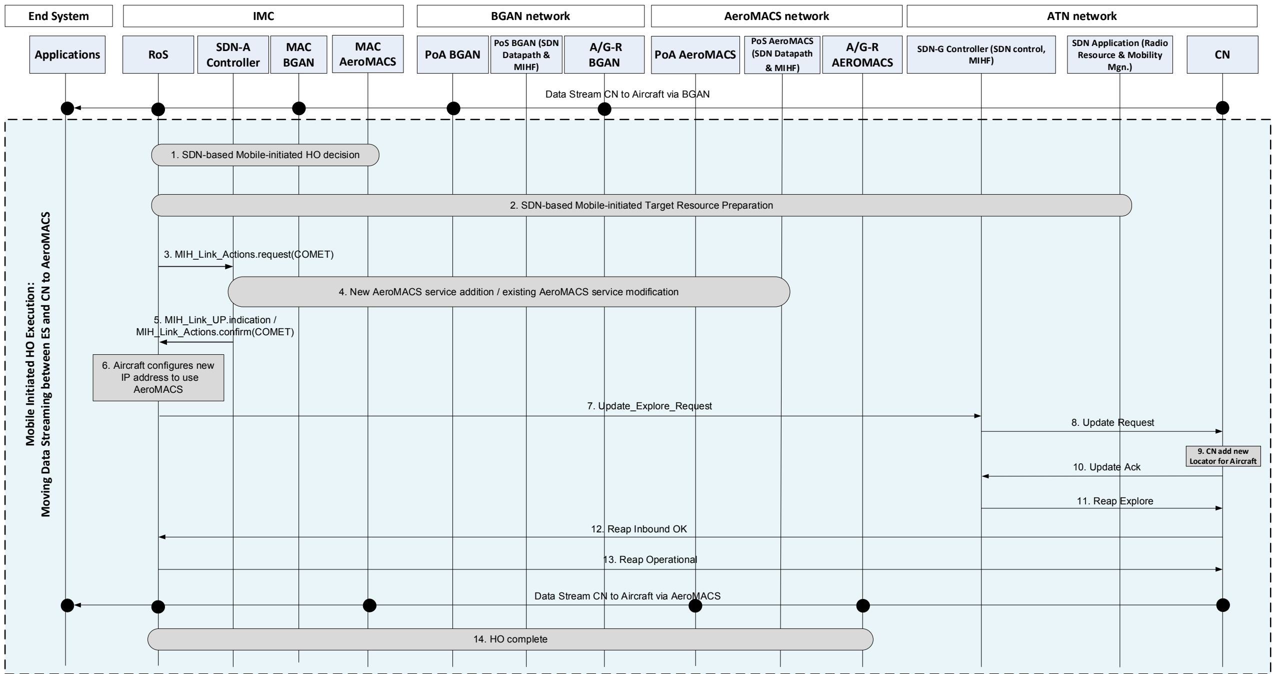

Fig. 4. Forward Link Mobile Initiated HO from BGAN to AeroMACS using MIPv6/SHIM6/MIH (SDN based).

B. LISP

LISP splits location from an identity to provide native mobility and multi-homing. With LISP, mobile clients can be seamlessly equipped with multiple wireless interfaces, and handover from different points of attachment, or among interfaces. LISP considers two different types of addresses: Endpoint Identifiers (EIDs) and Routing Locators (RLOCs). EIDs identify hosts and are assigned independently from the network topology, while RLOCs identify network attachment points, and are used for routing and forwarding of packets through the network. This allows an EID to remain unchanged even if a topological change occurs, such as a handover. LISP then defines functions for mapping between the two address spaces and for encapsulating traffic originated by devices using non-routable EIDs for transport across a network infrastructure that routes and forwards packets using RLOCs. The devices with non-routable EIDs refer to the devices whose addresses are EIDs only and are not globally routable IP addresses; these EIDs are not found in the legacy Internet routing table. In transit, packets are encapsulated; the outer header contains RLOCs while the inner header contains EIDs. The LISP specification defines two network elements: The Ingress Tunnel Router (ITR) and the Egress Tunnel Router (ITR). A LISP ITR accepts IP packets from site end systems on one side and sends LISP-encapsulated IP packets toward the Internet on the other side. A LISP ETR receives LISP-encapsulated IP packets from the Internet on one side and sends LISP-decapsulated IP packets to site end systems on the other side. LISP also introduces a Mapping System (MS/MR), a distributed database that maps EIDs onto RLOCs.

