SOFTWARE DEFINED RADIO TECHNOLOGY IN COMMERCIAL AND MILITARY APPLICATIONS: A CONTRAST IN REQUIREMENTS

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ABSTRACT

This paper compares and contrasts the use of software defined radio technology in commercial and military applications. The paper begins by presenting a macro definition of what software defined radio really means with respect to various market segments within the military and commercial spaces, and then explores the value proposition of SDR within those segments. Key SDR technologies are then examined, with the goal of defining how these technologies support the defined value propositions. Finally, a case study is provided to illustrate these issues that explores the use of software defined radio technology in military and commercial satellite communications platforms.

1. INTRODUCTION

Software defined radio technology is permeating both the commercial and military wireless communications markets for next generation systems. The reason is simple: SDR technology allows communications devices to move from traditional "stove-pipe" architectures, where the radio platform supports a single air interface standard with pre-defined features, to an architecture that allows the modification or addition of services and features while the communications system is in service and without a significant new investment in hardware. While the advantages of this technology are significant in both the commercial and military markets, the value proposition for software-defined radio differs significantly in these two spaces. As a result, while many of the technologies applied in software-defined radio are common across both military and commercial platforms, the specific implementations of SDR technology vary significantly based on market segment and the position of the technology within the value chain. This paper examines the business case for software-defined radio in the commercial wireless infrastructure and military communications markets, comparing and contrasting the value proposition for SDR in each of these market spaces, and exploring some of the trade-offs in technology selection that are made when mapping operational requirements for SDR platforms against these value propositions.

2. THE BUSINESS CASE FOR "SOFTWARE DEFINED RADIO"

Within the wireless community, there exist multiple definitions for what a software-defined radio is, each offering a slight variation on the architectures associated with software-defined radio or the technologies that make software defined radio work. For the purposes of this paper we will adopt the semantics used by the SDR Forum in defining the evolutionary development of a software radio, which positions a software-defined radio as follows [1]:

> "*SDRs provide software control of a variety of modulation techniques, wide-band or narrow-band operation, communications security functions (such as hopping), and waveform requirements of current and evolving standards over a broad frequency range. The frequency bands covered may still be constrained at the front-end requiring a switch in the antenna system.*"

Adding support for software definition to a radio platform comes at a price: SDR-based systems are generally more expensive than traditional "stove pipe" radios, and they often involve an increase in size, weight, and power over their fixed function equivalents. So why go with an SDR solution? The answer depends on the specific needs of the various markets for radio technology [2].

2.1. SDR in Wireless Military Communications

Military command, control and computer communications consists of multiple ad-hoc tactical networks that interface to each other and to backbone communications networks through a variety of wireless communications gateways nodes [3][4]. The military currently supports hundreds of legacy waveforms within this "system of systems", each with its own unique air interface specification and independent link/network layer protocols. At any given time, the specific waveforms required by a military radio are dependent upon both the tactical situation and the availability of the various communications networks. As such, the key challenge for a next generation military radio is the ability to "reconfigure on the fly", often many times per minute, to allow the radio to simultaneously interoperate in this ad-hoc environment with multiple tactical, strategic, and coalition networks.

The value proposition, then, for Software-Defined Radio in military communications is that SDR technology allows each channel within a radio to be dynamically reconfigured with different waveforms, both at the time of deployment and during operation [5]. This includes both legacy waveforms as well as future waveforms whose features and capabilities are as yet undefined. In addition, by standardizing on a family of software-defined radios versus supporting dozens of independent stove-pipe devices, a number of economic benefits are incurred which define the primary value proposition for SDR in commercial wireless infrastructure devices.

2.2. SDR in Commercial Wireless Infrastructure

The adoption of any technology, including software defined radio, in the commercial wireless infrastructure space is driven primarily by market economics. Unlike military radios, commercial infrastructure devices typically support at most two or three waveforms, so the ability to dynamically reconfigure the radio, while attractive, is not a primary concern. Instead the key drivers in defining radio architectures in the commercial domain are time to market and total cost of ownership.

The trend for SDR in commercial wireless infrastructure, therefore, is in a value proposition that allows a wireless OEM to address the needs of multiple market segments with a common platform architecture, typically by integrating an application specific RF front end with a software-defined digital transceiver subsystem [6][7]. For example, an OEM targeting the wireless Internet market may adopt a single digital transceiver platform for use in both a cellular base station and a fixed broadband wireless access gateway [8]. The economic advantages of this model are outlined in [9] and include the following:

- The development cost of the SDR platform reduces the non-recurring engineering costs associated with hardware development of the digital transceiver to a single development project for multiple market segments.
- The adoption of a common digital transceiver architecture allows software components supporting one market segment to be reused in another, reducing the overall cost by the vendor in software development.
- Time to market is significantly reduced for each subsequent air interface supported by the platform, since software development will no longer have any dependencies on the hardware development schedule, and software reuse will allow faster application turn around.
- Installation and support costs are significantly reduced, since a common set of inventory can be utilized for multiple markets, and the technical support team only needs to be trained on a single platform.

