A LOW COST MULTI-BAND/MULTI-MODE RADIO FOR PUBLIC SAFETY

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ABSTRACT

Existing radio communications systems employed in public safety applications today are a disparate mix of equipment operating at frequencies ranging from 25 MHz to 4.99 GHz and using modes ranging from basic analog FM to VoIP. This has created a frustrating and potentially dangerous problem in that first responders from different organizations are often unable to communicate effectively. Existing solutions to this problem are predominately network-based, which requires prior planning and coordination. So, it is desirable to implement some degree of user-based interoperability; that is, to have some radios which are capable of operating in any system without the aid of network-based infrastructure. Such radios would need to be able to operate in any frequency band using any mode that might be encountered. In this paper, we describe the requirements for such a radio and consider technical feasibility issues. Specifically, we consider a software defined radio (SDR) approach in which the radio uses a small number of RF front ends, each having relatively wide bandwidth and with tuning range sufficient to access most spectrum relevant to public safety communications. Also, two different types of baseband processing strategies will be compared to assess the advantages and disadvantages of Software Communication Architecture (SCA)-based SDR for public safety applications.

1. INTRODUCTION

Due to the lack of interoperability in radios, law enforcement officers, firefighters, and emergency medical service personnel often cannot readily communicate with one another, which results in unnecessary loss of lives and property [1]. In this paper we present a concept for a low cost multi-band/multi-mode radio which can be an intermediate solution to this problem. The proposed radio would bridge the gap that currently exists between present-day network architecture, characterized by multiple, "stove-piped" systems with cross-band repeaters and other network-based interoperability devices; and a long-term goal architecture, based on fully cognitive, software-defined radios. In the proposed approach, existing and emerging heterogeneous systems continue to operate or are installed without modification, but are accessed in a seamless and transparent manner using this radio. This radio will be capable of reception and transmission in most frequencies employed in public safety applications as shown in Table 1. Table 1 summarizes the frequency bands which are used, and the modes of communication that are used in each band. Modes include TIA-603 analog FM voice [2], APCO Project 25 (P25) digital voice and data [3, 4], TIA-902 wideband data [5, 6, 7], as well as various existing commercial wireless modes, including cellular, PCS, and IEEE 802-series wireless protocols. Users equipped with the proposed radio would nominally be able to communicate in any public safety radio system, immediately and without prior coordination.

The rest of the paper is organized as follows. Section 2 describes the intermediate user-based solution of the interoperability problem with some implementation issues. It also describes the associated ongoing project at Virginia Tech. A brief description and discussion of an SDR approach is presented in Section 3. A description of the hardware and software platforms of the proposed radio is presented in Section 4. Section 5 presents the accomplishments so far. Finally, the conclusions are drawn in Section 6 and some future research is dicsussed.

2. INTERMEDIATE SOLUTION

The ultimate goal is to implement standards-based systems which are able to accommodate new standards dynamically and flexible enough to select the band and mode automatically. There are some barriers, however, to achieve these goals, which include the time required to develop standards, maturity of technology, regulatory issues with the FCC, and cost/time required to replace equipment. So, a comprehensive system-based solution is probably decades away. In order to move toward these, an intermediate step is proposed, in which the existing user terminals are replaced with a low cost multi-band/multi-mode radio with backward

Table 1: Frequency bands and modes for public safety mobile radio communications. RL= Reverse link (mobile to base), FL= Forward link (base to mobile).

Band	Frequency (MHz)	Mode(s)	Remarks
HF	25-30	TIA-603	
VHF	30-50	TIA-603	
	138-174	TIA-603, P25	
	220-222	Voice/Data (not TIA-603)	5 kHz
UHF	406-512	TIA-603, P25	
700 MHz	764-776	TIA-603, TIA-902, P25, 802.16(e)	RL
	794-806	TIA-603, TIA-902, P25, 802.16(e)	FL
800 MHz	806-817	TIA-603, P25	RL
	824-849	Cellular (many modes)	RL
	851-862	TIA-603, P25	FL
	869-894	Cellular (many modes)	FL
PCS	1850-1990	PCS (many modes)	
ISM	2400-2483	IEEE 802.11	
4.9 GHz	4940-4990	IEEE 802.11, VoIP, UMTS/ TDD	

compatibility. Such radios would provide immediate relief for first responders without the dramatic changes to systems or operations.

