A Redundancy Software Design for Joint Radio Resource Management System in a Satellite-Terrestrial Based Aeronautical Communication Network

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Abstract. This paper presents a Master/Slave redundancy mechanism for the airborne Integrated Modular Radio to improve the reliability of the joint radio resource management (JRRM) system. The proposed mechanism adopts keep-alive heart beat messages and real time information synchronization to ensure a smooth switchover in the event of a platform failure. To enhance the scalability and decoupling of the system, the proposed hot swap solution makes the JRRM switchover transparent to both the higher layers and the lower layers. The experiment results and the performance obtained from the test-bed has proved the validity of the solution.

Keywords: Aeronautical Networking, RRM Redundancy, Integrated Modular Radio, Master-Slave Switchover.

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 Antennas. These three components form the SANDRA terminal [2]. While 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) [3] the IMR supports dynamic reconfigurability of operations on a specific radio link at any time and provides the flexibility for accommodation of

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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) [4] are all connected to the IR.

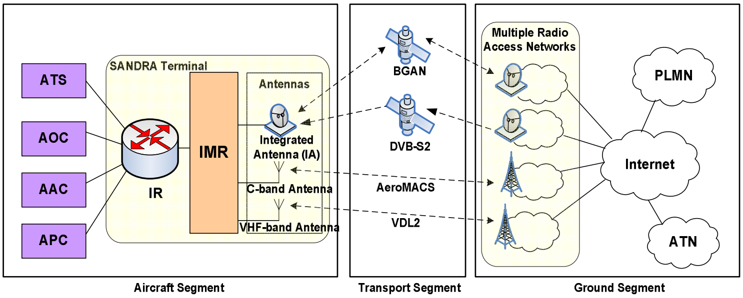

Fig. 1. SANDRA Network Architecture

In the Transport segment, four radio transport technologies are considered, namely, VDL mode 2 [5] in VHF band, BGAN [6] in L-band, DVB-S2 [7] in Ku-band and AeroMACS - a WiMAX [8] equivalence for aeronautics communications - in C-band. The Ground segment consists of multiple Radio Access Networks (RANs) and their corresponding core networks, the Aeronautical Telecommunication Network (ATN), the Internet and the Public Land Mobile Network (PLMN) for passenger communications. 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 concentrates on a redundancy design of the JRRM (Joint Radio Resource Management) to increase the reliability of the IMR. Readers are referred to [9] for the 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.

The rest of the paper is organized as follows: Section 2 is the general overview of the JRRM software architecture. Section 3 describes the need for a redundancy approach and the details of the proposed software design to support this redundancy behavior. It also describes the system startup flow procedures. The performance result of the proposed redundancy mechanism is presented in Section 4 and finally Section 5 presents the conclusion of the paper.

2 The SANDRA IMR Software Architecture

Fig. 2 depicts the general software architecture of the SANDRA IMR conforming to the SANDRA network architecture shown in Fig. 1. The hardware platforms are represented by the grey boxes.

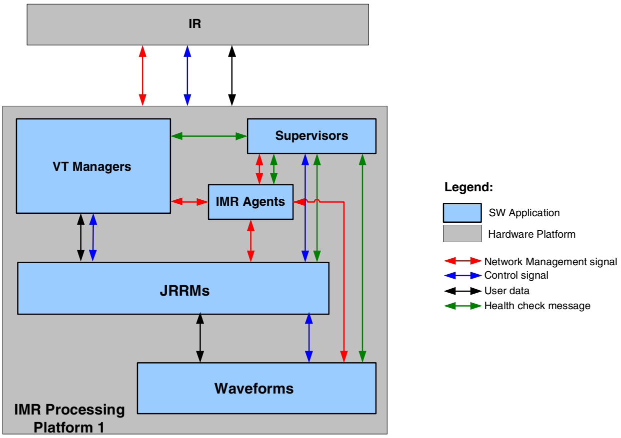

Fig. 2. General Software Architecture of the IMR

On each IMR processing hardware platform, there are five applications running:

- The Supervisor Application: The Supervisor Application is responsible for launching the JRRM and the waveform applications. On boot up, the Supervisor Application will launch the JRRM and tell the JRRM what waveform applications are available on the particular machine. The JRRM can then tell the Supervisor Application to launch a particular waveform. If a waveform application goes down, the Supervisor Application will inform the JRRM. The waveform application might be single application, or maybe a combination of a stack application and a physical layer application.
  The Supervisor Application would monitor all the applications it has launched by sending regular health check messages and monitoring their responses.
- The VT Manager: The Virtual Tunnel (VT) Manager[10] in the IMR works as user plane connection server and also encapsulates the IP packets in the SANDRA specific SAP messages before passing to the JRRM. It is responsible for establishing connections based on the real time information updated by the JRRM.
- The JRRM application: The JRRM, with its provision of adaptation functions and together with the link management functions, forms an adaptation layer between the IR and IMR for interfacing the network layer with the multiple underlying Radio Stacks. This adaptation layer provides the necessary features for the joint RRM purposes. It hides the underlying complexities of the multiple radio protocol stacks from the network layer (i.e. in the IR) and provides a uniform

interface to control the multiple radios. More details of the JRRM internal design and functionalities are defined in [9].

- The Waveform application: Three combinations of the waveforms may be loaded onto one of the two FGPA boards the VDL2+BGAN, the DVB-S2 or the AeroMACS. Thus at a particular time, maximum two combinations can be loaded into the two FPGA boards in the two IMR processing platforms.
- The IMR agent: This is a network management application which is responsible for collecting network management related information for the IMR. It consists of three main parts: a management interface, a Management Information Base (MIB), and the core agent logic.

The JRRM is the centre of all the IMR control plane signals. Control signals are sent to and processed in the JRRM to establish and destroy connections as well as to control behaviours of supervisor and waveforms. User plane data pass through the VT Manager, then the JRRM and reach the waveform for downlink direction and vice versa for the uplink direction data. The IMR Agent make use of management plane signals to collection system status, errors etc. and report all these information to the network management unit. The supervisor periodically sends keep-alive messages to all other applications and monitors the status of them.

3 JRRM Redundancy Design

3.1 Problem Statement

Safety and reliability are essential characteristics of any airborne applications. It has a significant impact upon effective operations. Although at present it may not be an essential requirement for the SANDRA IMR prototype to gain a DO-178B certifiable status [11], it is necessary for a commercial IMR to obtain the DO-178B certification in the future. As the key intelligent sub-component of IMR, the JRRM is critical for the normal operation of the whole SANDRA communication system to forward packets, resolve address, map QoS, manage links and etc. A failure of the JRRM will result in the failure of the IMR and thereby the whole SANDRA system. Hence to avoid such a failure it is imperative that the JRRM should backup all live session information and have the capability to switch all connections to the backup JRRM to provide uninterrupted service.

Also in order maintain the scalability of the IMR system, it is important that the redundancy mechanism is completely transparent to the supervisor and the underlying waveform protocol stacks.

The redundancy mechanism should be also transparent to the higher layers in the IR to minimize the coupling of these two modules and ensuring the modularity of the system. Another additional requirement for aeronautical communications is that the Master and Slave Node should switch their roles per flight base.

3.2 JRRM Redundancy Design

A 1+1 (Master/Slave) level redundancy solution is adopted for the JRRM to increase the reliability of the IMR so as to reduce the system failure level. As depicted in Fig. 3, the IMR consists of two IMR processing hardware platforms. Both IMR processing platforms have the same configurations and applications running except that the JRRM A in the IMR processing platform 1 works in a Master mode while the JRRM B in the IMR processing platform 2 works in a Slave mode. A Master mode node will be responsible for handling all user traffic and control signals from/to the IR and other applications; a Slave mode node only synchronizes information with the Master. The VT Manager co-located with the Master node is always active and process traffics while the one co-located with the Slave node synchronizes with the Master.