LISP Mobile Node (LISP-MN) [10] is a particular case of LISP. The functions of ITR and ETR are implemented in the LISP mobile node itself, which makes a single mobile node look like a LISP site. A LISP-MN receives a new RLOC when it moves or roams into a new network.

In LISP-MN, when an EID–RLOC mapping in the map database is changed, the new mapping information is notified to the network by means of "*Map-Register"*/*Map-Notify"* and "*Solicit Map Request*" (SMR) messages. However, the map-entry update mechanism in the standard LISP-MN shows long latency for the propagation of the updated mapping information. To provide LISP-enabled for ATC, AOC, AAC and APC services, the COMET network requires a fast update of EID–RLOC mapping.

In the following sections, the Standard LISP-MN, LISP-MN with Proxy Map-Reply [11] and the proposed SDN-based LISP-MN are presented for the forward link mobile initiated handover procedure from the BGAN network to AeroMACS network. The RoS in the aircraft is a LISP-MN capable router and the ground-ground router (G/G-R) in the ATN network is a LISP-capable router (xTR).

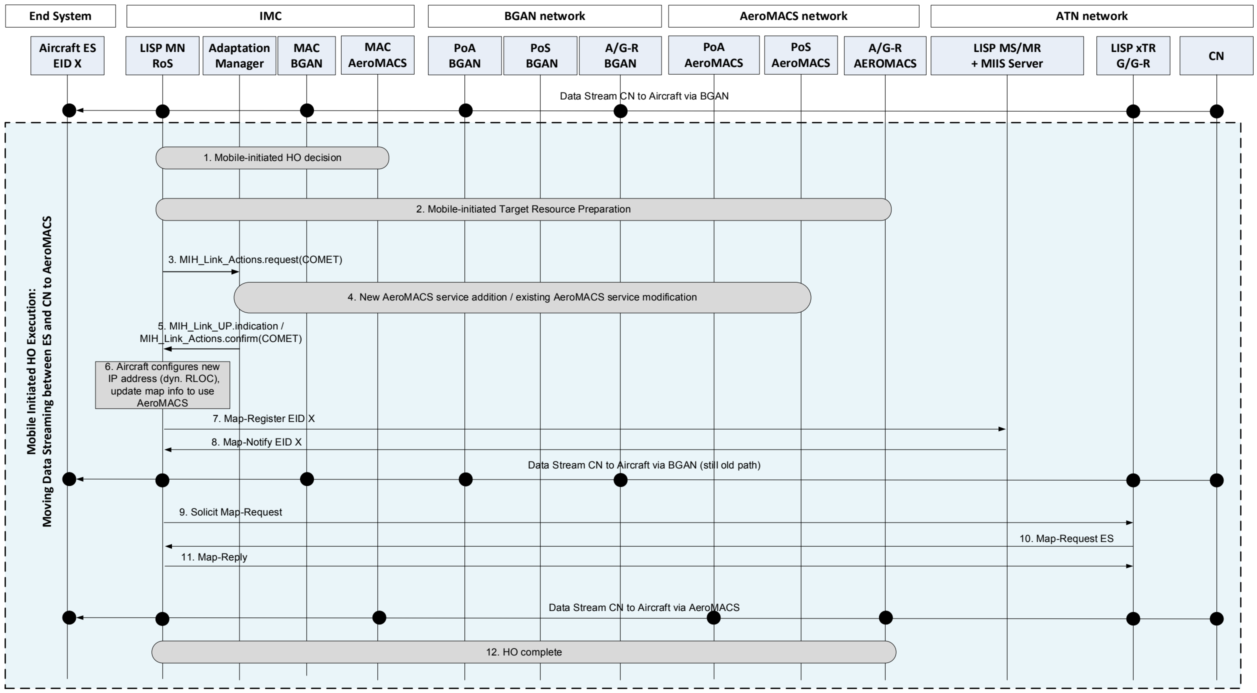

Fig. 5. Forward Link Mobile Initiated HO from BGAN to AeroMACS using Standard LISP-MN.

