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A Technology Demonstrator of a Novel Software Defined Radio Based Aeronautical Communications System

Y. Cheng[1], K. Xu[1], Y. F. Hu[1], P. Pillai[1], J. Baddoo[2], A. Smith[3], M. Ali[1], A. Pillai[1]

[1]School of Engineering and Informatics, University of Bradford, Bradford, BD7 1DP, UK
[2]Thales UK, Worton Drive, Worton Grange, Reading, RG2 0SB, UK
[3]Thales UK, Manor Royal, Crawley, RH10 9HA, UK
Emails: <y.cheng4, k.j.xu, y.f.hu, p.pillai>@bradford.ac.uk,
<jim.baddoo, aleister.smith>@uk.thalesgroup.com,
< m.ali70, a.pillai>@bradford.ac.uk

Abstract

This paper presents the architectural design, software implementation, the validation and flight trial results of an aeronautical communications system developed within the Seamless Aeronautical Networking through integration of Data links Radios and Antennas (SANDRA) project funded by the European 7th Framework Aeronautics and Transport Programme. Based on Software Defined Radio (SDR) techniques, an Integrated Modular Radio (IMR) platform was developed to accommodate several radio technologies. This can drastically reduce the size, weight and cost in avionics with respect to current radio systems implemented as standalone equipment. In addition, the modular approach ensures the possibility to dynamically reconfigure each radio element to operate on a specific type of radio link. A radio resource management (RRM) framework is developed in the IMR consisting of a communication manager for the resource allocation and management of the different radio links and a radio adaptation manager to ensure protocol convergence through IP. The IMR has been validated though flight trials held at Oberpfaffenhofen, Germany in June 2013. The results presented in the paper validate the flexibility and scalability of the IMR platform and demonstrate seamless service coverage across different airspace domains through interworking between the IMR and other components of the SANDRA network.

Keywords: *integrated modular radio, integrated communications system, aeronautical communications system, software defined radio, joint radio resource management, SANDRA demonstrator.*

1. Introduction

Aircraft information and communications systems are undergoing a major transformation. Moving away from federated avionics architecture, the Integrated Modular Avionics (IMA) architecture has significantly reduced the weight and maintenance costs of commercial airlines. By hosting a multitude of avionics applications of differing criticality levels in a high-integrity and partitioned environment on a shared computing platform, the IMA approach was reported to have reduced 2000 pounds off the Boeing 787 Dreamliner avionics suite and cut the part numbers of processor units by half in the A380 avionics suite [1].

Building on the IMA concept, the EU FP7 project SANDRA [2] marked a significant step in developing an Integrated Modular Radio (IMR) platform that offers a high degree of flexibility, scalability, modularity and reconfigurability. The project started in October 2009, completed with a successful flight trial carried out in June 2013 in Oberpfaffenhofen, and formally completed in December 2013. By exploiting the Software Defined Radio (SDR) [3] technology, the IMR hosts multiple radio applications on a common multi-core processor platform through resource partitioning. Since radio waveforms are implemented as independent software modules instead of as standalone radio equipment, this can drastically reduce the size, weight and costs in airborne communication systems. In addition, a Radio Resource Management (RRM) framework, which forms an integral part of the IMR platform, exploits modular radio approach to dynamically reconfigure each core element to operate on a specific type of radio link through the SANDRA Radio Resource Manager,. Waveform updates can be performed by a simple change in the software libraries. The RRM framework exploits the open IEEE 802.21 Media Independent Handover (MIH) [4] standard to provide a unified protocol framework to support different radios, thus offering both flexibility and scalability to accommodate legacy, emerging and future radio technologies.

This paper describes the mechanism on how the RRM drives the SDR operations. In particular, the implementation of the JRRM and its interface with the SDR-driven waveform processor in the SANDRA demonstration are described. Following this section, Section 2 gives a description of the SANDRA architecture and the IMR design. Section 3 describes in detail the SANDRA demonstrator. The SANDRA flight trial and results are presented in Section 4 and Section 5 concludes the paper.

2. SANDRA Network and Architecture Design Overview

The aeronautical communication network architecture considered in SANDRA is illustrated in Figure 1, where the SANDRA terminal in the Aircraft segment is the core development component within the SANDRA project.

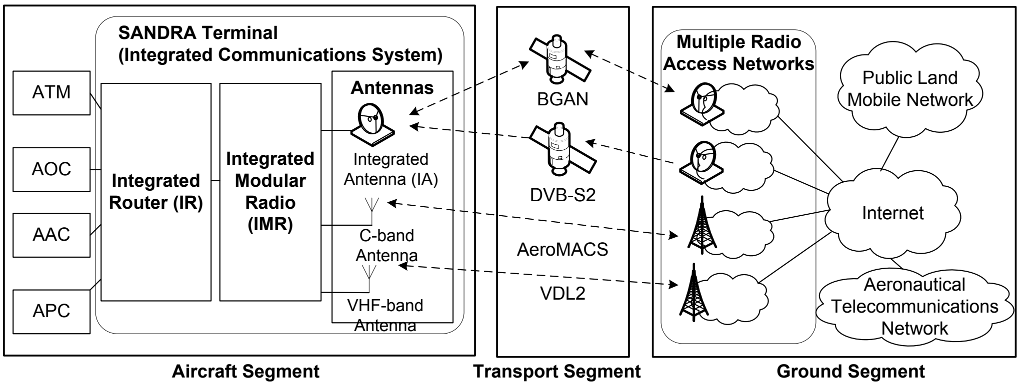


Figure 1: The SANDRA Aeronautical Communications Network Architecture

The SANDRA Terminal is a conceptual realisation of an onboard integrated communications system made up of an Integrated Router (IR), the IMR and a number of antennas. The IR carries out higher layer functions such as routing, security, Quality of Service (QoS) provision and mobility. The IMR is a standalone component interfacing on the left with the IR through its radio resource management (RRM) module and on the right with a set of antennas through a set of waveform processors. The following waveforms are considered in SANDRA:

- VHF Data Link Mode 2 (VDL2) [5]
- Inmarsat Broadband Global Access Network (BGAN) in L-Band [6]
- Aeronautical Mobile Airport Communications System (AeroMACS)) [7, 8] in C-Band
- Digital Video Broadcasting Satellite Second Generation (DVB-S2) in Ku-band (receive only) [9].

