SMART CARPET – A DISTRIBUTED COGNITIVE RADIO

Topic Session: 6.11
Stephen P. Reichhart (Air Force Research Laboratory)
(AFRL/IFGC, 525 Brooks Road, Rome, NY 13441)
(Phone: 315 330-3918, Fax: 315 330-3908)
(reichharts@rl.af.mil)
Bruce Youmans (PAR-Rome Research Corp.)

ABSTRACT

Electromagnetic threats exist in many forms on both the battlefield and at home. Current detection and countermeasure systems typically target only specific threats and perform limited actions. Furthermore, some countermeasure systems easily reveal themselves or cause disruptions of tactical systems. The need exists for a field-reconfigurable, distributed cognitive radio system that has the capability to integrate the communication system with a countermeasure system.

The Information Connectivity branch of Air Force Research Laboratory (AFRL) (Rome Site) has led programs in Software Radio Technology and has used the Software Radio Development System (SoRDS) to developed techniques for "Smart Radios". The AFRL team has developed a field deployable, distributed cognitive radio system for signal detection, signal identification, and emitter geo-location.

Field testing started in 2005, was comprised of three cognitive radios and an unknown emitter. A mobile emitter was detected at multiple locations with receive systems collectively reporting the locations on a graphical user interface with electronic topographical mapping features. The knowledge gained from this test provided the basis of four major improvements to the system. The new system would be: 1) expanded to any number of additional nodes with a minimum of four nodes (additional nodes improving accuracy and field coverage); 2) miniaturized nodes (each node includes: an embedded computer, Global Positioning System (GPS), Radio Frequency (RF) transceiver and Wireless Local Area Network (WLAN)); 3) improved signal detection and identification software; and 4) a "smart router" added to stream signal information to a loitering Unmanned Aerial Vehicle (UAV) or reach-back facility.

This paper describes the field testing and demonstration of the "Smart Carpet" distributed cognitive radio system was conducted at AFRL in 2007. Four field probes were constructed, each consisting of a PC-104 computer, high–speed counter, RF transceiver, GPS and ZigBee wireless communication modules.

Software development for the Smart Carpet system was divided into three major subsystems. The probe subsystem consisted of embedded software enabling the probes to scan, detect, identify and log RF emissions. The messaging subsystem software enabled the master router to remotely configure each probe for specific operations and to coordinate the probes into a simultaneously executing "sensor carpet" for electronic threat detection. The master router software was developed to perform complex operations on signal data retrieved from the probes, and present the information in various formats depending on the system being notified.

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.

SMART RADIO

The AFRL/IFGC smart radio design goal was to use the inherent processing power of the software defined radio to give the radio the 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? Are we mobile and at what speed are we traveling? Are we airborne or at ground-level? What bandwidth is possible considering the transmitter, the receiver, the transmit path, the environment, the type of data, and the priority of the transmission?

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.

PAST AFRL DEMONSTRATIONS: PUBLIC SAFETY BRIDGE

Past AFRL Smart Radio demonstrations have shown the possibility of using software defined radio for public safety. First 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 Smart Radio we proved 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.

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).

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.

PAST AFRL FIELD TEST: 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 tri-lateration 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 Sight (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 microsecond 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, tri-lateration 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 CARPET: A DISTRIBUTED COGNITIVE RADIO

A smart network of software defined radios should be able to sense, locate, communicate, avoid (notch) or jam any communications signal in a given area; which action chosen depends on the mission. An effective system must have the capability to detect, geolocate and jam the RF emission of a potential threat, before the threat has time to carry out its purpose without jamming friendly tactical radio communications.

The present generation SoRDS was developed as a distributed cognitive radio system of four identical nodes. Each node has a complete, independent computing subsystem consisting of a PC-104 form factor processor board. The IF/RF subsystem on each node is the Rockwell Miniature Radio CODEC (MRC). Each node has both GPS and ZigBee WLAN modules and antennae enabling all location-aware nodes to form a Wireless Personal Area Network (WPAN). The nodes, each responding to commands from a master router, form the "Smart Carpet" distributed cognitive radio.

The nodes are each packaged in a 730 cubic inch PVC enclosure with a metal ground plane and self-adjustable length antenna to support multi-band frequency monitoring/jamming. The enclosures were designed to be robust for vehicle mounting or outdoor, weather-resistant applications. An air-droppable enclosure is also planned. For our field testing, the probes were stationary, with each mounted on construction tripods. The nodes operate on 12 VDC input power from either vehicle or battery.