Similar to the MIPv6 case, the IEEE 802.21 MIH control framework is also used in conjunction with LISP. It is assumed that LISP MS/MR and MIIS server are co-located in the ATN network.

1) Standard LISP-MN: Fig. 5 illustrates the signalling procedure for seamless handover using the Standard LISP-MN approach. Step-1 to step-6 are similar to MIPv6 as described in previous sections. In step-6 the map database in LISP-MN RoS is updated. In step-7 LISP-MN RoS sends a "*Map-Register"* message to the mapping system. All the control messages from step-7 are being exchanged over AeroMACS interface of aircraft. The "*Map-Register"* message includes the new mapping information. This Map-Register step ensures that the mapping system keeps an up-to-date EID–RLOC mapping in LISP-MN RoS. In step-8 the MS/MR replies with the "*Map-Reply*" to LISP-MN RoS. In step-9, LISP-MN RoS sends a "*Solicit-Map-Request"* (*SMR*) message to LISP xTR G/G-R. Upon receiving the *SMR* message, LISP xTR G/G-R is notified that the map database of LISP-MN RoS has been updated and then sends a "*Map-Request*" to the mapping system, followed by a "*Map-Reply*" with the new mapping information. After these five steps, traffic destined to Aircraft ES EID X is directed from the BGAN network to the AeroMACS network.

2) LISP-MN with Proxy Map-Reply: According to [11], an ETR can request, by setting the "proxy Map-Reply" flag (P-bit) in the "*Map-Register"* message, that the Map-Server answer "*Map-Requests*" on its behalf instead of sending them to the ETR. Fig. 6 illustrates the signalling procedure for seamless handover using the LISP-MN with Proxy Map-Reply approach. In step-7 in the "*Map-Register*" message that is sent from LISP-MN RoS to MS/MR, the P-bit is set to 1. This enables the MS/MR to reply to "*Map-Request*" messages from LISP xTR G/G-R on the behalf of LISP-MN RoS as in step-10 and step-11. This helps minimize control traffic on the radio links from the ATN network toward the aircraft that is very costly.

3) SDN-based LISP-MN: Fig. 7 illustrates the signalling procedure for seamless handover using the SDN-based LISP-MN approach. The map-entry update latency can be further decreased by customizing two LISP messages: "*Solicit Map-Update*" and "*Map-Update*". A "*Solicit Map-Update*" message is proposed to notify an update of the map database. In step-7 the LISP-MN RoS sends a "*Solicit Map-Update*" message to the SDN-G controller immediately after the LISP-MN RoS has updated its map database. Then, in step-8 the SDN-G controller directly send "*Map-Update*" to the xTR in the network to update the map cache of the xTR with the new EID–RLOC mapping. Compared with the standard LISP, where the update of the map database requires five steps, the proposed SDN-based LISP-MN requires only two steps as shown in Fig. 7.