The RRM module within the IMR performs lower layer functions such as radio resource allocation and QoS mapping. Readers can refer to [10, 11] for a more detailed description of the SANDRA network architecture

2.1 General IMR Architecture Design

The IMR platform developed in SANDRA is intended to be capable of providing the complete communications infrastructure for an aircraft. The systems which are candidates for IMR modules include radio and satellite communications, traffic collision avoidance system, instrument landing system etc. The radio functionality splits into three main components[12]:

- “The Front End” which includes antennae, HPA and DLNA;
- “Transceiver Functionality” which includes band specific RF circuits, ADC and DAC;

- “Processing Functionality” which includes DSP [13], channel coding protocol stack and application.

Figure 2 illustrates the partitioning of radio functionality used in SANDRA. However, it has to be noted that other ways of partitioning are still feasible. For example digital up/down conversion and coarse channelisation may be viewed as part of transceiver functionality or processing functionality.

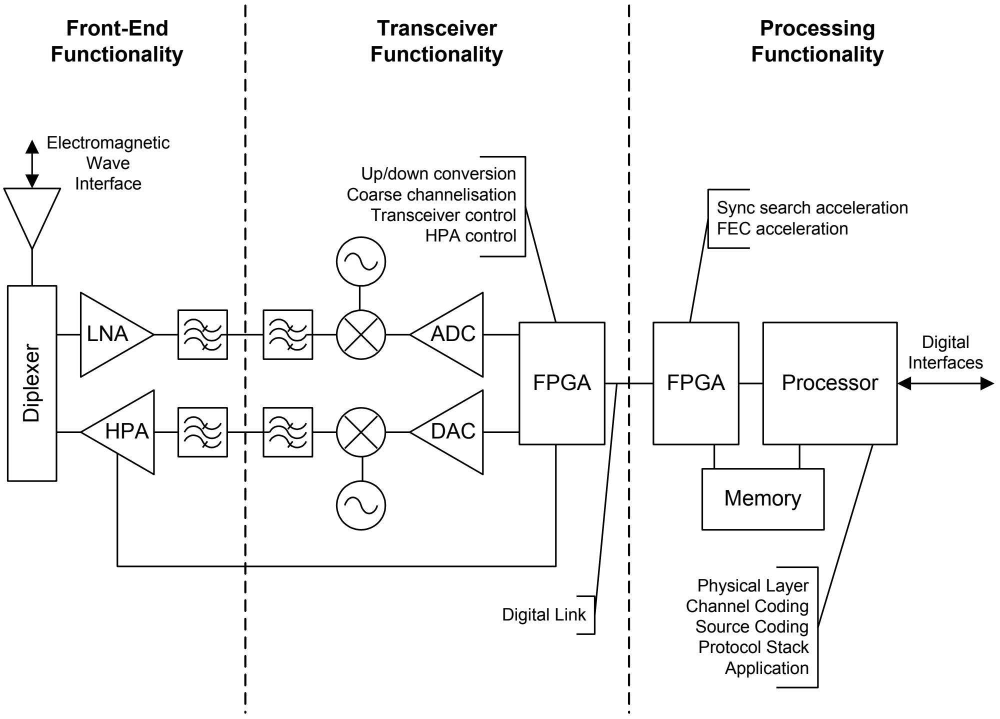


Figure 2: Example Partitioning of Radio Functionality

The above partitioning of radio functionality supports an architecture where a common baseband processing solution is used in combination with transceiver functionality that is designed for different systems or area of the spectrum. This gives the potential for cost saving by maximising reuse of the design, isolating the transceiver functionality if required and physically separating the location of transceiver functionality and processing functionality. It also provides architectural flexibility since in some systems, it is desirable for the transceiver functionality to be located close to the antenna to reduce cable losses.

Such architecture is enabled by modern high-speed digital links which can be placed between the processing units and transceiver units. Recent technology trends have moved from multi-drop parallel buses to point-to-point serial links, examples being Serial RapidIO (SRIO), Peripheral Computer Interconnect Express (PCIExpress), Ethernet and the Common Public Radio Interface (CPRI)[14]. However, point-to-point links can be attractive since they are faster, simpler and more reliable than multi-drop links. Modern high-speed serial links include equalisers at the receivers to improve signal integrity.

The higher speeds are also achieved because the clock is embedded in the signal, and there is no need to keep several electrical lines synchronised as is required with parallel buses.

IMR as a concept raises a number of issues. With current aviation communications systems most are isolated from one another and have very little in the way of security mechanisms. However, with an integrated system which contains a large amount of digital signalling this is no longer the case and security is an issue which must be addressed. Another issue to be considered with IMR is support for Seamless Networking, including handling of asymmetric links, while the majority of this is handled at the network level, it has an impact on the IMR radio as a consistent interface has to be provided by all the links supporting Seamless Networking.

To address the issue of seamless networking, a RRM framework has been designed to support interworking between the different radio waveforms using IP as the convergent mechanism building on the IEEE 802.21 MIH framework. The following sections addresses issues related to seamless networking and redundancy management of the SANDRA Radio Resource Manager. Security and certification are outside of the scope of this paper.

2.2 The SANDRA RRM Architecture for Seamless Networking

The SANDRA project supports heterogeneous radio waveforms and provides a number of radio services for an aircraft. There is a need for overall control facilities to control the various radio access technologies of the IMR. There is also a need for seamless networking facilities for routing traffic over a suitable radio bearer. To cater for those needs, a SANDRA radio resource management (RRM) framework has been derived to collaboratively provide radio resource management and seamless networking capabilities between the IR and the IMR. The design of the RRM is based on ETSI Broadband Satellite Multimedia (BSM) SI-SAP (Satellite Independent – Service Access Point) concept and IEEE 802.21 Media Independent Handover (MIH) framework to separate the radio dependent functions from the radio independent functions. The SI-SAP QID concept is adopted to perform the QoS support operations by providing the RRM with suitable information exchange set to enable QoS mapping between layer 2 and layer3 of the protocol stack. The MIH framework is adopted to provide a uniform mechanism to control the different radio access technologies. Through the RRM framework, the IR and the IMR work in collaborative manner to provide global and seamless mobility solution across the different radio networks.