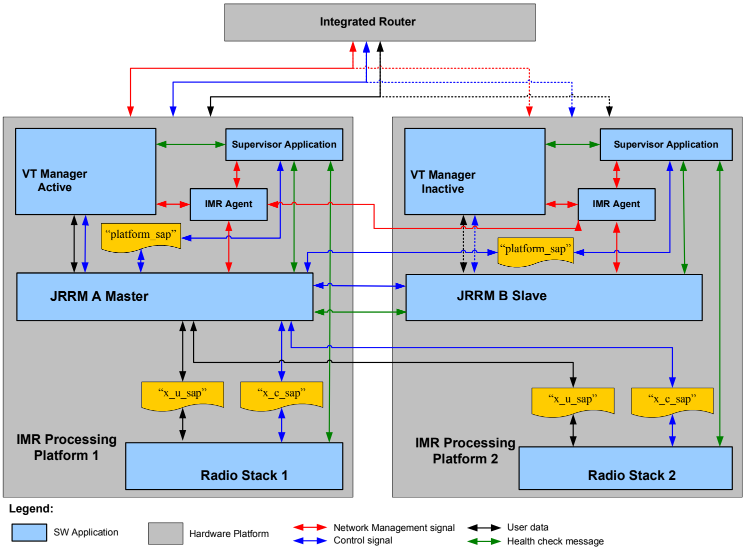

Fig. 3. The Architecture of JRRM Redundancy Design

Keep-alive messages are sent by the Master JRRM to the Slave JRRM and should be responded by the Slave JRRM which ensures that both the Master and the Slave JRRMs know each others status. Once the Slave JRRM detects the failure of the Master JRRM, it will take over the task of the Master JRRM immediately and becomes the Mater. Both the Master and Slave JRRM nodes are configured with the same IP and MAC addresses for the interface towards the IR while one being enabled and the other one being disabled. From the IR's point of view, only one IMR processing platform exists.

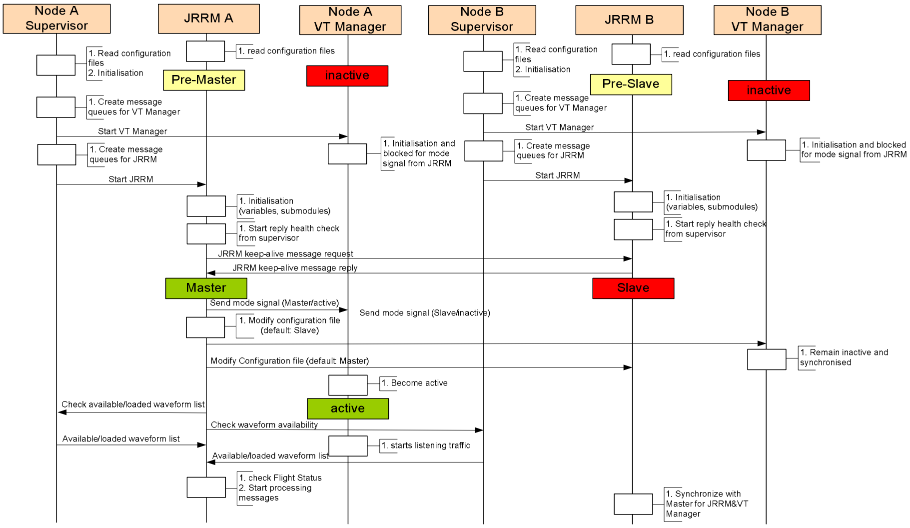

Fig. 4. JRRM system start up routines

As shown in Fig. 3, the Master JRRM not only reads the messages from the local supervisor and the waveforms, but also reads the ones belonging to the remote applications. In the case of Master-Slave role switchover, the Slave JRRM will read all the queues. This makes JRRM's location transparent to the supervisor as well as the waveforms.

On system booting up, it is important to guarantee that there is one and only one Master exist at a particular time. This is achieved by a confliction detection procedure during system boot up as shown in Fig. 4.

1. On system booting up, all the JRRMs will read the JRRM configuration files stored on the local disk. From the configuration file, it is assigned a preliminary working model either as pre-Master or pre-Slave. This will enable the two JRRMs to switch working mode per flight base rather than randomly picked up status.
2. The JRRM will initiate all sub-modules as the pre-assigned working mode.
3. The JRRM assigned with Master mode starts sending keep-alive message to the Slave JRRM. The slave JRRM starts listening and responding to the keep-alive message. If the Master JRRM receives keep-alive messages request from another Master, it will compare the system up time with the one contained in the keep-alive message, the one starts first will be the winner. Similarly, it a Slave JRRM has not received keep-alive message for a certain period of time, it will starts sending keep-alive message request and check whether another Master exist and decide whether to take the role of Master.
4. The Master JRRM selected from the above step will be the formal active Master and be responsible to rewrite the configuration files on both platforms to swap the predefined master/slave modes. Mode change indications will also be sent by the master JRRM to all VT Managers to work as master or slave.

