Software Defined Radio applied to Mission Oriented Sensors Array - A proposal to advanced Embedded Systems architecture

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Abstract

The variety of Embedded Systems (manned and unmanned), sensors and waveforms available for communication, require the development of an architecture that facilitates the portability of sensorial processing applications (SPA). It is also desirable that this architecture enables the adaptability of the waveform and SPA according to the operating context. Thus, considering an embedded system with a Mission Oriented Sensors Array (MOSA) and transmitting data through an SDR, this will enable an architecture that integrates the SPA with a control system of the SDR. One of the advantages of this standardization remains in the development and portability of adaptive systems, modifying the waveform and SPA according to the operating conditions. The data channel features and the requested Quality of Service (QoS) are examples of operational conditions in the context of this work. One way to achieve this standardization is to use the SCA architecture in conjunction with the structure of a MOSA. Thus, an architecture integrating a MOSA with an SDR will be presented, both in an SCA environment, that promotes greater interoperability and portability of hardware and software.

Keywords: *SDR, SCA, MOSA, Embedded Systems,* C^4ISTAR

1 Introduction

In the past the simplicity of wars allowed victories to be won by the action of only one Armed Forces. Succeeding in missions was more related to the leadership of the chief, to the difference of personnel, to the use of mass and personal bravery than to the judicious coordination of elements of nature and of different organizations. The latest wars and conflicts have revealed that great victories have been achieved through integrated naval, land and air forces. Current conflicts tend to be limited, undeclared, of unpredictable duration, with fluid and diffuse threats. This context requires military forces capable of working together, with flexibility, versatility and mobility. [1] [5]

The planning of a Joint Operation differs from the Singular Operations by the heterogeneity of the employment processes and by the technical-professional peculiarities of the Component Forces. The importance of coordinating and integrating command, control, communication, computing and intelligence structures in order to facilitate surveillance and reconnaissance operations, C^4ISTAR Systems, as well as logistical operations is directly related to success in the operations of the knowledge age [4].

The network-centric warfare (NCW) elevated situational awareness to a level unimaginable ten years ago, for both the individual combatant and the chain of command. It streamlined decision-making, ensuring mission accomplishment, and controlling its execution over time. This made it possible to adapt them in real time to the need for combat. In this interoperability scenario, the need arose for integration of existing Decision Support Systems (C^4ISTAR).

Therefore, it became necessary to develop communication systems that interacted with heterogeneous systems without major changes in hardware. In this scenario emerges Software Defined Radio, capable of using various waveforms and cryptographic algorithms, defined through the software, according to the operational scenarios. This has been possible due to advances in several areas such as: analog-to-digital conversion, antennas, digital transmission, digital signal processing, software architecture and device processing capability such as General Purpose processor (GPP) [2].

The versatility of RDS allows embedded systems to operate in a variety of conditions and environments. Unmanned Systems are composed by a lot of embedded systems such as: communication, control, navigation, positioning, sensors payload. The main task of civil and military applications in Unmanned systems is the acquisition of data. However, due to the low data rate and the time requirements of the real time applications, on-board pre-processing is required before its transmission. The MOSA (Mission Oriented Sensor Arrays) [6] is a type of hardware and software architecture for Autonomous Systems that meets these requirements.

To allow the reuse of components (e. g. middleware), to avoid unnecessary processing between the two systems and to enable the development of adaptive applications, it is necessary to integrate the two architectures. With this, one can develop an application that, according to channel conditions, modifies the pre-processing of data.

This paper aims to present a proposal for integrating the RDS architecture into the MOSA architecture for the production and processing of real time data, composing an advanced architecture for Embedded Systems, raising the situational awareness of the decision maker and increasing the power of combat. To validate the concepts presented in this work a case study is planned to be carried out next November in the Amazon region.

The Section 2 presents the SDR Program of the Brazilian Ministry of Defense. Section 3 present the MOSA Architecture. Section 4 integrate the MOSA within a SDR-SCA compliance in an interoperability proposal. Finally, section 5 presents the concluding remarks and future works.