A conceptual view of a radio implementing user-based interoperability is shown in Figure 1. From the user's perspective, the radio behaves as if it contains many different radios; perhaps as many as 8 different radios assuming 1 radio per band. However, since there are frequently multiple channels of interest per band, the effective number of radios needed to achieve truly seamless interoperability is actually much greater. On the other hand, it is unlikely that the user would (or could) utilize more than just a few channels at a time. For example, the user might wish to engage in data communications simultaneously with monitoring one or more voice channels, and can only effectively engage in voice dialog on one channel at a time. Thus, a literal implementation of the architecture suggested by Figure 1 is not necessary, or desirable. Although recent developments in device miniaturization and integration suggest that such an approach might be possible, it would appear to be an inefficient use of hardware.

A more attractive scheme is shown in Figure 2. In this approach, a smaller number of radios are used, but each radio is an SDR with relatively wide tuning range and bandwidth spanning many channels. Each SDR is capable of tuning only one band at a time, but is capable of supporting multiple channels per band. SDR technology is particularly attractive from the perspective that the radio depicted in Figure 2 could be designed to accommodate additional/new modes through software download. An important consideration in comparing the architectures suggested by Figures 1 and 2 is that each of the SDRs in Figure 2 is dramatically more complex than the individual radios depicted in Figure 1, especially if each SDR must support all bands shown in Table 1.

Virginia Tech is currently developing an experimental multi-band/multi-mode radio for public safety applications under a project sponsored by the U.S. Department of Justice

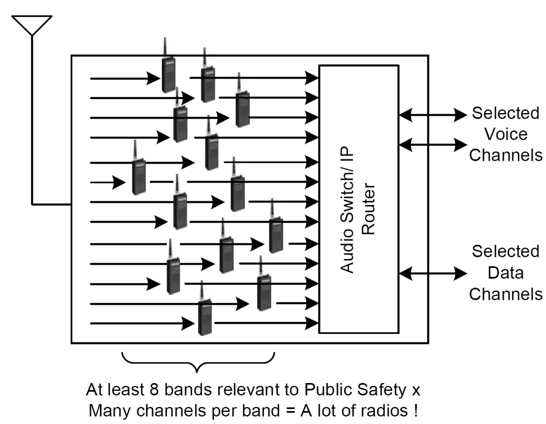

Fig. 1: Conceptual view of the user-based interoperability radio.

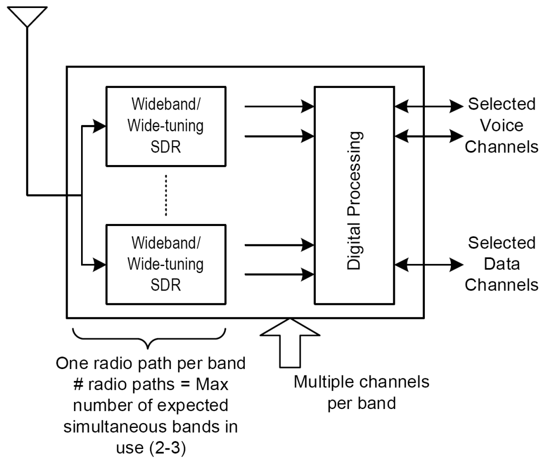

Fig. 2: Functional view of the proposed radio (shows receive side only; transmit side is similar to this).

[8]. The goal of this project is to develop and demonstrate a single radio which can operate in these bands using all modes allocated in each band for the public safety applications. This is a three years project (October 2005 – September 2008) with open and free dissemination of results at each phase. The goal of this project also includes the explicit implementation of analog half-duplex (PTT) Narrowband FM voice, a P.25 digital voice mode, and Rudimentary (PHY-only) 802.11b. The developed radio should be able to operate on multiple channels simultaneously, even across bands and modes. Following guidance from the sponsor, acting on input from an advisory committee consisting of public safety communications professionals, it was decided at the beginning of the project to limit the frequency range of interest to bands above 50 MHz; i.e., not to include 25-50 MHz. Thus, the total frequency range for our radio is from 138 MHz to 4.99 GHz.

After development and proof of concept, the aggressive cost reduction and the validation through laboratory testing and field demonstration will be performed.

3. SDR APPROACH AND CHALLENGES

The concept of an all-band/all-mode radio has already been explored by the U.S. military, most recently through the Joint Tactical Radio Systems (JTRS) program [9]. JTRS emphasizes the use of SDR technology as the means to facilitate flexible multimode operation. Through JTRS and its predecessor programs over the last 15 years has emerged a rapidly-maturing Software Communications Architecture (SCA) [10], which provides a unified framework for implementation of SDR software and common techniques for interfacing to SDR hardware. At first glance, it might appear that new military SDRs, such as those becoming available as a result of JTRS, might be the basis for an immediate solution to the public safety radio problem.