The savings accrued by these advantages over the life of the platform amortize the increased cost of the SDR system across multiple products, realizing a significant savings for the vendor over the life of those products. In addition, the common platform architecture is somewhat future proof in that new features and new capabilities can be added to the product without re-engineering the hardware platform.

2.3. Comparison of Value Proposition

The value proposition for the use of software defined radio in both the military communications and the commercial wireless infrastructure markets is summarized in Table 1. While all of the identified features of SDR technology drive the value proposition for using SDR in these two spaces, the primary importance of these features varies significantly based on market segment.

Table 1: Features of SDR Platform Supporting Value Proposition in Military and Commercial Markets

Feature of SDR Platform	Military Communications Market	Commercial Wireless Infrastructure Market
Reconfigure-ability	Primary	Secondary
Upgrade-ability	Primary	Secondary
Time to Market	Secondary	Primary
Total Cost of Ownership	Secondary	Primary

3. TECHNOLOGY SELECTION AND THE SDR VALUE PROPOSITION

The selection of technologies to be used in a software - defined radio is made by weighing the value proposition for SDR in a given market space against the specific operational requirements for the radio platform. This section will explore some of the trade-offs in technology selection for the commercial wireless infrastructure and military communications spaces as they apply to the value proposition for SDR. While this analysis is not definitive, it does indicate some logical trends that extend from the market requirements.

3.1. Signal Processing Device Selection

The selection of processing devices to support a defined range of waveform applications is a key step in the architectural definition of an SDR platform. Consider the reference module for a software-defined base station presented in Figure 1[10]. The closer to the RF front end of the architecture, the higher the level of performance that is typically required in the signal processing devices for the SDR platform, and conversely, the further from the RF front end, the higher the level of programmability that is typically required in the signal processing devices.

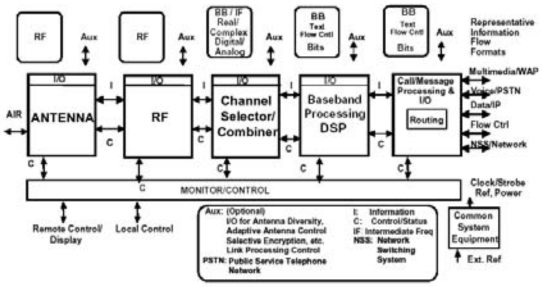

Figure 1: SDR Forum Base Station Reference Model

Table 2 presents four base signal processing devices (Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), Digital Signal Processors (DSPs), and General Purpose Processors (GPPs)) evaluated against specific selection criteria [11]. In this table, the devices are subjectively rated on a scale of 1 to 5 for each category, with a 1 indicating a poor choice for that category and a 5 indicating an outstanding selection. As a broad generalization, ASIC and FPGA devices are typically utilized for high speed front end processing, a mix of DSP, FPGA, and General Purpose Processors (GPP) are utilized for baseband processing, and GPPs are typically utilized for link and network layer processing. The specific mix of processing elements is largely determined by mapping the value proposition for using SDR technology against the specific requirements of the target market segment.

In the military communications domain, the need to dynamically reconfigure the platform to support large numbers of often disparate waveforms dictates the use of devices with a high level of "programmability". Since these waveforms must also be maintained across platforms developed by multiple original equipment manufacturers (OEMs), the total cost of ownership is reduced significantly when waveform components from one vendor can be retargeted to another vendor's platform with a standards based software communications architecture connecting the components [3][5]. As such, the use of general-purpose processing devices, such as the MPC7410 processor, is indicated wherever possible in a military communications platform, since these devices offer the maximum in reconfigurability and programming models that support both standards based communications interfaces and source code reuse. FPGA and DSP devices are only utilized where necessary to address performance or size, weight, and power constraints, with FPGAs typically limited to high speed front end processing.

Table 2: Evaluation of Selection Criteria for Various Signal Processing Devices

	Cost per Unit	Programmability	Performance
ASIC	5	1	5
FPGA	1	3	5
DSP	4	4	3
GPP	3	5	2

In contrast, the number of waveforms supported on a commercial SDR platform is much more constrained. As such, the portability of waveform components is not nearly as critical in the commercial domain, and so the broader use of ASIC and DSP devices within the SDR architecture is indicated to minimize the overall cost of the platform. The obvious downside to this philosophy is that the development cycle for an ASIC device is usually quite long, and as such, unless a commercial off the shelf ASIC is available with programmable features that address the specific needs of the SDR platform, time to market constraints indicate the use of FPGA devices in lieu of ASICs for the initial deployment of the system. In this paradigm, FPGAs are often phased out and replaced with ASICs as higher volumes of the platform are produced, as shown in Figure 2 [12].