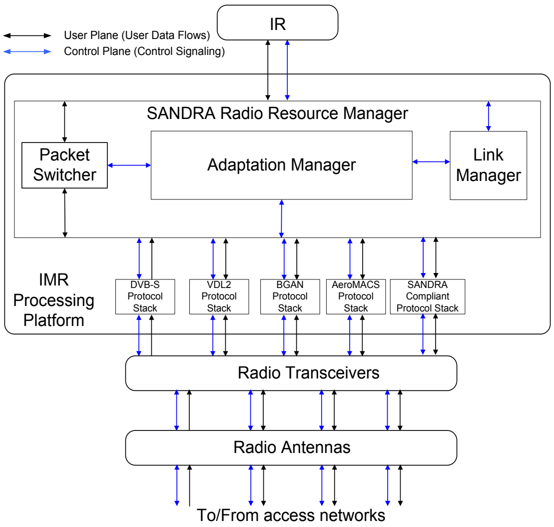


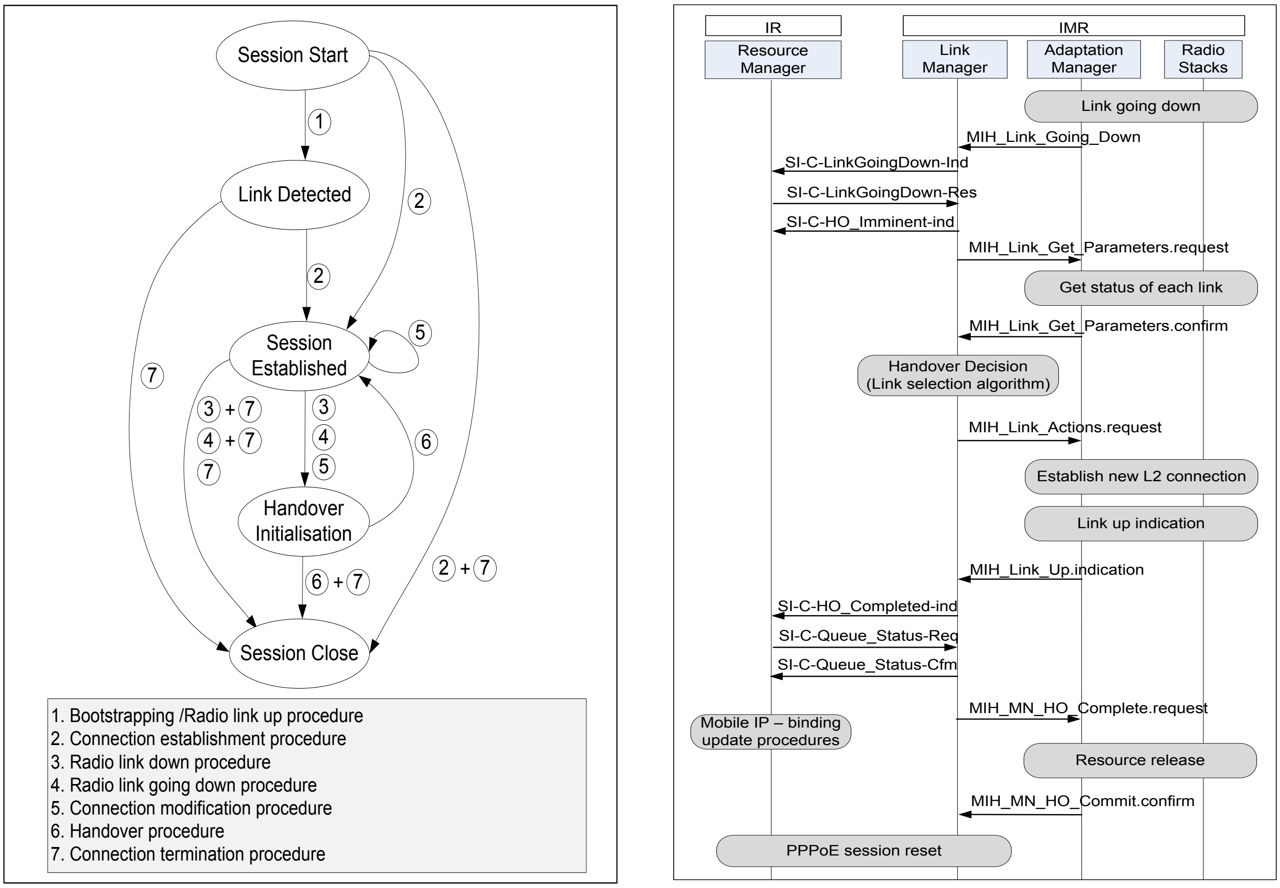
Figure 3: SANDRA RRM Functional Architecture

Figure 3 shows the SANDRA RRM functional architecture, which consists of a Packet Switcher that switches the packets to the appropriate radio link in the user plane, an Adaptation Manager that provides protocol conversion and address resolution functions for mapping network layer identities onto link specific identities, a Link Manager (LM) for link selection and link configuration. While the IR is responsible for managing network layer connections and the IMR for link layer connections, the SANDRA RRM is the central functional component between the IR and the IMR to perform collaborative connection management functions including connection establishment, termination and modification over various radio links. Although SANDRA only selected AeroMACS, BGAN, VDL2 and DVBS-2 in the demonstrator, it can accommodate future SANDRA compliant protocol stack as shown in Figure 3 with software update. To map the network layer onto the link layer connections, the SANDRA session concept is introduced. A session can be specific or general. Each session has an associated PPPoE tunnel for user plane data traffic between the IMR and the IR. A specific session is established upon a specific resource request from the IR. In this case, the IR can dictate the link selection policy, whereas the IMR can allocate radio resource on the specified link. For a general session establishment, the IMR can make a decision on the link selection from suitable links, which can satisfy the QoS requirements. In the SANDRA system design, four radio links are supported. For the baseline link selection algorithm, a simple link priority order is listed as below:

AeroMACS (1) > VDL2 (2) > DVB-S2 (receive only) (3) > BGAN (4)

The priority order listed above is a general list based on the consideration on the transmission speed, propagation delay and the cost of the radio resource. For example, if the AeroMACS link incurs the shortest propagation delay and cheapest cost, it is given the highest priority. The priority order is applied to a candidate link list which contains all suitable radio links for a specific resource request (RR). It is possible that radio link(s) may not appear in the candidate link list as a result of, for example, constraints imposed by the flight phase on the use of radio link due to security reason. In this case the link selection controller can send the request to the selected radio link following the priority in the order list.

There are basically five states and seven operation procedures defined between the IR and the IMR for one session. Figure 4a shows the states transition diagram and the operations between the states. When a new session is required to be created for data transmission, the *Session Start* state is triggered. When the SANDRA RRM detects the existence of a radio link due to bootstrapping or radio link up indications, the *Session Start* state is transferred to *Link Detected* state. Once the radio resource is allocated to the requested session, the system enters into the *Session Established* state, which indicates an active session. In this state, IR transfers data to radio access network and vice versa. If the radio link for the active session is down for some reasons, the system will try to handover the session to other available links or it will enter into *Session Close* state if no available link can be found.



a. Session Status Transition

b. IMR Controlled Session Handover

Figure 4: Session Status Transition Diagram

The message sequence chart shown in Figure 4b demonstrates how MIH primitives can incorporate BSM SI-SAP primitives for seamless IMR controlled session handover. The BSM SI-SAP primitives are shown as the signalling messages carried over the interface between the IR and the IMR. These SI-SAP primitives trigger a sequence of MIH link independent primitives, which further triggers the link dependent primitives.

The handover is triggered by a link going down event, which can be initiated by the Radio Stack entity due to a degradation of signal strength. Upon detection of the link going down, the LM sends SI-SAP primitive *SI-C-LinkGoingDown-Ind* to the IR, which responds with *SI-C-LinkGoingDown-Res*. Immediately before carrying out the handover procedure, the LM sends the *SI-C-HO_Imminet-Ind* primitive to indicate a session handover to the IR. MIH primitives are used to collect the latest status from the available radio links for the LM to make handover decision and allocate radio resource on the target link. Once the layer 2 connection is setup, the LM notifies the IR of the handover completion via *SI-C-HO_Completed-Ind*. This then triggers the IR to collect the information required for updating mobile IP settings via *SI-C-Queue_Status_Req* primitive. After receiving the new networking information contained in the *SI-C-Queue_Status-Cfm* primitive, the IR performs the mobile IP update and resets the PPPoE tunnel for the new session. Finally the LM releases the reserved resource on the old link. A full list of the SANDRA SI-SAP primitives is described in Table 1.

Table 1: SI-SAP primitives[15]

Primitive	Parameter	Comment
SI-C-Queue_Open-Req	Query_handler, QIDSPEC, Lease time	Resource request to setup a new session. The requirements for the session are specified by the QIDSPEC parameter, such as QoS requirements.
SI-C-Queue_Open-Cfm	Query_handler, QIDSPEC, QID, success flag, lease time, error_code	Resource request confirmation.
SI-C-Queue_Modify-Ind	Query_handler, QID, lease time, error_code, QIDSPEC	Indicate the modification of a session (identified by a QID).
SI-C-Queue_Modify-Rsp	Query_handler,	Response the modification of a session (identified by a QID).
SI-C-Queue_Modify-Req	Query_handler, QIDSPEC, QID, lease time	Request the modification of a session (identified by a QID).
SI-C-Queue_Modify-Cfm	Query_handler, QIDSPEC, QID, Success flag, lease time, error_code	Confirm the modification of a session (identified by a QID).
SI-C-Queue_Close-Ind	Query_handler, QID,error_code	Indicate the closing of a session (identified by a QID).
SI-C-Queue_Close-Res	Query_handler, QID	Response the closing of a session (identified by a QID).
SI-C-Queue_Close-Req	Query_handler, QID	Request the closing of a session (identified by a QID).
SI-C-Queue_Close-Cfm	Query_handler,	Confirm the closing of a session (identified by a

	QID,error_code	QID).
SI-C-Queue_Status-Req	Query_handler,QID	Request the session status
SI-C-Queue_Status-Cfm	Query_handler, QIDSPEC, QID, IP_CoA_forward, IP_CoA_return, error_code	Confirm to the session status request with all associated parameters such as the IP addresses assigned.
SI-C-Link-Req	Query_handler	Request the status of links
SI-C-Link-Cfm	Query_handler, N, Link_id[N], error_code	Confirm the link status request. N is the number of links contained in the message.
SI-C-Link-Ind	Query_handler, N, Link_id[N], error_code	Link status indication. N is the number of links contained in the message
SI-C-Link-Res	Query_handler	Response to the link status indication
SI-C-HO_Imminent-Ind	Query_handler, QID, error_code	Handover imminent indicating a handover is started
SI-C-HO_Imminent-Res	Query_handler, QID	Handover imminent response
SI-C-HO_Completed-Ind	Query_handler, QID, success_flag, error_code	Handover completion indication
SI-C-HO_Completed-Res	Query_handler, QID	Handover completion response
SI-C-LinkGoingDown-Ind	Query_handler, Link_id, Time_interval,error_code	Link going down indication
SI-C-LinkGoingDown-Res	Query_handler	Link going down response

Note 1: All primitives contain a Query_handler as an unambiguous parameter for pairing corresponding req and cfm messages, ind and res messages.
Note 2: All ind and cfm primitives further contain an error_code, which can be used to inform the IR of the reason for the primitive being sent (mainly for integration testing and debugging purposes).