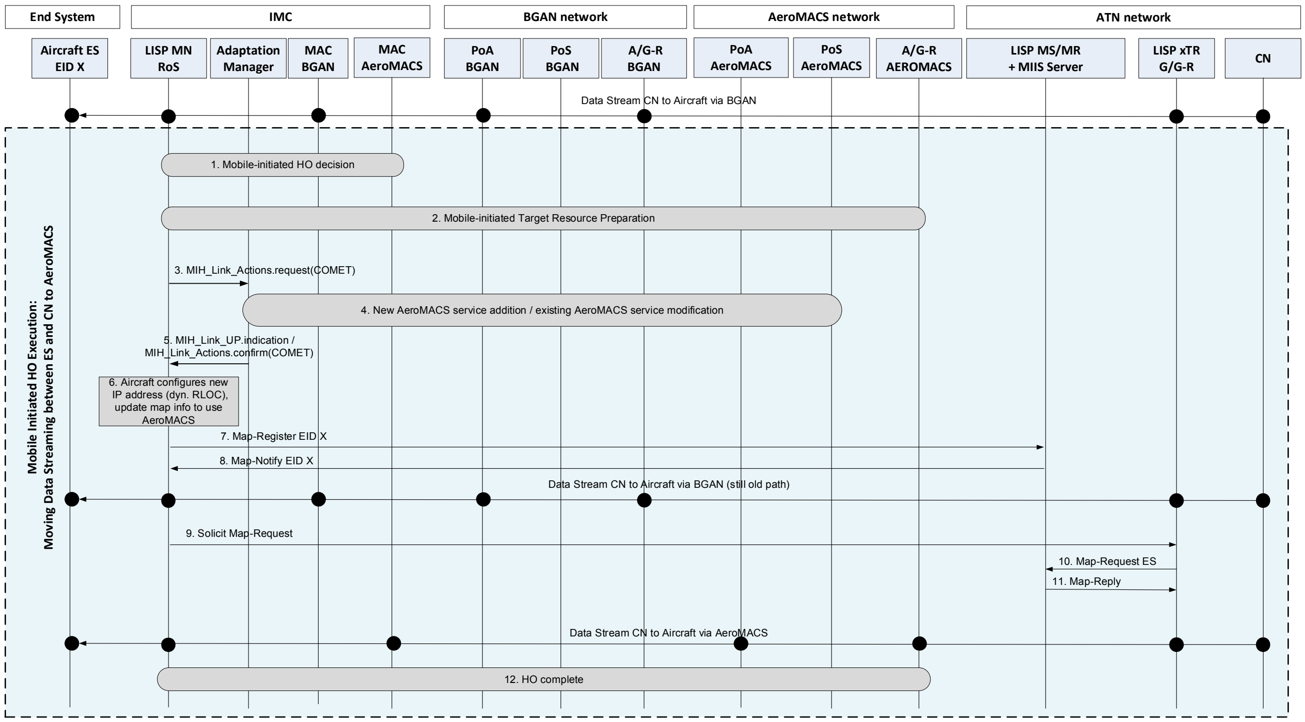

Fig. 6. Forward Link Mobile Initiated HO from BGAN to AeroMACS using LISP-MN with Proxy Map-Reply.

