Common RRM in Satellite-Terrestrial Based Aeronautical Communication Networks

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Abstract. This paper presents a collaborative radio resource management (CRRM) scheme to support seamless aeronautical communications using satellite and terrestrial access technologies. The CRRM adopts and extends the IEEE 802.21 Media Independent Handover (MIH) framework and the ETSI Broadband Satellite Multimedia (BSM) SI-SAP concept to split the CRRM functions between the upper layers (layer 3 and above) and the lower layer (link layer and physical layer) of an aircraft terminal. Upper layer functions are managed by an integrated router (IR) on-board the aircraft and lower layer functions are provided by an on-board integrated modular radio (IMR) consisting of heterogeneous radio access technologies. A joint radio resource manager (JRRM) provides the abstraction layer for mapping higher layer functions into lower layer functions to enable collaboration. The CRRM scheme and its associated general signaling procedures are described in detail. Through the CRRM scheme, the connection establishment functions and seamless handovers between different radio technologies are performed by combining MIH primitives and BSM primitives. Analytical time-delay analysis is carried out to evaluate the signaling delay for connection establishment and handover procedures.

Keywords: Aeronautical networking, BSM, MIH, CRRM/JRRM, Handover, AeroMACS, DVB-S2.

1 Introduction

The EU Project SANDRA (Seamless Aeronautical Networking through integration of Data-Links, Radios and Antennas) [1] aims to design, specify and develop an integrated aircraft communication system primarily for air traffic management to improve efficiency and cost-effectiveness in service provision by ensuring a high degree of flexibility, scalability, modularity and reconfigurability.

The SANDRA system is a ‘system of systems’ addressing four levels of integration: Service Integration, Network Integration, Radio Integration and Antenna Integration. From the communications network point of view, SANDRA spans across three segments, namely, the Aircraft segment, the Transport segment and the Ground segment, as shown in Fig. 1. The Aircraft segment consists of three main physical components: the Integrated Router (IR), the Integrated Modular Radio (IMR) and the

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Antennas. These three components form the SANDRA terminal. The IR is responsible for upper layer functionalities, such as routing, security, QoS and mobility. The IMR takes care of lower layer radio stacks and functions including radio resource allocation, QoS mapping and adaptation functions. Through Software Defined Radio (SDR) [2] the IMR supports dynamic reconfigurability of operations on a specific radio link at any time and provides the flexibility for accommodation of future communication waveforms and protocols by means of software change only. The physical separation between the IR and the IMR has the advantage of increased modularity and identifying distinct management roles and functions for higher layer and lower layer components with IP providing the convergence. The Antennas include a hybrid Ku/L band Integrated Antenna (IA), a VHF antenna and a C-band antenna. The IA is a hybrid Ku/L band SatCom antenna to enable an asymmetric broadband link. The various end-systems i.e. Air Traffic Service (ATS), Airline Operation Centre (AOC), Airline Administrative communication (AAC) and Aeronautical Passenger Communications (APC) [3] are all connected to the IR.

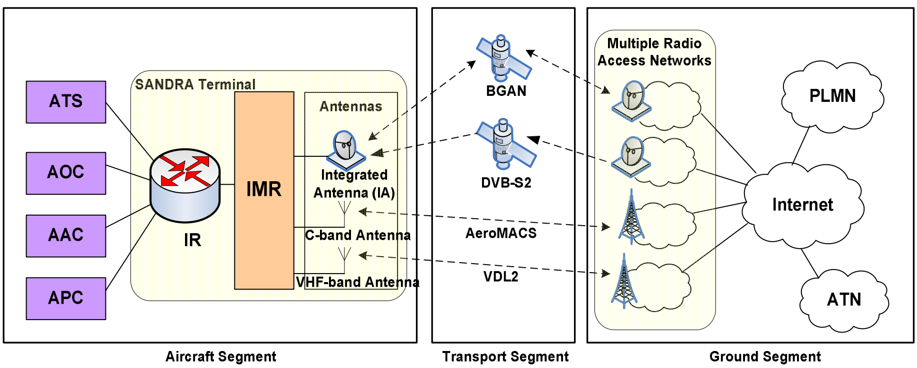

Fig. 1. SANDRA Network Architecture

In the Transport segment, four radio transport technologies are considered, namely, VDL mode 2 [4] in VHF band, BGAN [5] in L-band, DVB-S2 [6] in Ku-band and AeroMACS - a WiMAX [7] equivalence for aeronautics communications - in C-band.