3. SANDRA Proof-of-Concept Integrated Modular Radio Demonstrator

The SANDRA IMR demonstrator is illustrated in Figure 5. From hardware perspective, it shows two common processing platforms, three transceivers and one receiver. The processing platforms are connected to the transceivers and receiver by CPRI. The processing platforms also connect to each other and to the external Integrated Router (IR) via Ethernet.

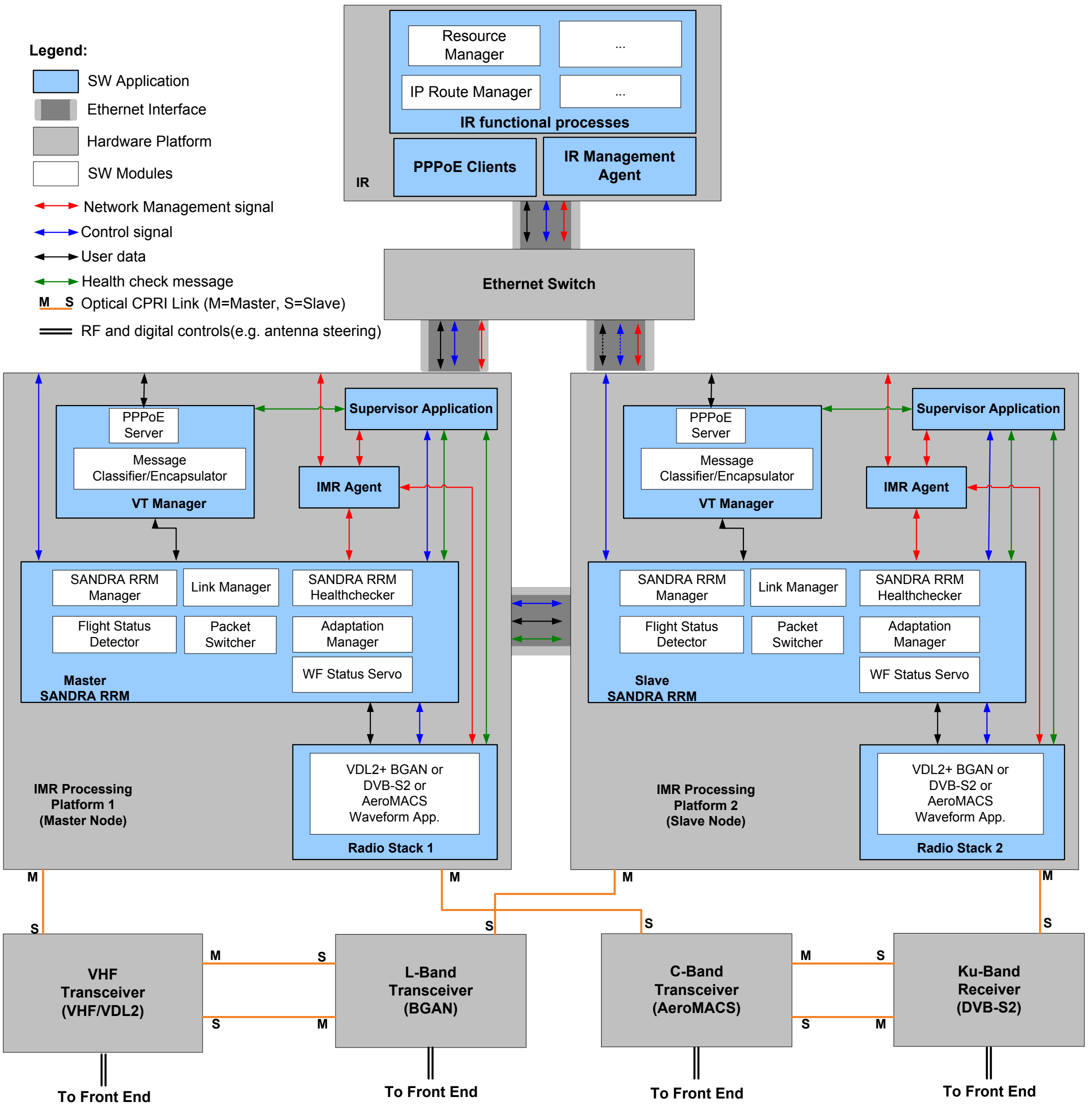


Figure 5: SANDRA RRM Software Architecture

The processing platforms run the SANDRA Radio Resource Management applications, with one acting as a master and the other as a slave. They interface with the IR for the provision of communication services and decide which waveforms should run on each platform. The platforms are intended to run VHF/VDL2 and BGAN waveforms at the same time, or an AeroMACS waveform or a DVB-S2 waveform. The IMR demonstrator supports redundancy in terms of the high-speed links and processing platforms. If a processing platform running a high priority waveform goes down, it is possible to disable the lower priority waveform and start running the high priority waveform on the second platform. A full IMR is likely to require CPRI based switches to more easily configure links between processing platforms and transceivers.

Figure 5 also depicts the software architecture of the SANDRA terminal down to the Radio Stacks. On each IMR processing platform, there are five applications running:

- The Supervisor Application: This is responsible for launching the SANDRA RRM and the various waveforms. The SANDRA RRM can then tell the Supervisor Application which application to launch. If a waveform application goes down, the supervisor will inform the SANDRA RRM.
- The VT Manager: The Virtual Tunnel (VT) Manager in the IMR works as PPPoE server as well as packet encapsulator converting between IP packets and SANDRA specific SAP messages. It is responsible for establishing PPPoE connections with the IR based on the real time information updated by the SANDRA RRM, such as service names and IP addresses. It is also controlled by the SANDRA RRM whether it works as Master mode or Slave mode.
- The SANDRA RRM application: This is the core SANDRA RRM application responsible for the IR and IMR to perform RRM functions in a collaborative manner. It consists of the SANDRA RRM Manager, PacketSwitcher, Healthchecker, LinkManager, AdaptationManager, and FlightStatusDetector.
- The Waveform application: There are three possible combinations for waveforms to be loaded into one of the two processing platforms, the VDL2+BGAN, the DVB-S2 or the AeroMACS.
- The IMR agent: This is a network management application which is responsible for collecting network management related information. It consists of three main parts: a management interface, a Management Information Base (MIB), and the core agent logic.