2 Software Defined Radio Defense Program

Software Defined Radios (SDR) technology represents the state of the art in military telecommunications worldwide. In this context, the Ministry of Defense has assigned the Army Technological Center (CTEx) of **(to** initiate the National Software Defined Radio Program of the Ministry of Defense (SDR Defense), whose objective is to carry out the development of radio equipment prototypes based on SDR technology to supply the needs of tactical communications as well as the Command and Control System of the Armed Forces[2].

2.1 NIPCAD

Since SDR is a complex technology, a need to subdivide the program into intermediate projects was identified identified the need to implement a program, composed of intermediate projects. At CTEx, the Nucleus of Innovation and Research in Communications Applied to Defense (NIPCAD) was created to carry out research and development in the area, as well as to manage technical development, the human and financial resources of the Armed Forces and of the development agencies allocated to that program.

Faced with the great scientific and technological challenge of mastering the entire R &D process of military equipment based on SDR technology, as well as initiating research in the area of Cognitive Radios to meet the tactical communications demands of the Armed Forces, NIPCAD/CTEx has been establishing partnerships with universities, teaching and research institutions and companies. The main research institutions that integrate the Program are the Naval Systems Analysis Center and the Navy Research Institute. Among the foundations, the Center for Research and Development in Telecommunications (CPqD) stands out.

2.2 SDR Project

The SDR Project is multidisciplinary and should contribute to the interoperability in the tactical communications of the Armed Forces, as well as to act in the cyberspace with freedom of action and security of communications.

The objectives of the project will be achieved through the development of radio prototypes, based on the SDR concept, capable of providing communication protocols adherent to the doctrine of the Brazilian Armed Forces, to the employment scenarios specific to the performance of these Armed Forces, as well as offering efficiency, availability and security in communications, both in terms of Electronic and Cybernetics Warfare.

In addition, the SDR Project has the following objectives: training of highly qualified human resources, knowledge domain of a strategic area for Brazil, promotion of the Defense Industrial Base, especially those related to the telecommunications sector, strengthening institutional links between civil and military research institutes, as well as creating conditions to promote research and developments in the area of Cognitive Radios.

The SDR-Defense Program comprises two development cycles. The first one aims to develop the prototype of vehicular radios that can be shipped in naval and terrestrial vectors. The second involves the development of prototypes of smaller and lighter radios, called handheld and manpack. The first development cycle is expected to last 10 (ten) years and is composed of 4 (four) phases.

During this period, prototypes of vehicular RDS are being developed operating in the HF, VHF and UHF bands. Analog and digital waveforms to operate on all these spectral bands, which will be integrated with various cyber-security mechanisms, Transmission security (TRANSEC) and communications security (COMSEC). Also being used the SCA waveform development environment kit to facilitate the development of new waveforms. This project uses the incremental development, in which new functionalities will be added to the prototypes of a certain phase to generate prototypes of the subsequent phase. Implementation of the first development cycle started in December 2012, and the scopes and predictions for the completion dates of the four phases of the first R &D cycle are as follows:

- First phase (SDR-vehicular operating in the VHF range): December 2018;
- Second phase (SDR-vehicular operating in the HF and VHF bands): December 2019;
- Third phase (SDR-vehicular operating in the HF, VHF and UHF bands): December 2020;
- Fourth phase (updating the HF, VHF and UHF waveforms, as well as completion of the waveform development platform): December 2022.

Figure 1 shows the Roadmap for the RDS-Defense Program.

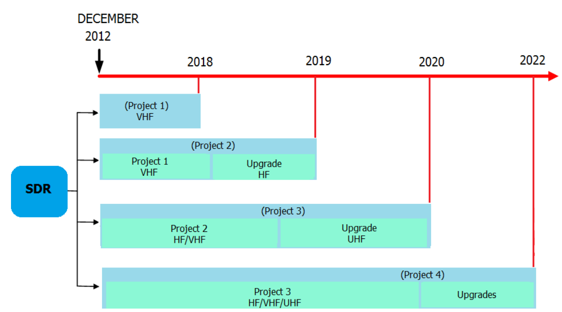

Figure 1: Roadmap SDR Program

The design of the first phase was divided into modules, one for management, one for integration and the others for the development of specific parts of the prototypes, such as: waveforms, security, front end and SCA core.