The Ground segment consists of multiple operators; multiple Radio Access Networks (RANs) and their corresponding core networks, the Aeronautical Telecommunication Network (ATN), the Internet and possibly the Public Land Mobile Network (PLMN, for passenger communications). The RANs can also be connected directly to the ATN and the PLMN on the ground. In order to provide mobility and security services for aeronautical communications, functional components such as the mobility server, security and authentication server are required in the ground segment to provide corresponding mobility and security information services. These components will be provided by the ATS/AOC/AAC and APC service providers of the ATN on ground.

This paper presents a functional architecture of the SANDRA terminal for radio resource management (RRM) and an approach to partition the functional entities between the IR and IMR for the configuration and reconfiguration of radio links during the connection establishment and handover.

2 The SANDRA RRM Architecture

Radio resource management includes network based functions and connection based functions. Network based functions encompass admission control, load control, packet scheduling and radio bearer allocation. Connection based functions include handover control and power control. Handover control function handles handover initiation, decision and execution processes to ensure call/session continuity.

The SANDRA project concentrates on radio link selection decision among the four heterogeneous radio access technologies during admission control, packet scheduling and handover processes. Radio bearer allocation functions for individual radio link access technologies will not be considered as this is outside the scope of the project. More specifically, this paper describes a RRM architecture framework where radio link selection decisions are made collaboratively between the IR and the IMR.

To provide efficient RRM among heterogeneous networks, QoS and routing related parameters have to be considered along with the real-time link conditions and characteristics. A collaborative RRM mechanism is derived to monitor and manage the resources available in the different radio links to ensure that the application QoS/SLA requirements are met during connection establishment and handover processes. Fig. 2 shows the collaborative RRM functional and protocol architecture of the SANDRA terminal.

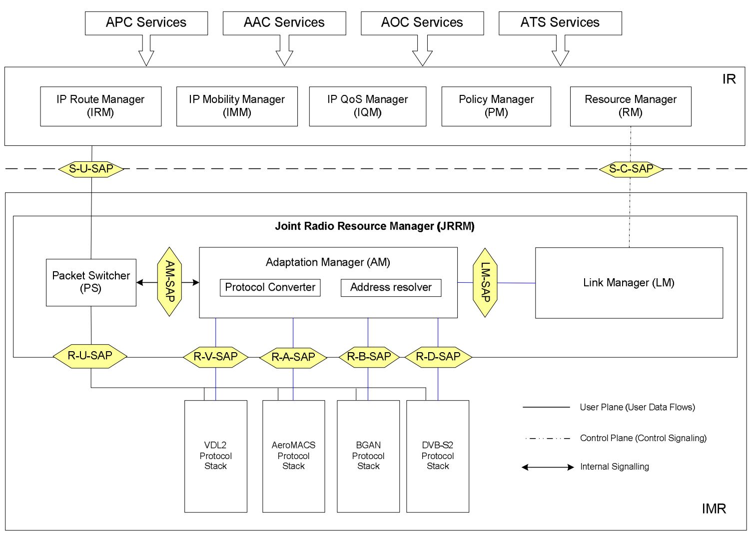

Fig. 2. RRM Functional Architecture

From the protocol stack point of view, the application layer supports APC, AAC, AOC and ATS services. The IR represents the network layer of the OSI stack and contains the following functional entities:

- IP Route Manager (IRM): This entity provides IP routing and IP address management functions. It interacts with the IP Mobility Manager (IMM) to enable mobility management functions to be carried out. For NEMO [8] support, the IRM will manage the IPv6 and IPv4 prefixes assigned to the mobile network. It is also responsible for setting up Mobile IP tunnels to the correspondent node and reverse tunnels to the Home Agent using IPv6 encapsulation.