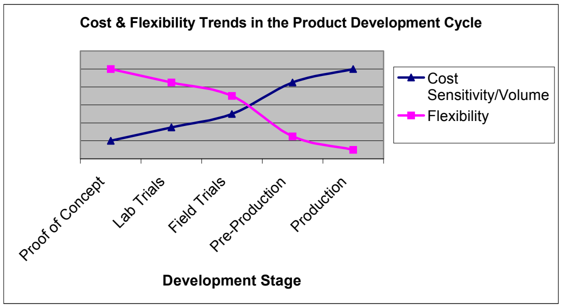

Figure 2: Cost vs. Flexibility in Life of a SDR Platform

3.2. Platform Definition

Once the processing devices for use in a software defined radio have been selected, the next step in the SDR design is to map these devices to a hardware platform that addresses the physical constraints of the SDR system and establishes a communications infrastructure supporting the required signal and data flows throughout the platform [9]. The two key issues that often constrain technology selection in this process are the ability to upgrade the platform and the system reliability.

3.2.1 Design for Upgrade-ability

Hardware technology roles over every three to five years, while wireless communications systems are often in the field for a significantly longer period of time. As such it is important to have an upgrade path that allows the SDR platform to evolve over time to incorporate new features and new capabilities while protecting the existing hardware and software investment.

The ability to upgrade drives the value proposition for the use of SDR in both the commercial and military spaces. To support technology insertion, this upgrade path typically includes the use of a modular architecture, where the various hardware, software, and waveform components can be replaced, updated, or extended without requiring the wholesale replacement of the SDR platform. The specifics of the modular design, however, are driven by the total cost of ownership within a defined market space. For example, in the military communications market, where waveform support across multiple vendors platforms is a driving concern, open system standards based hardware and software interfaces are often mandated to allow modules to be mixed and matched between OEM providers and to allow for the maximum possible use of COTS devices [5]. In the commercial space, however, sensitivity to total cost of ownership often drive OEM vendors to develop custom interface standards specific to their market needs. The specifications for these interfaces often represent significant intellectual property for the vendor, and are therefore tightly controlled [13].

3.2.2 Reliability

Reliability is another key technology driver in an SDR platform. For the commercial market, down time on a communications channel could represent a significant loss of revenue, while in the military market, loss of a channel can be more catastrophic, possibly resulting in loss of life.

Many of the technologies used in the SDR must be selected to address the specific reliability issues for the target market. In the military market, the SDR platform may need to be configured to operate in a harsh environment, which may include extended temperature ranges, humidity, shock and vibration [14]. Operation of the platform is guaranteed for a specific deployment through the use of redundant subsystems and the elimination of single points of failure. For commercial applications, the SDR platform operates in a more controlled environment, and as such ruggedization is typically limited to extended temperature. Operation of each channel guaranteed to 99.999% uptime performance through the elimination of single points of failure and the use of hot swap.

3.3. Summary

Table 3 compares and contrasts the trade-offs in technology selection for the commercial wireless infrastructure and military communications spaces as they apply to the value proposition for SDR.

Table 3: Technology Tradeoffs vs. Market Requirements

	Military Communications	Commercial Infrastructure
Device Selection	Emphasis on General Purpose Processors, where practical, to maximize waveform portability FPGA Devices limited to front end processing in final production systems to maximize programmability	Emphasis on programmable ASIC devices, where practical, to reduce total cost of platform FPGA Devices used instead of ASICs for front end processing in initial systems to accelerate time to market
Design for Upgrade-ability	Modular hardware and software design allowing easy technology insertion based on open system industry standards	Modular hardware and software design allowing easy technology insertion based on OEMs internal standards optimized for reduced cost
Design for Reliability	Ruggedization requirements may include extended temperature, humidity, shock and vibration. Operation of the platform guaranteed through the use of redundant subsystems and the elimination of single points of failure	Ruggedization requirements typically limited to extended temperature. Operation of each channel guaranteed through the use of Hot Swap and the elimination of single points of failure

4. CASE STUDY: SDR IN SATELLITE COMMUNICATIONS

4.1. Overview

To illustrate the concepts presented in the sections above, let us consider a case study exploring the value proposition and technology selection for an SDR platform for use in satellite communications. This case study will be presented first from the perspective of the commercial wireless infrastructure market, and then for the military tactical communications market, which will be compared and contrasted with the commercial case. While the exact details of the target platforms will not be revealed, the analysis presented will be consistent with real world solutions [6][15][16][17][18].