The SANDRA RRM can control and manage the various radio links and control which radio waveform should be loaded onto the processing platform. It can then establish connection over the links according to the various QoS requirements. Handover of connections from one link to another can also be performed if a radio link is lost. The two SANDRA RRMs on the two platforms work in a Master-Slave configuration, whereby a hot swap can take place if the master SANDRA RRM fails due to any hardware or software failure. These provide the reliability and redundancy features that are critical for the aeronautical communication systems. For safety and reliability reasons, at least 2+1 redundancy must be achieved for aircraft equipment. Consider that four radios are being included in SANDRA, a total of 12 standalone radio equipment are required to be onboard the aircraft. With the IMR concept, only three processing platforms are required. This represents a 75% weight and cost reduction, which is significant.

3.1 Detailed Design of the SANDRA RRM Modules

To process multiple requests in parallel, the LM is designed with multiple sub-link managers which are separate working threads, dedicated to process individual sessions. One session is identified by a queue identifier (QID) as indicated earlier. In the case of a waveform which does not support parallel requests, a mutex mechanism is designed. One type of radio has one mutex lock to keep all sub-link managers synchronized when processing link specific messages. Each sub link manager can be in a state of READY, ACTION or PARAM. When the sub-link manager is in the READY state, it can start processing new requests. When the sub link manager starts processing a session close, open or modify action request, it enters the ACTION state and waits for confirmation messages. Similarly, a sub link manager will enter the PARAM state and waits for reply messages when process get parameters request. Either a timeout event or a confirmation can drive the sub link back to the READY state from ACTION or PARAM.

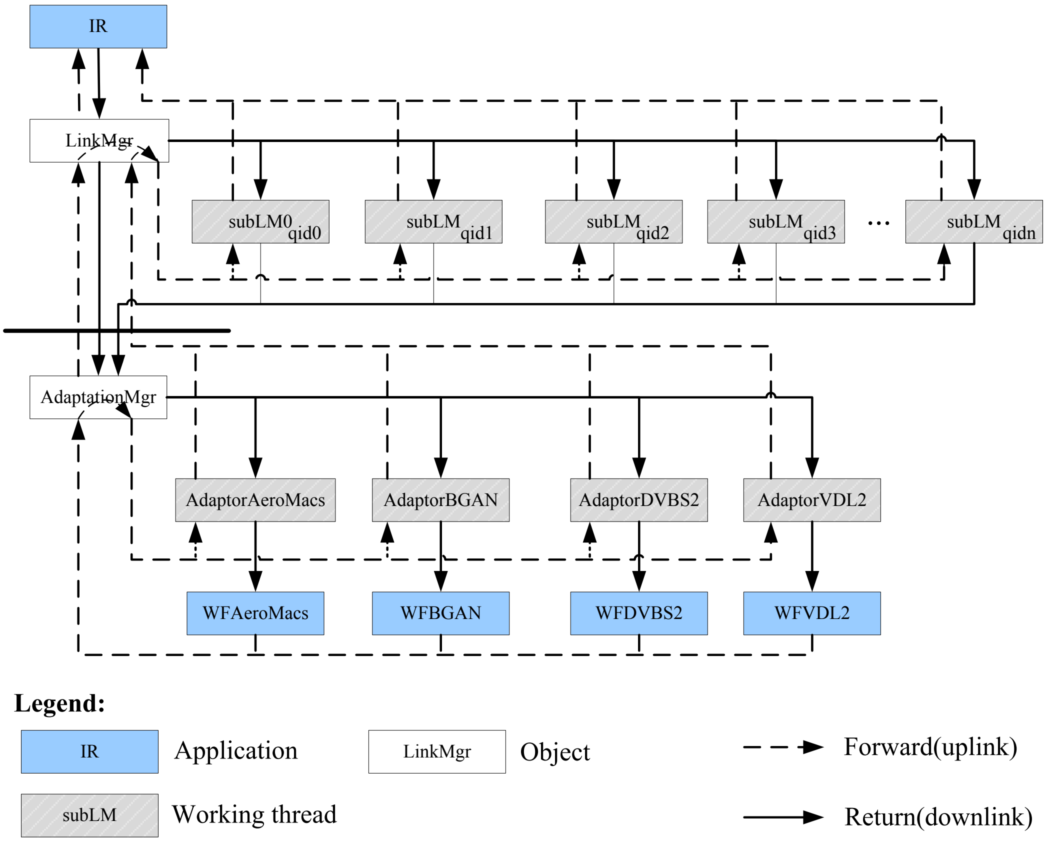


Figure 6: SANDRA RRM Return Signal Handling Design

Figure 6 shows the messages processing flows in the SANDRA RRM. As shown in solid lines, when the general LM receives messages from the higher layer entity, the IR, it will forward all requests to the related sub-link managers. The sub-link manager will first try to get the locks of its links and process the requests accordingly. As an exception, the sub-link manager 0 is not related to any connections. It is reserved for the LM to process non-connection specific messages. For example if the LM receives a Close request from the IR but the QID does not exist, then QID 0 will handle this message and send an Error code to the IR.

Figure 6 dashed lines show the forward signal handling design of the SANDRA RRM. There are different waveform adaptors controlled by the Adaptation Manager, where each of them is dedicated for a specific radio link. When the adaptors receive messages from the waveforms, the messages will be processed and translated by the adaptors and then send to the LM for further processing. If the messages are related to connections, then sub-link managers will process them, otherwise the LM will handle the messages directly (e.g. link up events).

4 IMR Evaluations in the SANDRA Flight Trial

4.1 SANDRA RRM Test Setup

A series of flight trials were carried out from 24/June/2013 to 26/June/2013 on the D-ATRA A320 aircraft. There were 6 sorties at a rate of 2 flights per day. On average, each sortie lasted for 90 minutes including taxiing, take-off, and landing phases. Tests were performed onboard during the 45 minutes cruising phase.