- IP QoS Manager (IQM): This entity maps application layer QoS parameters onto to those in the IP layer. It also performs packet classification, packet buffering and packet scheduling functions.
- IP Mobility Manager (IMM): This entity enables the SANDRA terminal to roam from one network domain to another while maintaining session connection during handover when there is a change in the point of attachment of the terminal. Specifically, the IMM is responsible for neighbor discovery, router advertisement, mobility header management and binding update processing. It is also responsible for handling multihoming and network mobility (NEMO) functionalities.
- Policy Manager (PM): The PM manages and maintains a database of the flow-specific policies or rules that specify the traffic flow characteristics (e.g. QoS requirement, cost, security level, etc.) that the radio links may need to meet. These policies may also contain preferences of radio links for individual flows. These rules will facilitate the link selection decision for traffic flow with policy constraints.
- Resource Manager (RM): This entity monitors the availability of the different radio links, any reserved resources on them and maintains a view on the different IP traffic flows. It identifies whether there is a need for more resources based on the type of session requests or on the current status of the IP queues.

The IMR representing the data-link and the physical layer of the OSI stack consists of four different radio protocol stacks. A SANDRA specific Joint Radio Resource Manager (JRRM) is also located here. It is responsible for managing and controlling the resources made available to the underlying radios in a uniform and consistent manner and provides a single common interface between the IR and the IMR. Functional entities included in the JRRM are the Adaptation Manager (AM), the Link Manager (LM) and the Packet Switcher (PS). Both the AM and the LM are control plane entities whereas the PS is a user plane entity.

The AM supports protocol mapping for protocol conversion between the IR and the IMR and address resolution functions for mapping between network layer identities onto link specific identities. In addition, it also carries out a switching function equivalent to the MIH Function (MIHF) for handover to support handover services including the Event Service (ES), Information Service (IS), and Command Service (CS), through service access points (SAPs) defined by the IEEE 802.21 MIH [9] working group.

The LM performs link selection and link configuration functions and together with the RM in the IR forms the Connection Manager (CM). The CM as a whole acts as a MIH user in the MIH framework.

The PS is responsible for switching data packets received from the IR in the user plane to the destined radio modules according to a packet switching table generated and passed by the address resolver in the AM during connection establishment. The packet switching table essentially contains the mapping of the QIDs [10] defined in the BSM SI-SAP concept onto different radio link identifiers (Link IDs). As a result, each data packet can be switched directly to the radio modules without passing through the AM in the user plane.

3 SANDRA Collaborative RRM Mechanism

The collaborative RRM mechanism defined in SANDRA considers collaborative connection management, collaborative QoS management and collaborative mobility management in relation to admission control, packet scheduling and handover functions as described in the previous section through cross-layer collaboration between functional entities in the IR and the IMR and using the session concept. While the IR is responsible for managing the network layer connections, the IMR is responsible for the link layer connections. The collaborating entities, the RM and the LM, are grouped into a single cross-layer entity - the CM. The relationships of the CM with the PM, IQM, IMM and AM is depicted in Fig. 3.

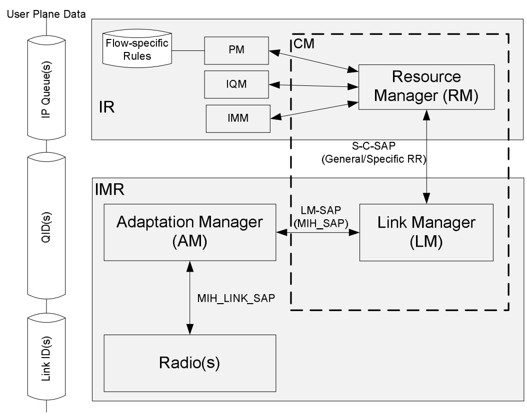

Fig. 3. Cross-layer collaborative connection management

3.1 The SANDRA Sessions Concept

The SANDRA Sessions mechanism is used for connection management and connection bindings between the IR and the IMR in order to provide efficient RRM and to meet the QoS requirements. Sessions are used to map corresponding data queues within the IP layer and the link layer.

In SANDRA, the term "session" corresponding to a single connection is between a given IP queue and a link-layer queue. As shown in Fig. 4, there is a one-to-one mapping between the IP queues and the sessions. In BSM [10], the QID is used for mapping IP queues to BSM queues. This QID concept has been adopted and extended within SANDRA to identify the IP queues in the IR and the corresponding session with the IMR. Hence, the sessions will be represented by a QID, which is unique for every session.