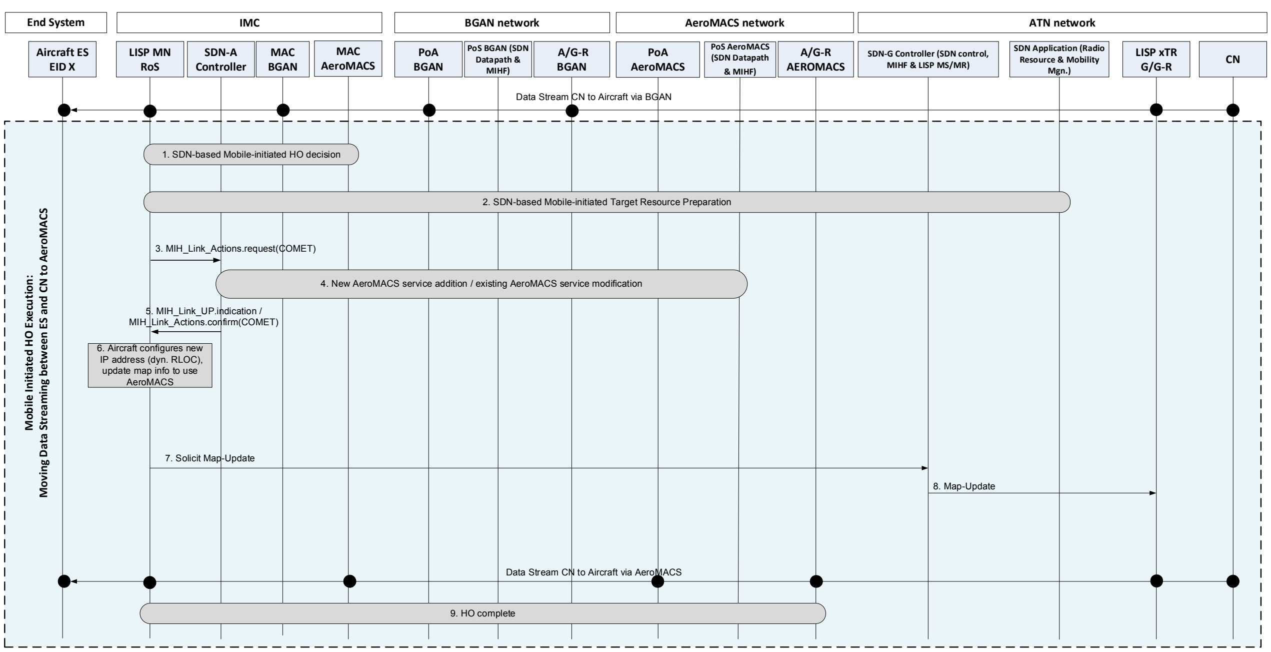

Fig. 7. Forward Link Mobile Initiated HO from BGAN to AeroMACS using SDN-based LISP-MN.

C. *Case Study: A comparison between LISP-MN and Mobile IP with Shim6 in both SDN-based and Non-SDN based approaches*

To evaluate the performance of the handover procedures, time delay analysis has been carried out based on the message sequence charts. However, it is important to note that the delay from step 1 to step 6 is not taken into the following calculations, the delay difference between the two different mobility protocols from step 7 onwards is investigated. The various wired and wireless links and interfaces between different network components shown in the above message sequence charts have been considered. In general, the total time taken to transmit a single message over any given link D_{Total} can be expressed as the sum of four delay components [12, 13]:

$$D_{Total} = D_{Prop} + D_{Proc} + D_{Trans} + D_{queue} \quad (1)$$

where, D_{Prop} is the propagation delay, D_{Proc} is the processing delay, D_{queue} is queuing delay and D_{Trans} is the transmission delay. The general queuing delay D_{queue} for any network entity, based on an M/M/1 queuing model can be expressed as $D_{queue} = \frac{1}{\mu - \lambda}$ where μ is the service rate and λ is the arrival rate. Table I presents the various parameters adopted for evaluating the delay of the handover procedures. The channel capacity is assumed to be 5.5 Mbps for AeroMACS using 64 QAM 1/2 [14], 492Kbps for BGAN [15], and 100 Gbps for the wired MAN connections between the Access Network and Ground ATN Network [16]. Propagation delays of 250 ms for Geo satellites, 5 µs for AeroMACS, and 5 ns for wired MAN of a one-meter long cable are assumed. The transmission delay over a transmission link has been derived by dividing the average packet size with the data rate of that particular link.

1) Signalling delay analysis of MIPv6 with SHIM6: The delay for the handover procedure using MIPv6/SHIM6 based mobility protocol is expressed as follows:

$$\begin{aligned} D_{MIPv6} &= D_{Aircraft-AeroMACS} + D_{AeroMACS-ATN} + D_{within\_ATN} \\ &= \left[(P)\left\{D_{Prop} + D_{Proc} + D_{Trans} + \left(\frac{1}{\mu - \lambda_{wireless}}\right)\right\}\right] + \\ &\left[(Q)\left\{D_{Prop} + D_{Proc} + D_{Trans} + \left(\frac{1}{\mu - \lambda_{wired}}\right)\right\}\right] + \\ &\left[(R)\left\{D_{Prop} + D_{Proc} + D_{Trans} + \left(\frac{1}{\mu - \lambda_{wired}}\right)\right\}\right] \end{aligned} \quad (2)$$