Figure 2 shows the front views of the two types of prototype intended to be developed in the first development cycle of the RDS-Defense Program (RDS-Defenses Vehicle Versions). Figure 3 shows the overview of the prototype

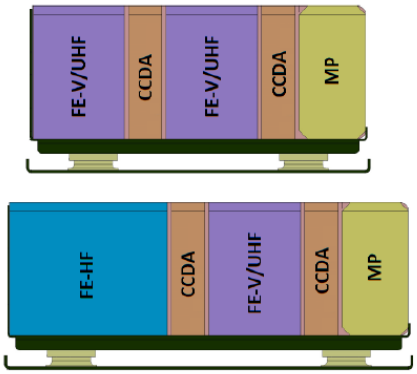

Figure 2: SDR Modules

These prototypes are composed of:

- MP - Processing Module, where the signal processing in base-band is performed;
- FE-V/UHF - Front end operating in the VHF and UHF bands, which are responsible for generating the electromagnetic waves to be irradiated by the antennas and to perform analogue filtering;
- MSCA - SCA Middleware Module;
- MFOSCA - SCA Waveform (VHF) Module;
- CCDA - Digital-Analog Control and Conversion, an integral part of the Radio Frequency Module;
- MSEG - Security Module;
- FDSCAC - SCA Compliance Development Tool;
- MPLAN - Communications Mission Planner.

Figure 3 shows the integration of the prototype with the Brazilian Army Decision Support System "C2 in combat" in laboratory and and in operational vehicle.

Figure 3: Integration Test

3 Mission Oriented Sensors Array

The MOSA (Mission Oriented Sensor Arrays) architecture discussed in this article has the potential to provide real-time, ready-to-use information made in embedded data processing machines embarked on Unmanned Vehicle Systems (UVS), reducing the need to send video streams or high resolution images. As a consequence, the minimal communication bandwidth to carry on data in real time reduces significantly.

The main characteristic of MOSA architecture is the division of the system into two distinct modules: the vehicle module (the safety-critical UVS element) and the MOSA module (the non-critical UVS part). MOSA systems include a set of embedded sensors that provide raw data for specific applications.

In addition to hardware, a MOSA system also includes the software required to perform a mission, to communicate with all sensors, and send / receive data to / from the vehicle. Integrated processing reduces the complexity of raw data in ready-to-use information [7].

Figure 4 shows a simplified functional diagram of the MOSA architecture and the interconnection between its system components. The topology of the system may change according to the application.

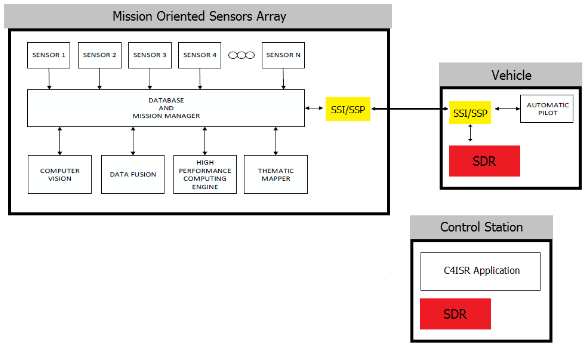

Figure 4: Basic Architecture of MOSA Systems

Model-Driven Development (MDD) is used in the construction of MOSA systems. MDD is a software development methodology where the key elements are models, from which the code is produced. Using MDD, rapid prototyping of complex systems can be achieved through the automatic generation of high-performance code. This code can be embedded in electronic components to be applied in real-time environments.