Every session between the IR and the IMR will have a certain QoS profile based on the desired application requirements that are being carried by the session. It is important that the QoS parameters of the IP queue are mapped to the session QoS and then further mapped to the QoS of the link-layer queue.

Different sessions are required for the different support radio links within the SANDRA system. Hence, if two active radio links are present, then at least two sessions are required to carry data over the two radio links, i.e. one for each radio. In other words, the same session cannot be used for carrying data over two radio links.

Radio technologies like VDL2 and DVB-S2 only provide single type of radio bearers and hence limited RRM functionalities. Only a single type of radio connection may be established between the terminal and the ground infrastructure of these radio technologies at any given time. Therefore within SANDRA, only a single session is required between the IR and the IMR for these radio technologies. Newer radio technologies like BGAN and AeroMACS support multiple radio bearers of different QoS simultaneously. As such, multiple sessions may be present between the IR and the BGAN and AeroMACS radio stacks.

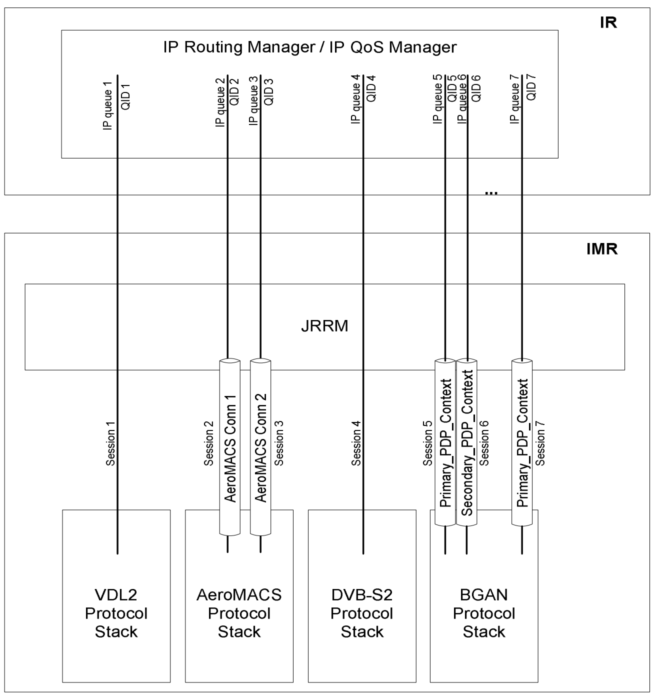

Fig. 4. The SANDRA Sessions concept

A session can be general or dedicated, depending on whether the radio request (RR) is a general RR or a specific RR. A general session means that a session is established without specific restrictions apart from satisfying the QoS requirements. In this case, the LM can make decisions on link selection - to select the most suitable link available which can satisfy the requirements specified in the RR. In addition, user traffic from multiple applications can be transmitted on the same session. The RM in the IR will make the decisions on how to use these general sessions to transmit user data. Thus, the IR and IMR make collaborative decisions on the session establishment. The former decides on the way how user data from multiple applications will be transmitted on different sessions whereas the latter decides on the most suitable link access technology for the requested session. A dedicated session is established for a specific application; only data from this specific application can be transmitted on the requested session. If a RR from the IR includes policy based routing decision, for example a dedicated radio link should be used for this specific RR due to regulatory or geographical constraints, the LM in the JRRM of the IMR should try to set up the session on the specified radio link. In this case, the IR makes decision on which link access technology should be used and informs the IMR through a specific RR so that the IMR can collaborate by allocating resource on the specified radio link for the requested session.

3.2 Collaborative Connection Management

Connection management functions including connection establishment, connection termination and connection modifications are carried out by the CM that enables decisions on network layer and link layer connections to be established by the RM in the IR and the LM in the IMR collaboratively.