In equation (2), P represents the total number of messages exchanged between Aircraft and target network (AeroMACS) over the wireless link, Q denotes the number of messages exchanged between target network and ATN network over the wired link, and R denotes the number of messages exchanged between entities within ATN network and CN over the wired link. The values of {P, Q, R} are {5, 5, 5} for MIPv6/SHIM6 and {3, 3, 5} for SDN-based MIPv6/SHIM6. The values of {P, Q, R} have been obtained by counting the number of messages between different entities in each signalling chart for both directions. For example in Fig. 3, we can see that between Aircraft and AeroMACS, between AeroMACs and ATN, and between entities within ATN, there are 5 messages that are 7, 9, 10, 11, and 12. The sizes of the different messages used in MIPv6/SHIM6 signalling charts are shown in Table I. **Error! Reference source not found.**

2) Signalling delay analysis of LISP-MN: The delay for the handover procedure using LISP-MN based mobility *protocol follows* the same approach as in equation (2). However, the values of {P, Q, R} has been updated to take into account the LISP-MN cases. P represents the total number of messages exchanged between Aircraft and target network (AeroMACS) over the wireless link, Q denotes the number of messages exchanged between the target network and ATN network over the wired link, and R denotes the number of messages exchanged between entities within ATN network over the wired link (between LISP MS/MR and G-G/R LISP xTR). The values of {P, Q, R} are {5, 5, 3} for Standard LISP-MN, {3, 3, 3} for LISP-MN with Proxy Map-Reply, and {1, 1, 1} for SDN-based LISP-MN. The sizes of different LISP-based messages are shown in Table I.

Fig. 8 shows non-SDN based signalling delay of the handover from BGAN to AeroMACS using different mobility protocols, i.e. MIPv6, LISP-MN and LISP-MN with Proxy Map-Reply respectively. It can be seen from both figures that an increase in the arrival rate will cause an increase in the total signalling delay as a result of an increase in the queuing delay D_{queue}. Fig. 8 illustrates LISP-MN with Proxy Map-reply exhibits the lowest delay for non-SDN based approaches as MS/MR replies to Map-Request messages from LISP xTR G/G-R on the behalf of LISP-MN RoS step-10 and step-11 in Fig. 6 that minimizes control traffic on radio links from the ATN network toward the aircraft. On the other hand, MIPv6/SHIM6 protocol shows the highest delays for the non-SDN based approach. The reason for this increased total delays in the MIPv6 case is due to host-based mobility as all the signalling exchange is taking place between aircraft and the CN.

Fig. 9 illustrates the comparison between SDN based MIPv6/SHIM6 and LISP-MN approaches. The graph in this figure shows that SDN-based LISP-MN has lower handover delays as compared to the SDN-based MIPv6/SHIM6 approach. In case of SDN-based LISP-MN, all five messages from standard LISP-MN (i.e. MAP-Register, Map-Notify, Solicit-Map-Request, Map-Request and Map-Reply) are replaced by two newly created "Solicit_Map-Update" and "Map-Update" SDN-based COMET message. This reduces most of the control messages exchanged between the aircraft network and ground network, hence reduces the total delays. The statistics of SDN-based "LISP-MN with Proxy Map-Reply" approach are not considered in Fig. 9 as the behaviour of both SDN-based LISP-MN and SDN-based "LISP-MN with Proxy Map-Reply" will be same under SDN-based COMET architecture.