In order to communicate with the aircraft, MOSA uses a standard interface, called SSP / SSI (Smart Sensor Protocol / Smart Sensor Interface). SSP is the communication protocol, while SSI is the interface that allows the MOSA system to use various services provided by the stand-alone vehicle, particularly the data transmission with the remote ground control station (GCS). MOSA systems can be used in different UVS that have been adapted to communicate through SSI / SSP.

The communication protocol uses a plug-and-play mechanism to verify that the vehicle is capable of performing a specific mission. This possibility is negotiated between the MOSA and the vehicle during the handshake phase of the protocol. In some cases, longer or better vehicle stability may be necessary, among other limiting factors. According to these limitations a MOSA systems will, in whole or in part, execute a planned mission.

The MOSA approach leads to modern autonomous systems that can perform complex missions, presenting decision-making capabilities and optimizing data flow, in real time, within the limits of communication channels.

Although in complex systems, such as medium and large UVS, hardware costs does not present a limitation, the use of MOSA can provide great versatility and flexibility in the process of developing sensor systems for new applications. Different sensors and processing units can be integrated into the best cost / benefit arrangement for a specific application. It is designed to automatically perform missions that can be pre-programmed at the GCS. In addition, missions can be reconfigured in case of events that may compromise mission results or degrade flight safety, such as an unexpected change in atmospheric condition. MOSA can dynamically choose the best sensor arrangement for a given atmospheric condition, mitigating the impact on mission results.

Those basic capabilities, of checking the system capabilities and optimizing the embedded system topology (e.g. number and type of sensors), requires that the system to know the sensors attached to itself and to describe it capabilities. For that end was developed the Smart Sensor Protocol (SSP) and the Smart Sensor Interface (SSI).

The project of the SSP was focused in the simplicity and, once that it is just a mechanism for interfacing, it provides a simple layer and that should not cause overhead in the communication between the entities. It provides connection, verify the viability of the execution of the mission, enables the communication between the entities during the mission execution and ends this cooperation section. It does not interfere in the data been exchanged, so that it should be easy to adapt this protocol for other architectures of autonomous vehicles [3].

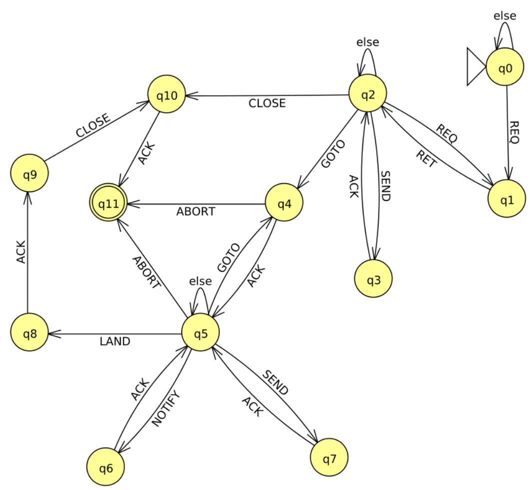

Figure 5: State Machine of the SSP [3]

The protocol it self follows the stages of the mission execution. A state machine of the mission execution with the headers of the messages in each stage can be seen in figure 5. The mission stages and respective states are as follows:

1. Negotiation and Mission viability: q0, q1, q2 and q3;

2. Mission Execution: q4, q5, q6 and q7;

3. Mission Ending: q8, q9, q10 and q11;

Although it can be argued that this structure limits the execution of the mission, this enables the simulation of the mission and assure the behavior of the system in various failures scenarios. For a more detailed description of see [3].

4 MOSA & SDR - Interoperability Proposal

Due-to the integrated characteristics required in the NCW presented in section 1, unmanned-systems must provide real-time data to the C^4ISTAR systems.

As a consequence, due to the amount of data, delays in network and scarce channel bandwidth, it is necessary to control the pre-processing step, waveform and data flow to achieve this real-time requirement. This requires MOSA to change the pre-processing step according to the available waveforms.

