

A VHF/UHF/CELLULAR/VOIP SMART RADIO BRIDGE FOR PUBLIC SAFETY CONFLICT AND DISASTER MANAGEMENT

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ABSTRACT

This paper describes a demonstration of an user-friendly, software definable, "smart" radio in a public safety, conflict and disaster management application. This is the second in a series of demonstrations which will incrementally assure the end users of the realizability of fielded "software programmable radios" (i.e. Joint Tactical Radio System (JTRS)). A "smart" radio monitoring a transmission must recognize the type of waveform received, including frequencies, modulation, data type (voice, data, sensor data) and have the ability to automatically reconfigure itself to communicate. A "smart" radio must also be able to sense the electromagnetic environment and make changes to maximize bandwidth, Quality of Service (QoS) and maintain security. A "smart" radio will enable more efficient communications by allowing the radio to choose the correct waveform, the correct data rate, the correct compression algorithm, the correct RF power, and the correct transmission path. Decisions have to be made based on many criteria including: data/voice priorities, low probability of intercept vs. anti jam, atmospheric conditions and hardware resource availability.

This demonstration shows the reachback capability of a Software Defined Radio (SDR). Responders in the field use UHF/VHF radios to communicate locally, however many interested parties not at the scene need to monitor and communicate with the people in the field. Using the capabilities of the SDR we have shown the ability to bridge/monitor/communicate with the field radios using cellular or Voice Over Internet Protocol (VOIP). With cellular or VOIP the field communications can be monitored anywhere there is a telephone or an internet connection.

This effort was demonstrated on the Software Radio Development System (SoRDS). SoRDS is a fully programmable and reconfigurable software radio, developed by the Air Force Research Laboratory at Rome, New York (AFRL Rome) and is capable of transmitting and receiving voice, data, video, or network traffic. SoRDS is a portable platform that enables rapid

development and demonstration of wireless communication applications. The SoRDS concept was to create a software reprogrammable and hardware upgradeable testbed to support evaluation of wireless voice, multimedia and network radio communication applications. SoRDS consists of a general purpose processing sub-system, an adaptive computing sub-system and an IF/RF sub-system. Using SoRDS, wireless applications can be developed from algorithm to implementation and baseband to RF. SoRDS is JTRS capable so the research done can be directly transitioned to JTRS.

INTRODUCTION

Military and Public Safety radios in the future must possess the intelligence to detect and connect to multiple radio networks. The radio must be aware of its environment, the type of data to be sent, whether the "radio" has permission to send the type of data, and the priority of the data. The radio must be location-aware and know who is within "hearing" distance (both good and bad). The radio must make decisions to choose the correct waveform, frequency, processing requirements and security features necessary for interoperability.

BACKGROUND

The Air Force Research Laboratory (AFRL) Information Grid Connectivity Branch (IFGC) (Rome Site) teamed with PAR-Rome Research Corporation (RRC) to design, develop and implement a software reprogrammable, hardware reconfigurable, wireless communication testbed. The purpose was to provide a wireless testbed for evaluation and comparison of various communication waveforms and algorithms.

The testbed is centered around the Software Radio Development System (SoRDS). SoRDS is a fully programmable and reconfigurable software radio, based on a common personal computing platform and is capable of transmitting and receiving voice, video or network traffic. SoRDS is a portable platform that enables rapid

development and demonstration of wireless communication applications.

This paper will describe how SoRDS is used as a launch-pad for field-able wireless smart radio applications.

DESCRIPTION OF SORDS

SoRDS was created to provide a software reprogrammable and hardware upgradeable testbed to support evaluation of wireless voice, multimedia and network radio communication applications. SoRDS consists of a general purpose computing system, an adaptive computing system, a Global Positioning System (GPS) system and an IF/RF system.

The SoRDS general purpose computing system consists of a high-end Pentium-based PC in a 4U rack-mount chassis. The Red Hat version of the Linux operating system is used on this platform. The use of Linux provides many advantages: it is extremely popular, stable, well supported and is open-source. From the perspective of interfacing, all vendors of the subsystems in SoRDS provide Linux drivers. The availability of license-free signal processing applications in public domain aids in the rapid development of prototype communication waveforms. Linux applications on SoRDS are optimized for high-speed data communication with the adaptive computing system. A suite of custom software tools, enabling the developer to take visual snapshots of baseband waveform data, have been created for SoRDS. These tools act as test points for measuring both system performance and data integrity in a non-obtrusive manner.