Figure 7 shows the airborne setup of the SANDRA system comprised of four separate racks: Rack 1 contained the Integrated Router and the connectivity to the different end-user systems. Rack 2 hosted the two Integrated Modular Radio processing platforms, Rack 3 was fitted with the RF units for the VDL2 and AeroMACS data links and Rack 4 was fitted with the BGAN RF units.

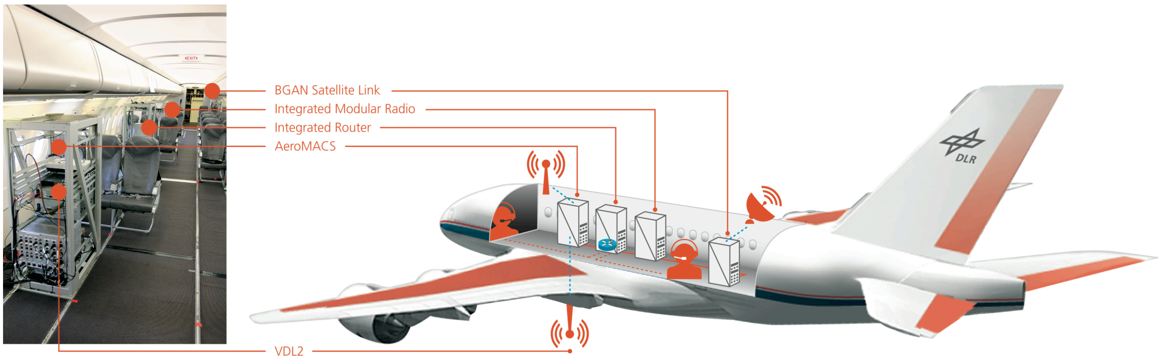


Figure 7: SANDRA Airborne System [16]

The essential settings set for the SANDRA RRM are listed in Table 2.

Table 2: SANDRA RRM settings

Parameter	Value
IMR_PC_1 network path	`/net/IMR_PC_1`
IMR_PC_1 IP addr	`192.168.224.35`
IMR_PC_2 Network path	`/net/IMR_PC_2`
IMR_PC_2 IP addr	`192.168.224.36`
IR port number	`40001`
IR IP Addr	`192.168.8.67`
ATN router IP addr	`192.168.8.112`
ATN router port	`40002`
BGAN PDP APN	`bgan.inmarsat.com`
SANDRA RRM log file prefix	`log_sandra_jrrm`
SANDRA RRM event log prefix	`log_jrrm_event`
NIC name with IR	`Wm0`
NIC name connecting IMR	`Wm1`

The list of available waveforms can be loaded on each IMR processing platform is listed in Table 3,

Table 3: Waveform availability

IMR Processing platforms	Waveforms can be loaded
IMR_PC_1	AeroMACS BGAN VDL2
IMR_PC_2	AeroMACS BGAN VDL2

During the flight trial, the same radio technology was used for both forward and return links for each connection, and there were no mixed connections as shown in Table 4.

Table 4: Connection type

Forward link	Return link	Tested
BGAN	BGAN	Yes
AeroMACS	AeroMACS	Yes
VDL2	VDL2	Yes
BGAN	DVBS2	No
AeroMACS	DVBS2	No

The priorities of waveforms to be loaded on each flight phase were configured as in Table 5. The SANDRA RRM first searches for an idle processing platform to load a waveform. If there was no such processing platform available, it tore down a lower priority waveform if a higher priority waveform had to be loaded.

Table 5: Waveform loading priorities

Flight phase	AeroMACS	BGAN	DVBS2	VDL2
Standing (STD)	4	3	1	2
Taxiing (TXI)	2	4	1	3
Taking off (TOF)	2	4	1	3
Initial Climbing (ICL)	1	4	2	3
En route (ENR)	1	4	2	3
Maneuverer (MNV)	1	4	2	3
Approaching (APR)	1	4	2	3
Landing (LDG)	2	4	1	3

Table 6 shows the different timeout values of various timers.

Table 6: Timers setting

Timer	Timeout value	Unit	Notes
_NET_ACCESS_TRY_TIMER	700000000	nano second	This defines the maximum nanoseconds for across network message queue delay during peak time
_INTERVAL_DOWN	1	second	The maximum duration the network status checking can be skipped when master/slave connection is down
_HC_TIMERVALUENSec	500000000	nano second	Master slave health check interval (Slave)
_HC_TIMERVALUESec	0	second	Master slave health check interval (Slave)
_HC_TX_TIMERVALUENSec	300000000	nano second	Master slave health check interval(Master)
_HC_TX_TIMERVALUESec	0	second	Master slave health check interval(Master)
_MIHMSGTIMEOUTnsec	0	nano second	MIH message timer
_MIHMSGTIMEOUTsec	25	second	MIH message timer
_BGAN_RoundTrip_Delay_sec	20	second	BGAN AT command reply
_Load_WF_TIMEOUT_Sec	12	second	Waveform confirmation
_Status_Request_Keep_Alive_Timer	5	second	Waveform health check message interval