As shown in Fig. 3, the PM is connected to a database of the application flow-specific rules and policies. These policies may govern the decision on which radio links can be used for different applications. Such policies may be based on the type of applications, type of planes, the location of the plane and flight path, etc. It may also be based on security and regulatory requirements that may restrict the applications to be transported over a specific radio link. Applications that do not have strict requirements specified by the policy manager may be transported over any one of the available links that satisfies the application QoS.

Upon reception of a session request specifying the application QoS requirement, the RM will decide whether it is a general session request or a dedicated session request by checking with the PM for any flow-specific rules or policies with which the requested applications must comply. Such policies may restrict the choice of radio links for its transportation. There may be some applications that do not explicitly send a request to the IR specifying the required QoS but may start directly sending the application data to the IR. The Resource Manager would be responsible for managing the resources required for such traffic also. As such, the RM carries out the first level of decision making. It is responsible for deciding when new resources are required, when resources are released, etc. It will also perform link selection decision upon receiving dedicated session requests.

The LM responsible for controlling the radio links and performs the second level of RRM related decision making for connection establishment. In the case of general session request, the LM performs suitable link selection by mapping the application QoS requirements onto the resource availability and the quality of the available links. The radio link that can most satisfy the QoS requirements will be selected and a session between the IR and the selected radio link will be established.

3.3 Collaborative QoS Management

In relation to satisfying the QoS requirements upon a service request, the IQM in the IR will control and manage the IP Queues. On receiving data from the higher layers, the IP QoS manager performs packet classification based on the type of application and perform packet marking using Diffserv codepoints. Codes corresponding to the QoS requirements are added to the IP header of each packet before sending it to the IMR. The IR also performs packet level scheduling of all incoming application packets based on their QoS requirements. The IR sees the different sessions between the IR and the IMR as different data tunnels though which different data needs to be sent. Application data as a result of a dedicated session request will be sent over a dedicated session, otherwise they can be sent over any available sessions that may satisfy its QoS requirements.

The IMR needs to be able to also setup appropriate link-layer connections that meet the desired QoS that is requested by the IR. This requires mapping the higher layer QoS parameters to the link-specific QoS parameters. If the radio link network cannot meet the desired QoS then another suitable link may be selected that could satisfy the QoS. If none of the available radio links is able to meet the desired QoS then the session request is rejected. The IR may then re-issue the resource request with the modified QoS parameters.

The IP QoS Manager in the IR is responsible for monitoring the IP queues to make sure that there are no packet drops within the system. The Packet Switcher in the IMR is also responsible to monitor any packet drops. These performance metrics need to be reported to the management Unit in the IR via the management plane.

When the existing sessions are not able to satisfy the QoS needs of the application, then new session may be setup or additional resources may be requested on the existing radio links. This would require QoS re-negotiation with the ground networks.

3.4 Collaborative Mobility Management

The SANDRA system supports multihoming where the IR can be connected to multiple ground networks via different radio links at any given time. Due to location constraints, handover support across different radios is required. For example, the AeroMACS radio technology would be primarily available only at the airports during taxiing, taking-off and landing whereas satellites will be the primary means for communications when the airplanes are at cruising attitude. In addition, an airplane may move out of coverage of a given satellite link and then enter into another. The fast movement of the airplanes presents another complexity for mobility management in terms of handover.

In SANDRA, NEMO will be used by the IR for providing local and global mobility solutions and seamless mobility across the different networks. The IR and the IMR work in a collaborative manner to provide a cross layer mobility management solution. The IR may request the IMR to handover sessions from one radio link to another if there are some rules that dictate that different links may be used by an application during different phases of the flight. The IMR will also periodically monitor the link conditions and if it detects that a given link is no longer available then it will initiate the handover procedure. In the case of a general session, the Link Manager will select another suitable active link that may already be active for other general sessions. The Link Manager will then handover the old link to the new link and informs the IR about the handovers. The IR may then initiate the NEMO/Mobile IP binding updates to the ground networks. In case a special session is already active on this link, the LM will inform the IR about this session so that the Resource Manager may perform suitable link selection for this session.

4 RRM Signaling Procedures

Attempts have been made to construct the message sequence charts (Fig. 5 and Fig. 6) to demonstrate how MIH primitives can incorporate BSM SI-SAP primitives for general session establishment (link selection by LM) and mobile controlled handover. From the figures, the BSM SI-SAP primitives are shown as the signaling messages carried over the interface between the IR and IMR. These SI-SAP primitives will trigger a sequence of MIH link independent primitives, which will further trigger the link dependent primitives.