The SoRDS adaptive computing subsystem is comprised of the Alpha-Data ADM-XRC board. The ADM-XRC is a high performance reconfigurable PMC (PCI Mezzanine Card) based on the Xilinx Virtex and Virtex-E Field Programmable Gate Arrays (FPGAs). The ADM-XRC complements the Virtex with a PCI interface, external memory, high density I/O, programmable clocks and flash boot facilities. SoRDS communication applications reside on both the general purpose processor and the FPGA. Applications for the Virtex FPGA are developed in VHDL. Typical applications for past projects include digital MODEMS for transmission and reception of voice and video. SoRDS communication applications are partitioned between the general purpose and adaptive computing systems in the design process to take advantage of the attributes of each processing system. A software tool titled the "Waveform Workbench" developed by PAR-Rome Research Corporation aids in the process of prototyping the design. This tool enables the user to rapidly develop and optimize

a waveform application on the SoRDS by providing real-time visualization tools for baseband data from within the



Figure 1. SoRDS

VHDL application on the Xilinx FPGA.

The SoRDS GPS system is implemented via the bc637PMC GPS receiver and time code generator board manufactured by Symmetricom (formerly Datum). This board requires an external GPS antenna/receiver. The purpose of the SoRDS GPS system is two-fold; it can provide GPS location and accurate time information for field test or mobile applications, and it can provide a periodic "heartbeat" timing reference for waveform applications that require time synchronization.

The SoRDS RF subsystem uses a Rockwell Miniature Radio CODEC (MRC) to convert digital data to an RF signal. The MRC provides SoRDS with a bandwidth of up to 5 MHz over a frequency range of 20 MHz to 2.5 GHz. The MRC has both serial and parallel interfaces. The serial interface is used for command information including mode, frequency, bandwidth and power selection, while the parallel interface is used for transmit and reception of I and Q data, each at a 12-bit resolution. The interface logic for both serial and parallel interfaces to the MRC is implemented in VHDL on the Virtex FPGA. SoRDS provides a complete, end-to-end

wireless transmit and receive development environment, from voice, data or video to RF and back.

SMART RADIO FEATURES OF SoRDS

The AFRL/IFGC Smart Radio software design goal was to make the radio's smart ability to sense, think and adapt separate from the waveform. In this design philosophy, any communication waveform in the radio's library could be loaded and executed based on decisions made by the radio itself.

A Smart Radio must be able to discover many things that will allow it to function properly, without user intervention. Data, voice and video all have different needs for processing, bandwidth, priorities and policy. Does the transmission need Low Probability of Intercept or Anti-Jam? Where am I? Where are you? Can we use this frequency in this country? What bandwidth is possible considering the transmitter, the receiver, the transmit path, the environment, the type of data, and the priority of the transmission?

The design challenge was creating the features that would provide the SoRDS with effective "smart radio" capability. To focus on these sensory and decision making features, we first developed and utilized a simple FM waveform application, compatible with most commercial off the shelf (COTS) FM radio handsets e.g. Family Radio Service and General Mobile Radio Service (FRS/GMRS) or VHF Marine. As the SoRDS can tune or frequency hop from VHF into S-Band, communication could be established with virtually any commercial FM radio band.

Once the SoRDS software was verified for interoperability, a radio bridging application was developed. Radio bridging requires two independent radio channels and is typically used for public service applications to "bridge" emergency responders using radios of different frequencies or modulation. This application was developed on a single channel SoRDS and tested using a "record" and "playback" technique.

A sophisticated scan and detect application was then designed for the SoRDS smart radio. A requirement was imposed that it must support potential field or mobile applications. The scan and detect feature enables the user to select any frequency band (e.g. FRS, VHF Marine, USMC), or to specify a start, stop and step frequency range to scan. When the frequency range is selected, the user may then specify a time frame for the scan or continually scan the spectral range. Finally the user must specify a threshold in dBm. If the receive signal at any scanned frequency exceeds this threshold value, an "active emitter" will be declared as found. At this time three events take place. First an ID number is generated and a log file is updated with the date, time (usec

resolution), frequency, GPS location of the SoRDS and average and peak receive level in dBm. Second, a message is sent to a software voice synthesizer to announce by voice that an emitter was detected at the specified frequency. Third, FM demodulation begins and the voice of the FM transmission is recorded and stored in a file for later playback. The file is named by the ID number assigned to the detected emitter. The voice recording feature stops when the emitter drops below the user-specified receive threshold. These three events are reinitiated for each detected emitter above the threshold for the entire scan.

An open-source software voice synthesizer (festival) for the Linux operating system was downloaded from the distribution website, built and installed on SoRDS. Its use would be to verbally announce detected emitters when found during a scan. The voice would report when an emitter was detected, providing its frequency and other details specified in a configuration menu.