Unfortunately, military JTRS products are extraordinarily expensive. The requirements of the public safety radio community (as shown in Table 1) are actually much simpler, involving a tuning range of “only” about 36:1 (considering the frequency range of 138 MHz to 4.99 GHz), compared to 1000:1 for military SDR. Furthermore, there is no need for contiguous coverage of this frequency span since much of the spectrum spanned is not available to public safety organizations. Severe environmental requirements, severe/complex security requirements, and need to support waveforms which are unique to military applications increase the cost of the military SDRs. Therefore, military SDRs are probably not appropriate solutions to this problem.

The SDR Forum, through its Public Safety Special Interest Group (SIG), has undertaken a study to assess the potential of and issues associated with SDR technology for the public safety application area [11]. They have pointed out that SDR technology has enormous potential to facilitate seamless interoperability in public safety applications. It also has significant potential for both life cycle cost reduction and enabling cognitive applications. While the potential benefits are significant and substantial, many issues remain to be resolved in order to achieve the envisioned benefits. Even to realize the initial step of multi-band radios, front-end RF, multi-band antennas, and front-end sampling technologies are critical and in need of accelerated development. As the frequency span covered by the radio increases, the technical challenges increase as well. The research challenges involved in achieving this goal include (1) difficult radio-frequency and software design issues, (2) development of methods to ensure that that new-found flexibility to exploit many different frequencies and modes through a single radio does not result in a loss of control over existing networks, and (3) development of security mechanisms to ensure that the radios cannot be intentionally or unintentionally misused, “hacked” over the air, or exploited to the detriment of public safety organizations if stolen or reverse-engineered.

4. HARDWARE AND SOFTWARE PLATFORMS

In order to implement this radio there are two approaches are being considered. Table 2 shows the summary of these two approaches. These are (1) a traditional "bottom-up" approach, implemented using an Analog Devices Blackfin embedded processor, (2) a port of the SCA, implemented on a Texas Instruments OMAP embedded processor. The latter approach emphasizes architectural compliance with potential benefits with respect to waveform portability, whereas the former approach emphasizes compact, memory and power efficient computing. These two strategies will be compared

Table 2: Hardware and software platforms in two approaches.

	Approach -1	Approach -2
Digital IF Processing	Altera Development Board (Altera Stratix FPGA)	Ettus Research USRP (Altera Cyclone II FPGA)
General Purpose Processing	Analog Device's Blackfin board with BF-537 processor	Texas Instruments OMAP
Software	C on μClinux	SCA-Compliant Embedded

to assess the advantages and disadvantages of SCA-based SDR for public safety SDR. The next two subsections describe the characteristics of these platforms.

4.1. Digital IF processing platform

The first approach uses an Altera EP1S25 development board, which includes an Altera Stratix FPGA processor [12] for the digital IF processing. It has two 12-bit 125 MHz A/D converters and two 14-bit 165 MHz D/A converters. During the reception of the signals FPGA accepts A/D input and outputs a swath of spectrum from the digital passband in complex baseband form after the digital downconversion. It does the opposite during the transmission of the signals.

In second approach, we use the Universal Software Radio Peripheral (USRP) to take care of the digital IF processing. The USRP board, developed for the GNU Radio users, is a hardware component, which is very suitable for implementing some real time software radio applications [13]. It has four 12 bit 64 MHz A/D converters and four 14 bit 128 MHz D/A converters. These four input and four output channels are connected to an Altera Cyclone EP1C12 FPGA. This FPGA connects to a USB2 interface chip, the Cypress FX2, and on to a personal computer.

4.2. General purpose processing and software platform

For general purpose and baseband processing the first approach uses the Analog Devices ADDS-BF537-STAMP board, which includes the 500 MHz ADSP-BF537 Blackfin processor [14]. The Blackfin ADSP-BF537 device contains many on-chip peripherals such as Parallel Peripheral Interface (PPI), Serial Ports (SPORTs). The STAMP board also includes 64 MB on board SDRAM and is intended to be used with the μClinux operating system that is derived from the Linux kernel. This board is part of the Blackfin/μClinux open source project [15]. Factors which make μClinux an attractive choice include open source code availability, royalty-free licenses, open source community support, tools availability, networking support, portability, and an extensive application base. All software development and compilation is performed on the workstation and is transferred to the target hardware through serial port or Ethernet port.