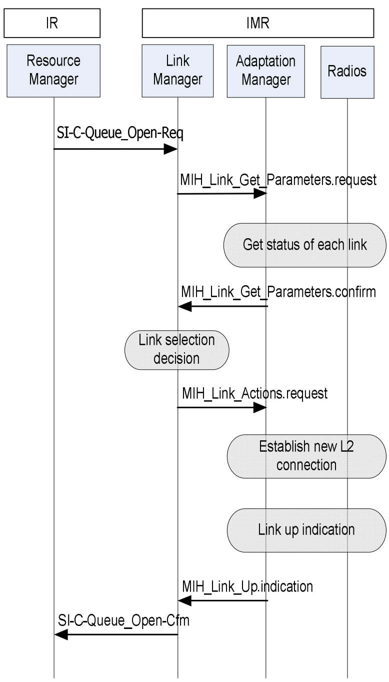

Fig. 5. General session establishment

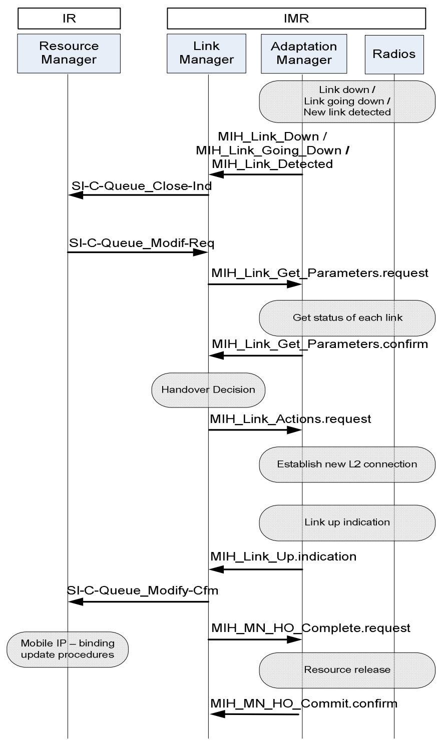

Fig. 6. General Mobile controlled handover

From Fig. 5, the resource request in a new session establishment procedure is handled by the ETSI BSM SI-C-Queue_Open-Req primitive that demands specific QoS requirements to be fulfilled by the IMR link setting. Upon reception of this primitive, the IMR makes use of MIH primitives to check the link status of each available radio technology then perform the link selection function to establish L2 connection on the selected radio technology. Finally, the ESTI BSM

SI-C-Queue_Open-Cfm primitive is used by the IMR to confirm the establishment of L2 connection with the IR.

Fig. 6 presents the L2 connection establishment procedure for handover using the ETSI BSM SI-C-Queue_Modify-Req primitive that indicates a new queue modify request due to the unavailability of resources on a given link or the detection of a newly available link that triggers a handover event. Consequently, QoS re-negotiation is required on the new link. This phase is then accomplished by making use of both ETSI BSM and MIH primitives as can be seen from the first three signaling message exchanges between the IR and the IMR.

5 Performance Analysis of RRM Procedures

To perform the delay analysis the links and interfaces between different network components shown in Fig. 5 and Fig. 6 have been considered. All messages involved in the procedure like connection establishment and handover have been taken into account in calculating the different delay components. 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 [11, 12]:

$$D_{Total} = D_{Prop} + D_{Proc} + D_{Trans} + D_{queue} \tag{1}$$

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 $D_{queue} = \frac{1}{(\mu C - \lambda)}$ where μ is the service rate, C is communication channel capacity and λ is the arrival rate [13, 14].

In both the session establishment and handover procedures, signaling messages are exchanged between different entities of the IMR, between the IR and the IMR, and over the radio links. Signalling messages exchanged between entities within the IMR, although not shown in Fig. 5 and Fig. 6 will only account for the processing delay, $D_{proc.}$ Message exchanged between the IR and the IMR contributes to the total delay over the wired link as the IR and the IMR are connected via the Ethernet and that over the selected radio link also involved all four delay components as indicated in equation (1).