The objective is to enable MOSA to consult the waveform capacities and check if they are compatible with the mission. For this end, it is necessary to expand the MDF to add waveform requirements. One approach is to consider the following parameters for tactical operations [2] [8]:

- Number of nodes in the network
- Antenna characteristics
- Velocity of the UVS
- Maximum reach
- Frequency of operation
- Throughput
- Delay
- Jitter
- Bit Error Rate (BER)
- Package Error Rate

This minimal requirements will be generated in the planning of the mission.

All this information must be consulted in the SCA environment so that the MOSA control component can check if the mission requirements are meet. This would be done in the first step depicted in of figure 5 in states $q1$ to $q3$.

For that end, an SCA application will be created to enable MOSA communication with SDR-SCA Applications. As presented in section 3, the MOSA communication with the UVS is performed through UDP or TCP/IP, depending on the system requirements. So, it is visible to the SDR SCA components. If that is not the case for some legacy MOSA system, an RS232 communication can be established and a SCA Device created to enable the integration. This case can be seen in figure 6.

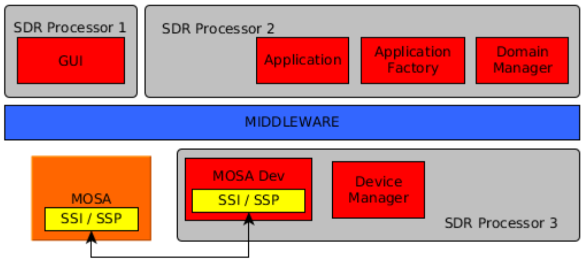

Figure 6: Basic SCA Architecture for Legacy MOSA

If the MOSA system has a network interface, them the hole SCA system can be implemented under the SCA mindset. All sensors can be SCA Devices and the SPA as a SCA Application. This case is presented in figure 7. That would provide more integration and would enable both systems to use computing power for both SPA and WF processing.

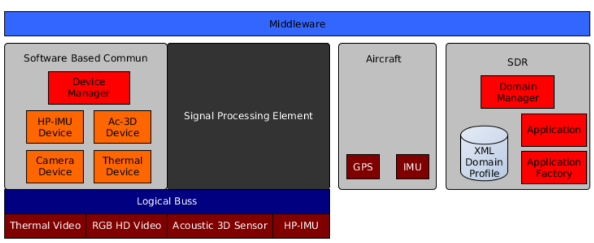

Figure 7: Basic SCA Architecture MOSA

In both cases the operation sequence would proceed as follows: MOSA System check the available WF through **MOSA Device**. It then determines whether there is some that meet the minimum requirements. After, appropriated requests would be done to instantiate and start the respective WF and to configure the SPA accordingly. After that, MOSA would continue if the mission is partially or fully feasible.

That could be useful in a mission such that if the communication bandwidth has more than $1200Kbps$, it would stream pre-processed video, like a smart-frame. Otherwise, if there is at least $2.4Kbps$, then the mission would be partially feasible and would only send important triggers after the SPA data is pre-processed and analyzed.

This represent a major step towards improving the usability of both systems by enabling the update of systems main characteristics through software updates. Also, this improves the resources usage, reducing energy consumption by optimized processing and weight reduction.

5 Concluding Remarks and Future Works

The objective of this work was to present a proposal of integration of the SDR architecture with the MOSA architecture for the production and processing of data in real time. It focused on presenting the main aspects of the system. The flexibility and modularity of an SDR embedded in an autonomous vehicle, coupled with the plasticity of the SCA compliance, can optimize communication by enabling the selection, portability and development of new mission-oriented waveforms.

It is envisaged that the proposed model greatly facilitates the selection and adjustment on-the-fly of the mission waveform using techniques such as Spectrum Sensing and Dynamic Spectrum Access (SS and DSA). It is intended to finalize simulations and field tests with the proposed architecture at the end of this year, allowing the validation of functional and performance aspects.

The preliminary analysis presented indicates that MOSA and SDR-SCA architectures are compatible, so that its integration can represent a major step towards improving the usability and enhancement of autonomous systems in civil and military applications.

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