An open-source software GPS mapping feature (gpsdrive) for the Linux operating system was also downloaded from the distribution website, built and installed on SoRDS. Its use would be to track the position of the SoRDS when used in a mobile application. Capabilities include the tagging and labeling of waypoints of known emitters, line tracking of the SoRDS position on a scrolling map when mobile and displaying a map of the surrounding terrain in both 2D and 3D and in various square mile resolutions.

The SoRDS user interface presents the major Smart Radio functions by colorful tabbed index pages. The page tabs are labeled "COMM", "BRIDGE", "SCAN/DETECT", "GPS MAP" and "WVFM". The SoRDS user interface was developed in the Tcl/Tk script language. Tcl/Tk was selected because of ease in rapid development of sophisticated GUIs and its ability to interface easily to existing C/C++ applications.

SMART RADIO FIELD TEST: UNKNOWN EMITTER GEOLOCATION

Following an initial lab demonstration, an effort was begun adding geolocation of RF unknown emitters to the SoRDS Smart Radio. A field demonstration of this feature was made in the summer of 2005. The physics implemented for this first field demo was trilateration of a source emitter by received field strength.

A field test of the SoRDS Smart Radio was performed at the AFRL's Stockbridge Test Site. The objective of the test was to use three Smart Radios widely separated in the field to detect and geo-locate a unknown, mobile "fox" emitter. The three Smart Radios first find each other via an ad-hoc network, then scan, and detect

the fox emitter. The radios work and think together, ultimately geo-locating the fox emitter by tri-lateration. The test objective was to sense, detect and determine the position of a unknown emitter within a 100 meter radius of its actual position. This demonstration has both public safety and military applications.

AFRL's Stockbridge Test Facility is a 300 acre test site located on a hilltop 1250 ft above sea level in a rural area approximately 18.75 miles from the AFRL Facility in Griffiss Business Park. It is in a relatively "RF quiet" area. Its use is typically for antenna pattern measurements on large-scale aircraft. This site has several open fields enabling the three SoRDS units to be positioned within mutual Line of Site (LOS). The mobile fox emitter would travel within the triangle formed by the three SoRDS locations. At each SoRDS receive location a portable shelter with AC generator was installed. Each location has two omni directional RF antennas, one for GPS and the other for both the SoRDS ad-hoc network and sensing unknown emitters. All transmissions are non-encrypted as no security is required for this test.

The geo-location test scenario was executed in four phases named "Establish Network", "Calibrate Range", "Scan and Detect" and "Find Emitter". In the "Establish Network" phase, each SoRDS unit has no a priori knowledge that the other units exist in the field; hence a "master" SoRDS unit initiates a search. This mode is performed by wireless data communication software application that uses the SoRDS RF subsystem. The application uses Manchester-II modulation and can transmit or receive data on any frequency in the SoRDS's spectrum. A "field networking" frequency known by all SoRDS is reserved for this purpose. The application on the master SoRDS transmits its hostname and requests the hostname / GPS location of each slave SoRDS. The master then enters receive mode to detect a response from each slave. The data communication application in both master and slave SoRDS waits a random time period between transmissions to avoid collisions. The master SoRDS acknowledges each response from slave units. This mode executes for a user-specified time period to enable the master to map itself and the slave SoRDS locations. Following detection of all slave SoRDS units, the master SoRDS uses the GPS coordinates to calculate the distance between itself and the other two SoRDS, and displays each as waypoints on a mapping application.

In the "Calibrate Range" phase, the master SoRDS Smart Radio sends a message over the "field networking" frequency to each SoRDS in sequence informing it to either transmit or receive a signal on a designated frequency for a specified time period. The master SoRDS also transmits and receives a signal in sequence. Only one of the three SoRDS will transmit at a

time. At the end of the time period, the master SoRDS requests the receive logs of each SoRDS unit, which will be sent and acknowledged by the master SoRDS. The master SoRDS then reviews each log to verify each SoRDS unit received another SoRDS signal. The master SoRDS then uses the Receive Signal Strength Indicator (RSSI) levels, transmit power levels and system characteristics to calculate the range between each SoRDS.

In the "Scan and Detect" phase, the designated master SoRDS Smart Radio sends a message over the "field networking" frequency to inform each slave SoRDS to begin scanning a predetermined spectrum profile. The spectrum profile includes the frequency range to scan, the frequency step, the dwell time on each frequency, the time duration of the scan and the threshold in dBm at which each SoRDS should declare detecting an "active emitter". During the scanning time period, each SoRDS tunes to a frequency and measures the RSSI level for the dwell time period, comparing it to a threshold value. Whenever the receive threshold is exceeded, the software will log the date, time (to usec resolution), frequency, GPS location of the SoRDS and average and peak RSSI levels in a log file. When the time duration of the scan has elapsed, each SoRDS stops scanning and sends its log file to the master SoRDS over the field networking frequency.