In evaluating the total delay for the two procedures, the values as shown in Table I apply. The channel capacity is assumed to be 45 Mbps for AeroMACS [15], 492Kbps for BGAN [5], 80 Mbps for DVB-S2 [16] and 100 Mbps for the wired ethernet [17]. Propagation delays of 250 ms for Geo satellites, 167 μs for AeroMACS, and 5 ns for wired Ethernet 1 meter long cable are assumed. The transmission delay has been derived by dividing the average packet size with data rate of particular technology. For example the size of an average packet being transmitted over wired link is 55 bytes and the data rate of an Ethernet link is 100 Mbps, therefore by converting packet length in to bits and dividing it by data rate gives a transmission delay of 0.0000044 sec or 4.4 μsec. The number of messsges, K_{sel}, exchanged over the selected link for session establishment is 6 for BGAN, 9 for AeroMACS and 2 for DVB-S2 [18]. In terms of session establishment, the total delay is expressed as follows:

$$D_{Total} = P(D_{Proc}) + 2\left\{D_{Prop} + D_{Trans} + D_{Proc} + \left(\frac{1}{\mu C_i - \lambda_{wired}}\right)\right\} + (K_{sel})\left\{D_{Prop} + D_{Trans} + D_{Proc} + \left(\frac{1}{\mu C_j - \lambda_{wireless}}\right)\right\} \quad (2)$$

From [18], total number of messages represented by P, exchanged between entities within the IMR and their associated delay is represented by the first term on the right hand side of equation (2). Value of P is 26 for BGAN, 16 for AeroMACS and 6 for DVB-S2. The second term denotes the total delay between the IR and the IMR where there are two message exchanges as shown in Fig. 5. The third term denotes the total delay over the selected radio link, where K_{sel} denotes the number of messages required for session establishment over the selected wireless link. C_i and C_j denote the capacity of wired and wireless communication channel.

Similarly, the signaling delay for handover shown in Fig. 6 has been represented by equation (3). The symbol Q in the first term at the right hand side of equation (3) represents total number of messages exchanged within IMR entities. Value of Q is 34 for BGAN, 30 for AeroMACS and 22 for DVB-S2.

$$D_{Total} = Q(D_{Proc}) + 3\left\{D_{Prop} + D_{Proc} + D_{Trans} + \left(\frac{1}{\mu C_i - \lambda_{wired}}\right)\right\} + \left[(K_{Sel})\left\{D_{Prop} + D_{Trans} + D_{Proc} + \left(\frac{1}{\mu C_j - \lambda_{wireless}}\right)\right\}\right] \quad (3)$$

Table 1. Parameter value chart

No.	Parameter Name	Symbol	Value
1	Arrival rate at wireless interface	$\lambda_{wireless}$	10 to 95 s^{-1}
2	Arrival rate at wired interface	λ_{wired}	10 to 95 s^{-1}
3	Service rate	μ	100 s^{-1}
4	Wireless channel capacity	C_j	45,0.492, 80 Mbps
5	Wired channel capacity	C_i	100 Mbps
6	Wireless link Propagation delay	$D_{Prop.}$	250ms, 167µs
7	Wired link propagation delay	$D_{Prop.}$	5ns
8	Wireless transmission delay	$D_{Trans.}$	293µs,2.4µs, 23µs
9	Wired transmission delay	$D_{Trans.}$	4.4 µs
11	Average packet processing delay	$D_{Proc.}$	5 ms
12	Number of messages exchange required between mobile node and network entity for session setup.	$K_{sel.}$	6(BGAN), 9(AeroMACS), Approx. 2(for DVB-S2 receiver synchronization)
13	Average packet length	BGAN	18 bytes
		DVB-S2	24 bytes
		AeroMACS	129 bytes
		Wired link	55 bytes

In the delay analysis the attributes of AeroMACS have been used for AeroMACS. Fig. 7 and Fig. 8 show the total signaling delay during session establishment and during seamless vertical handover respectively.