5. The Master JRRM performs its role, such as sending keep-alive message requests, handling all control signals and user data, checking flight status to load waveforms etc..

4 Performance Evaluation and Results

The test-bed developed to measure the performance of the proposed mechanism is consists of an IR which is a Dell Vostro 430, Interl® Core™ i5 CPU, 2x2.67GHz, 2.00GB Memory PC running Fedora Linux and two IMR Processing platforms with the same model PCs as IR but running QNX 6.5.0.

The results in Fig. 5 shows the user plane data round trip delays before and after the Master-Slave switch over. It is assumed that the waveform emulator and the Master JRRM are on the same IMR processing platform before Master-Slave switch. As a consequence of the Master-Slave switch, the Slave JRRM becomes the Master and it is running on a different IMR processing platform from the waveform (cross platforms scenario). For one packet size test, the delay is measured as follows,

1. The IR stamps the system time and sends a packet to the JRRM;
2. The JRRM process the data and forward the data to the waveform emulators;
3. The waveforms emulators swap the Destination and source address of the packet and echo the same payload to the JRRM;
4. The JRRM analyze and return the data back to the IR;
5. The IR stamps the system time again and compare the time difference.
6. Repeat step 1-5 for one packet size 2000 times and get an average of one packet size to avoid random system error.

It was seen that as the packet size increases from 0 to 1400 bytes, the delay increases from 1.8 milliseconds to 2.8 milliseconds. The delays increases after the Master-Slave switchover, because the waveforms and the JRRM are on different hardware platforms and the cross-platform transmission of the data takes extra time, around 2 milliseconds.

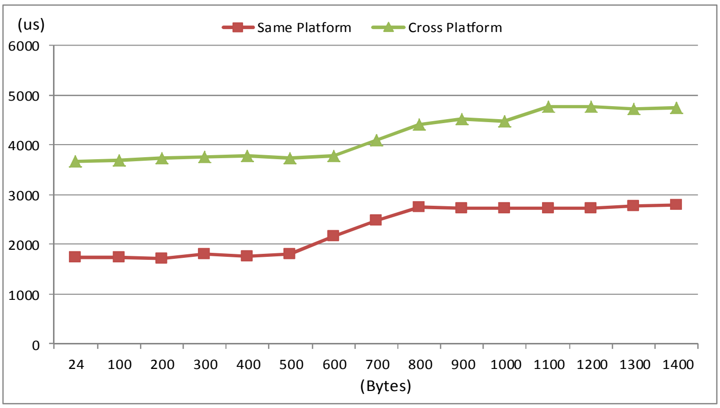

Fig. 5. Round trip delay

Table 1 lists the time consumed by different modules during the Master-Slave switch process. Regardless the number of active connections being established, health check module and traffic processing module consumed 3.0 milliseconds and 6.0 milliseconds respectively to become a fully functional Master from Slave mode. The time for the VT Manager to function from inactive to active varies from 5.0 milliseconds to 12.0 milliseconds depend on the number of active connections.

Table 1. Master-Slave Switch over time

Modules \ Active Connections	1	5	10
Health check module	3.0 ms	3.0 ms	3.0 ms
Processing module	6.0 ms	6.1 ms	6.1 ms
VT Manager	5.0 ms	8.5 ms	12.0 ms

5 Conclusion

This paper presents the Master-Slave redundancy mechanism for the IMR. The design, signaling procedures and SAPs involved in the backup solution are described in detail. The solution also meets the requirement of the transparency of the JRRM switchover towards other components, such as the IR and the waveforms. This approach is validated and proved to be efficiency by the experiments results. The overall delay within the IMR system is far less than 10ms no matter the system is in normal operation or post-switched across platforms operation.

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