In the second approach, the Texas Instruments OMAP 5912 processor provides an interesting platform for implementing a SCA compliant radio [16]. This platform provides an ARM 926EJ-S processing core running at 192 MHz with a C55 DSP core also running at 192 MHz. The Open Source SCA Implementation Embedded (OSSIE) project is an initiative by the Mobile and Portable Radio Research Group (MPRG) at Virginia Tech to provide a platform that is simple, easy to expand, and open-source for the development of waveforms following the guidelines laid down by the SCA specifications under the JTRS program as well as the Object Management Group (OMG) [17]. The ARM core is a low-power RISC processor that can support the needed software infrastructure to support OSSIE as well as a signal processing core designed specifically for wireless communications. The OMAP 5912 OSK (OMAP Starter Kit) board contains OMAP 5912 processor as well external interfaces, such as a USB port and an interface for Compact Flash memory. The configuration of the board allows for 32 MB of on-chip memory. Additional memory is also available through the Compact Flash interface. The Openembedded (OE) development environment, which provides the basic compiler tools and some of the libraries necessary for OSSIE, is used to produce file system images for embedded Linux hardware [18].

5. ACCOMPLISHMENTS

This section summarizes the accomplishments of this project so far. Detailed technical reports including software and support files are available via the project website [8].

5.1. SCA based approach

Currently, we have demonstrated SCA-based FM receiver and transmitter applications on a PC. These applications process audio through the PC's sound card, allow monitoring two frequencies simultaneously and allow the user to reply to transmissions on either channel. This is an interim step to implementation of baseband processing on the OMAP processor using the OSSIE framework. The work done for this project led to the creation and improvement of several software components for the OSSIE program. Improvements were made to the USRP and sound input/output components. Components developed for the OSSIE project includes a decimator, an interpolator, a FM demodulator, a FM Modulator and a FM transceiver controller. Additional integration of the OSSIE SCA implementation into the OpenEmbedded application development environment is required to implement these applications on the OMAP. Also, the OMAP implementation in use is unable to accept a sample rate greater than 25 kSPS; thus, a revision to the USRP firmware will be necessary to reduce its output sample rate. Since the rate is too low to support many of the modes in Table 1, future work will rely on the non-SCA approach described next.

5.2. Non-SCA based approach

In our non-SCA based approach, digital IF processing is implemented completely on an Altera Stratix class FPGA. The FPGA accepts 120 MSPS from an A/D and outputs a swath of spectrum from the digital passband in complex baseband form at 468.75 kSPS. The FPGA firmware is custom Verilog HDL developed by our team. This is accepted by the Blackfin processor using a glueless asynchronous transfer using the Blackfin's parallel port interface (PPI). The Blackfin runs the μClinux operating system and the applications are developed in the C programming language. Recently, we demonstrated an FM receiver application in which the FPGA output is demodulated and delivered to a speaker via an embedded audio codec processor. The binary footprint of the application is 103 KB, and the total memory footprint of this application (including the operating system and memory which is dynamically allocated by the application) is estimated to be 42.4 MB.

6. FUTURE WORK

Work on RF is currently in early stages. Already, the design of the antenna has emerged as at least as significant a problem as the design of the radio. It is unrealistic to expect that all bands from 138 MHz to 4.99 GHz can be implemented using a single antenna. If the radio is to be used for receive only, then good matching between the antenna and the radio is not essential (although nevertheless important for sensitivity) and a single broadband or multi-band antenna may be a reasonable option. If the radio is to transmit, however, then good matching is required in order to mitigate the reception of transmitted power into the receive sections of the radio. So, more research work should be done about the implementation of an antenna for this radio.

Aggressive cost reduction is a part of this project. We intend to continue to monitor developments in the wireless industry in order to be aware of useful new technology as it becomes commercially available to reduce the cost of this system. As an example, the FPGA based digital down converter (DDC) can now be replaced with an inexpensive dedicated IC such as the Analog Devices AD6636 [19]. Currently, we are investigating this DDC chip, which accepts input up to 150 MSPS, outputs up to 4 independent tuned outputs, and costs about $30 in 1k quantity, significantly less than the cost of an FPGA with sufficient resources to implement the same functionality.

7. ACKNOWLEDGEMENT

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