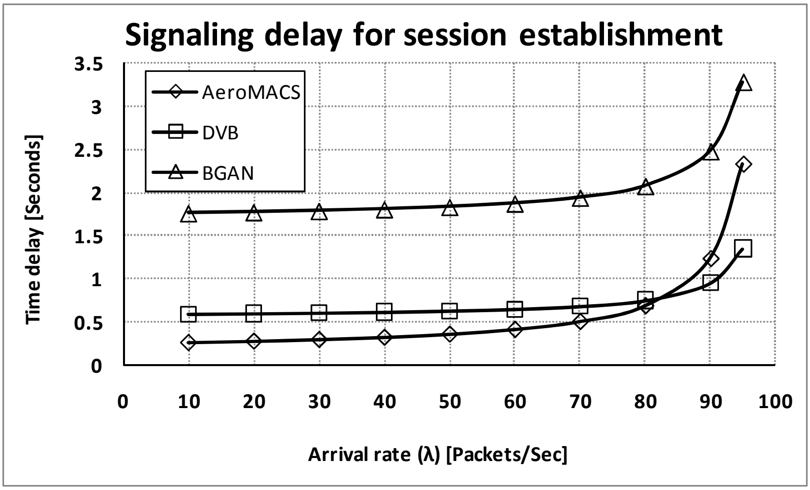

Fig. 7. Signaling delay for new session establishment on different technologies

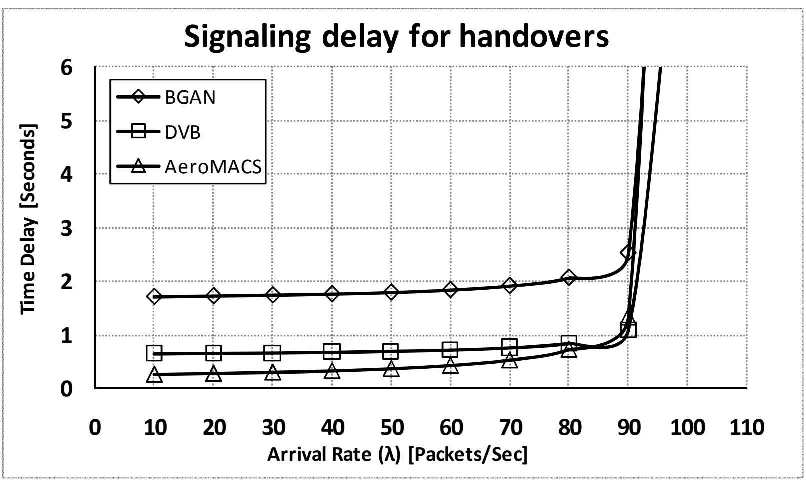

Fig. 8. Signaling delay to handover to different technologies

It can be seen from both figures that an increase in the arrival rate will cause an increase in the total signaling delay as a result of an increase in the queuing delay D_{queue}. Graphs in Fig. 7 illustrates AeroMACS exhibits the lowest delay for session establishment as its propagation delay is small and data rate is high. DVB-S2 has higher data rate than AeroMACS but incorporates high propagation delays. BGAN has the lowest data rate of 492 kbps and high propagation delays therefore it exhibits the highest total delay values in the graphs. The graphs also show that high data rate provides better results for high arrival rate. For example, the total delay for AeroMACS session establishment becomes more than that for DVB-S2 when the arrival rate goes beyond around 82 packets/sec. Similarly in case of handover DVB-S2 is proven better for higher arrival rate otherwise AeroMACS shows better results, having the lowest total delay values.

6 Conclusion

This paper presents the collaborative RRM mechanisms for an aeronautical communication network. It describes the sessions and QID concepts and shows how BSM and MIH standards are extended to enable signaling exchanges for the CRRM mechanism across different radio technologies. The paper also presents the RRM signaling procedures and the analytical model to measure the signaling delay for the different procedures. The results show that DVB-S2 offers more bandwidth and is more tolerant to an increase in arrival traffic. BGAN having lowest data rate and high propagation delay exhibits the highest total delays. AeroMACS, which will be used when an aircraft approaches the airport, having low propagation delay and high data rate, shows the lowest total delay. Since DVB-S2 has the same propagation delay as BGAN but with a higher data rate, its delay performance is better than AeroMACS under high arrival rate.

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