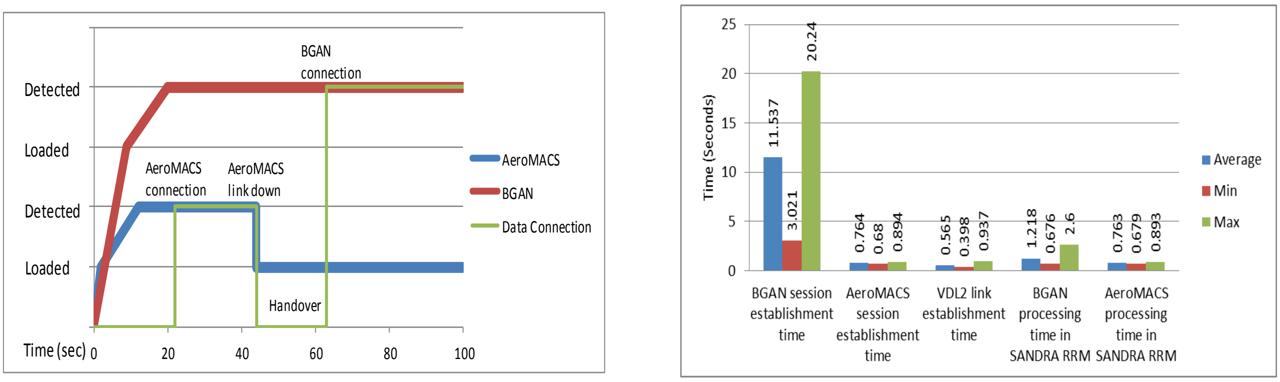
4.2 Session Handover

Figure 8a presents a scenario when AeroMACS became unusable and the data connection was handed over from AeroMACS to BGAN. The x-axis represents time in seconds. The y-axis represents different stage of radio link states. ‘Loaded’ means a waveform is launched and initialized successfully but is not yet usable. In this state, a radio is ready but has not not register or attach to the network yet. Detected indicates a signal has been reported as detected and connections can be made upon request.

At system start up, both AeroMACS and BGAN waveforms were instructed to be loaded in the IMR. At time equal to 22s, a general session request was triggered and the SANDRA RRM performed link selection algorithms based on the radio priorities, availabilities, QoS requirement etc. As shown in the figure, a connection was established over AeroMACS at the beginning. At 43s, AeroMACS became unavailable, this triggered the system to handover the connection from AeroMACS to BGAN. It can be seen that the connection was completely handed after 19 seconds.

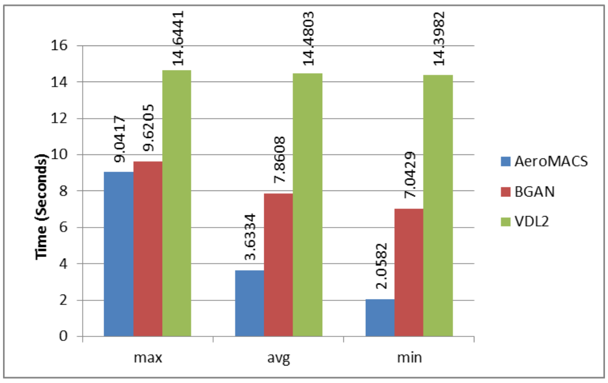
4.3 Session Establishment Time

Figure 8b shows the BGAN and AeroMACS session establishment time, the SANDRA RRM processing time from randomly selected BGAN and AeroMACS sessions and the VDL2 link establishment time during the flight trial. The session establishment time is the overall time of a session establishment from the reception of a session open request until the setup of the data tunnel is completed and is ready for data transmission. In order to express the processing time required by the SANDRA RRM more precisely, the SANDRA RRM processing time only measures the time used within the RRM modules excluding the layer 2 processing time, such as ranging, registration or attachment time. As the VDL2 session is managed by the Aeronautical Telecommunication Network (ATN) router on the ground, which is outside of the scope of SANDRA, only the VDL2 link establishment time was recorded. The VDL2 link establishment time is the time duration from when the RRM receives the link request from the ATN router until the VDL2 stack confirms the completion of the link establishment. The minimum VDL2 link establishment time recorded is 0.3 second and the maximum time being recorded is 0.9 second when the VDL2 radio stack in the SANDRA terminal has to search for the ground network. The minimum BGAN session establishment time recorded is 3.02 seconds when the BGAN radio stack in the SANDRA terminal has already been registered and attached to the BGAN network. The maximum time recorded is 20.24 seconds in the case of a fresh network registration, where network attachment has to be performed in order to set up and activate the Packet Data Protocol (PDP) context for the session open request. On the other hand, the AeroMACS session establishment is much quicker; it takes less than one second to complete a data connection with the ground station. However, the processing time used within the SANDRA RRM for BGAN and that for AeroMACS have the same order of magnitude despite the huge difference in their end-to-end session establishment time due to the fact that SANDRA RRM treats all waveform equally in a uniform way.



a. IMR Controlled Handover from AeroMACS to BGAN

b. Session Establishment and the SANDRA RRM Waveform Processing Time



c. Waveform Loading Time

Figure 8: Flight Trial Results

4.4 Radio Stack Loading Time

The radios in SANDRA testbed are software defined and dynamically configurable in accordance with different flight phases. The waveform loading time as shown in Figure 8c, which is defined as the duration starting from when a new flight phase triggered target configuration is obtained by the JRRM to the time when the requested waveform is loaded successfully by a supervisor application on the IMR platform. The supervisor application is responsible for execution the waveform loading commands and loading both radio stack, physical layer protocol stack and reconfiguring the transceiver. The average time for loading AeroMACS, BGAN and VDL2 are 3.6s, 7.8s and 14.5s respectively. AeroMACS has the largest variance compared to BGAN and VDL2 due to the uncertainty of the network discovery and selection processes, e.g. the ground station is unreachable when out of range.

5. Conclusions

This paper presents the challenges in designing the integrated hybrid radio system and presents the SANDRA joint radio resource management framework for an aeronautical communication network. It describes the SANDRA network and gives details on the IMR architecture design, implementation and realisation in the SANDRA demonstrator, which contributes to the key success of the SANDRA flight trial. The Integrated Communication System concept realised by the SANDRA terminal presented in the paper has been tested and validated in an Airbus A320 aircraft. During the three days with 6 sorties of flights, the SANDRA concept and features were explored and verified successfully including the SANDRA radio resource management, session establishment, session handover between hybrid radios, redundancy etc.. Meanwhile, the separation of processing functionality from transceiver functionality through the use of high-speed digital links, the use of a common processing platform for a variety of waveforms, dynamic radio resource management and some support for redundancy are validated, demonstrating the flexibility and feasibility of the IMR concept, which is central to the SANDRA terminal development.

The success of the SANDRA flight trial sets an exemplar for ongoing and future aerocom projects, where software defined radio is seen as the key for future aeronautical communication system development.

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