4.2. Commercial Satellite Gateway

For the commercial case study, consider a satellite gateway vendor looking to develop communication gateway systems for two separate markets:

- A consumer satellite communication network used to provide broadband internet access to the home. This gateway system must support a larger number of simultaneous user channels each with a significant bandwidth requirement.
- An enterprise satellite communications network for transaction processing and business-to-business communications. This system must sustain a larger number of end user channels at any given time than are required on the consumer network, but the bandwidth per channel is significantly lower.

In each of these markets cost is a driving factor in system architecture and technology selection: the cost of designing, building, installing, and maintaining the gateway communications devices must be offset by the revenue obtained through customer subscriptions to the network with a substantial return on investment. As such, it is decided to adopt a common platform architecture for both gateway systems consisting of a modular network specific RF front end coupled with a common software defined digital transceiver subsystem with sufficient capabilities to address both markets. This model allows for hardware and software development costs that can be shared across both products at a substantial savings to the vendor, as well as reduced inventory and support costs across the lifetime of the platform.

Processor selection for the digital radio subsystem consisted of VirtexE FPGA components for high speed IF processing and channelization, TMS320C6201 processors for baseband processing, and PowerPC750 processors for call/network processing. This mix of devices helped to meet the cost target for this platform while at the same time addressing time to market constraints, by avoiding the lengthy development process for custom ASICs.

A cPCI form factor was selected as the basis for platform definition for the gateway product, primarily because of hot swap support, since the down time of any channel in the system represents a significant loss of revenue. Hot swap technology minimizes the impact of a hardware failure by allowing the suspect device to be hot swapped out without impacting the rest of the system.

With that in mind, the architecture is organized into multiple channel cards. Each channel card consists of a baseband processing platform hosting four ‘C6201 processors, with a mezzanine card host four FPGA processors for IF processing and channelization attached to the base card. A commercial off the shelf baseband processing platform is chosen, again the reduce development costs and decrease time to market. Communications between the base card and the mezzanine card follow a custom standard that reduces the overall cost of the communications link while maintaining a tight, low latency, coupling between the DSP and FPGA processing elements.

Call and Network Processing in this system are done on a single board computer (SBC), with communications between the channel cards and the SBC provided via the PCI bus. A redundant SBC is also provided to eliminate this as a single point of failure in the system.

4.3. Reconfigurable MILSATCOM Terminal

For the military case study, consider a satellite communications upgrade program designed replace dozens of legacy satellite communications devices with a family of three or four re-programmable satellite terminals. This primary purpose for this upgrade program is two fold: to significantly improve the usability of the satellite communications network by the soldier in the field by reducing the number of simultaneous satellite communications devices that must be transported and operated, and to significantly reduce the logistical costs of supporting and maintaining this wide range of legacy devices. These new terminals will need to support all of the existing satellite waveforms, which vary from complex waveforms enabling very high date rate backbone communications to relatively simple waveforms with lower data rates and reduced processing requirements. In addition, it is important for this family of terminals to allow for as yet undefined future waveforms.

The business case for SDR in this scenario is quite clear, with the reconfigurable nature of SDR communications devices being the driving factor. As with the commercial solution, the needs here can be addressed through a common platform architecture consisting of an application specific RF front end, with a software-defined digital transceiver subsystem.

Unlike the commercial case, however, the wider range of processing and date rate requirements for this system dictates the broader use of general-purpose processors for baseband processing., with FPGAs still being the processor of choice for IF and channleization processing.. The channelization and channel processing in this case are implemented on separate cards in a scalable architecture to allow different combinations of FPGA and GPP resources to be applied based on the waveform requirements. Thus, this architecture will be reconfigured to allow multiple channels of low complexity waveforms to be processed on a single set of processing devices, or to distribute the processing of complex high-speed waveforms across multiple sets of processing devices. Like the commercial case, cPCI is the base form factor used for this SDR platform, with a Serial RapidIO communications fabric used in lieu of the PCI and custom data transports that of the commercial platform to support the wider range of reconfigurability of this platform while maintaining low latency communications throughout the system.

5. CONCLUSIONS

There is certainly a business case for SDR in the commercial wireless infrastructure and military communications markets today, and it seems that this trend will increase. However, while the basic architectures supported in these two market spaces are similar, the technology choices made in creating commercial and military SDR platforms often take divergent paths. Reconfigure-ability and upgrade-ability typically drive technology for SDR in military communications to the wider adoption of general-purpose processors and standards based modular form factors. Conversely, total cost of ownership concerns drive technology in commercial infrastructure to the wider adoption of DSP and ASIC technology in custom form factors tailored for cost efficiency. As technology advances over the next several years these differences will define the adoption of new technologies in both the Military and Commercial market spaces.

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