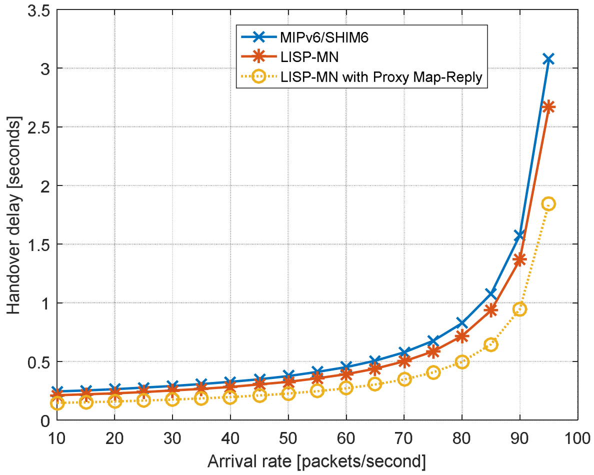

Fig. 8. Non-SDN based signalling delay of the handover from BGAN to AeroMACS using different mobility protocols.

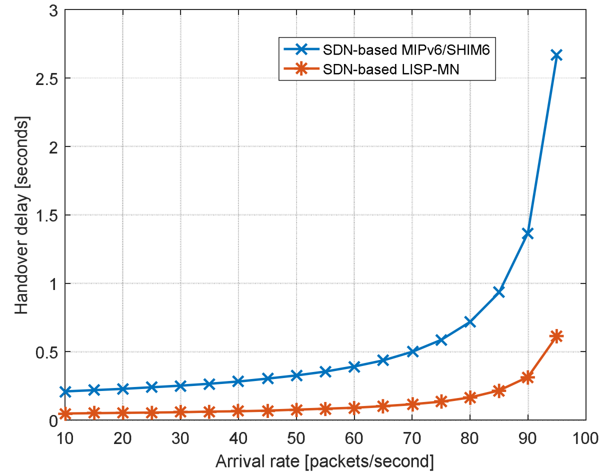

Fig. 9. SDN-based signalling delay of the handover from BGAN to AeroMACS using different mobility protocols.

Table 1: PARAMETER VALUE CHART

No.	Parameter Name	Symbol	Value	
1	Arrival rate at the wireless interface	$\lambda_{wireless}$	10 to 95 packets/sec	
2	Arrival rate at the wired interface	λ_{wired}	10 to 95 packets/sec	
3	Service rate	μ	100 packets/sec	
4	Wireless channel capacity	C_j	5.5, 0.492 Mbps	
5	Wired channel capacity	C_i	10 Gbps	
6	Wireless link Propagation delay	$D_{\Pr op}$	250ms, 5 µs	
7	Wired link propagation delay	$D_{\Pr op}$	5ns	
8	Wireless transmission delay	D_{Trans}	241 µs	
9	Wired transmission delay	D_{Trans}	13.2 ns	
10	Number of supported radio access technologies	n	2	
11	Average packet processing delay	$D_{\Pr oc}$	5ms	
12	Number of messages exchange required between Aircraft and target network, between the target network and ATN network, and between entities within the ATN network.	*{P, Q, R}*	LISP-MN	{5, 5, 3}
			LISP-MN with Proxy Map-Reply	{3, 3, 3}
			SDN-based LISP-MN	{1, 1, 1}
			MIPv6/SHIM6	{5, 5, 5}
			SDN-based MIPv6/SHIM6	{3, 3, 5}

IV. Conclusion

This paper presented an SDN-based aeronautical communication system architecture. Two different mobility protocols, LISP-MN and MIPv6/Shim6, for multi-home multi-link connections have been studied in conjunction with mobile-initiated handover in the forward link direction with different signalling flow charts. Performance comparisons have been carried out between the different mobility protocols, LISP-MN and MIPv6/Shim6, in terms of handover signalling delay for both SDN-based and non-SDN based architecture. Furthermore, LISP-MN with Proxy Map-reply has also been considered in the non-SDN based scenario. Simulation results show that the average handover delay for MIPv6/SHIM6 is 15.3 % longer than LISP-MN and 66.59% longer than LISP-MN with Proxy Map-Reply in the non-SDN based architecture. In the SDN-based scenario, the delay gap is even higher with MIPv6/Shim6 has an average delay of 333.14% more than that of LISP-MN.

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