In the "Find Emitter" phase, the master SoRDS receives and acknowledges reception of the log file from each SoRDS. It then reviews each log file for time-synchronous active emitters. When found, the RSSI levels are extracted and used in the range equation to calculate the distance between each SoRDS unit and the unknown emitter. As omni-directional antennas are used on each SoRDS unit, this computation will reveal a range but not a direction. To obtain the location of the unknown emitter, trilateration calculations are performed. The range values are used as radii and rotated around each known SoRDS position in the field. These three arcs will intersect at six points. The three closest intersection points will form a triangle around the location of the unknown emitter. The GPS location of the unknown emitter is determined from the circumcenter of the triangle formed by these three points.

The results of the geo-location test revealed that with reasonably clear LOS, the sensor network formed by the SoRDS units could detect and compute the position of an unknown emitter within a 100 meter radius with an 85% success rate. The position of the fox emitter may now be reported to a reach-back facility for reconnaissance.

SMART RADIO DEMONSTRATION: PUBLIC SAFETY VHF/UHF/CELLULAR/VOIP BRIDGE

A responder to any emergency needs to establish who is already at the scene, how are they communicating, what are they communicating, and the equipment on the scene. Everyone needs to be aware of what is happening around them in any emergency. A first responder's radio should scan the spectrum for transmitters, identify each by accessing a database of known transmitter types for comparison. The "smart" radio should then modify itself to communicate with any known transmitters on the scene. If the transmitter can not be found in the data base a network of "smart" radios can geo-locate the transmitter and provide the coordinates of the transmitter to the appropriate responder. "Smart" radios have the ability to communicate with everyone, bridge dissimilar networks and provide all types of data transfer (voice, video, and sensor).

In FY 2006, AFRL began looking at the needs of Emergency First Responders and how software defined radios could help. To gain an understanding of the needs and limitations of current communication equipment used by police, fire and emergency medical personnel, AFRL contacted and gathered information from organizations representing county, state and federal emergency response agencies.

The communication bridging capability of the SoRDS radio features were expanded to include cellular phone and Voice Over IP (VoIP). The objective was to demonstrate SoRDS as a bridge between two public safety first responders using radios in different frequency bands, and to leverage their bridged transmissions to a distant location using cellular phone and VoIP. SoRDS could provide intercommunication between multiple public safety services in a conflict or disaster situation and enables a remote site, at any location in the world, to monitor transmissions and/or provide command and control via telephone. The SoRDS radio could also act as an unmanned reachback facility, and can be vehicle or aircraft mounted. It can be remotely programmed via cell phone text messaging or via the internet.

The SoRDS VoIP server is implemented using the "asterisk" open source software package. The asterisk software package was developed under the GNU public license, executes under the Linux operating system and is maintained by Digium, Inc. The asterisk software package implements a complete Private Branch Exchange (PBX) telephone system including advanced features such as caller ID, telephone conferencing, call waiting, call forwarding, call recording, voice menus and voice mail. A Digium interface board provided the asterisk software an interface to the Public Service Telephone Network (PSTN). As a VoIP server, the asterisk software connects

the PSTN to IP, implementing all necessary functions in software. The asterisk VoIP server is configured using script files created by the user to configure multiple phone extensions and features tailored to each extension. The SoRDS hosts the asterisk application on a dedicated PC. Once the asterisk PC is connected to the PSTN via the Digium board, a software telephone application may be executed on any PC connected to the asterisk PC via IP.

The asterisk VoIP server application is configured to provide a phone number to a PC executing a softphone application. Using a softphone application on a PC that is IP-connected to the asterisk server, users may make or receive VoIP phone calls to any phone in the world free of charge. No VoIP service provider is required. The SoRDS uses the "eyeBeam" softphone application by CounterPath. The eyeBeam application provides an audio interface via the PC sound card to a microphone/headphone, and if desired, a video interface via a USB camera. While audio phone calls may be made to any IP softphone or PSTN-connected phone, video can only be sent to IP softphones compatible with eyeBeam.

To bridge one or more SoRDS radio channels to VoIP, a connection is made from the SoRDS radio audio interface to the audio interface of the PC controlling the SoRDS. The eyeBeam softphone application is then executed on the PC and a call placed to any PSTN phone at any location via the SoRDS asterisk VoIP server. The recipient of the call would then be able to converse with the radio users bridged by the SoRDS.

FUTURE WORK

The future of software defined radios in the service of the first responder depends not only on the unique and useful features that can be provided, but the ease of implementation. The first responders at the local level are not looking for new features they are looking for reliable, inexpensive voice communication. These radios will need to evolve into more intelligent systems that sense their operating environment and make decisions to adapt. The SoRDS Smart Radio currently demonstrates some of these "smart radio" features.