The nodes are each programmed to act as slaves, interpreting and responding to eighteen different commands sent via ZigBee by a master router. The master router may be located in another vehicle or loitering UAV. The master router has the capability of sending commands to the nodes in either broadcast or point to point mode.

Each node has a unique hostname, initially unknown to the master router. On network startup, the master router sends a "CQ" command in broadcast mode to "all nodes" in the vicinity as a "roll call". Any node receiving the command will respond, thus notifying the master router of all nodes available. To avoid a collision of responses, each node receiving an "all nodes" broadcast command will wait for a unique time delay before responding.

The master router must be able to communicate with at least one node in the network. Each node has the capability of message forwarding, thus if the master router cannot send a message to all nodes directly, it can send a command to a neighboring node to forward the message to the desired target node. As the master router finds all nodes and their locations, it maps the nodes and "heals" the network via message forwarding in the event one or more nodes become inoperative.

The nodes may be located in any position scheme, as far apart as 1 km from any other node. Separation between nodes depends on the terrain. Typical layouts are in a square or parallelogram or aligned in a column as if mounted in convoy vehicles.

The node software performs GPS, timing and RF functions. The node responds to commands from the master router for the node's GPS position, quality, number of satellites and GPS clock readings. The GPS also serves as a 1 pulse per second (PPS) generator to time-synchronize all probes in the field. Commands from the master router also perform node timing functions include setting and reading 1 PPS hardware counters and four, ganged 19.2 MHz hardware counters. The master router may also control any node's RF functions including transmit and receive on any one frequency, spectral scanning in receive mode, signal acquisition including peak, average and full signal capture, time difference of arrival (TDOA) measurement and spectral jamming. Each node can perform frequency hopping in either receive or transmit/jamming modes greater than 2000 hops per second across its entire spectrum from 20 MHz to 2.5 GHz.

The master router performs all tactical functions of the distributed cognitive radio including policy management, scenario setup and execution, mathematical hyperbolic positioning functions for geolocation and jamming. Commands sent to each probe may easily be built into a script file, with additional commands sent based on decisions made from node responses.

A field test was performed in August 2007 for the purpose of testing the geolocation and jamming capability of the Smart Carpet.

In the geolocation test phase, four nodes were set up in a column, 300 meters apart, emulating a convoy scenario. The master router, a laptop PC hosting the master router software and a ZigBee transceiver, was in a vehicle always within <1 km of all probes. To begin phase 1, the master router obtained the hostnames, GPS locations and GPS time of each probe by sending the "CQ", "GP" and "GT" commands, respectively. The master router then sends an "RC" command to initialize the Rockwell MRC, and "SP" commands to start the 1

PPS counter on each node. Finally, the "GS" command is sent to each node to clear and start the 19.2 MHz counters and setup for geolocation on a specific frequency set. To simultaneously start all nodes in the Time Difference of Arrival (TDOA) measurement sequence, the "GD" command is broadcast to all probes.

The TDOA measurement sequence in each probe remains active until a predefined receive signal strength threshold is exceeded. At this time, the 19.2 MHz counters stop, recording the time of arrival of the signal at each node. The master router then sends the "RS" command to each probe to respond with the 19.2 MHz counter values. On receipt of each node's counter values, the master router applies this data and the GPS location of each probe to the hyperbolic positioning algorithms to calculate the GPS location of the unknown emitter. Once the unknown emitter has been located, the information can be passed to a reach-back facility for appropriate action.

The Smart Carpet nodes were arranged in a variety of configurations. Unknown emitters were tested at various ranges and angles relative to the Smart Carpet network. Preliminary field test results with a reduced clock speed consistently geolocated an unknown emitter. The Smart Carpet system is capable of TDOA geolocation at the same accuracy as GPS.

In the jamming test phase, a Uniden cordless phone was used as a remote control device. This cordless phone employs frequency hopping across 20 channels in the 900 MHz band. The master router sent commands to each node to perform spectral scanning in this band, and to emit a jamming signal on any detected emission.

With the nodes in scan and jam mode, an operator used the Uniden cordless phone to send a dual-tone multi-frequency (DTMF) sequence by pressing digits on the cordless phone handset. The nodes detected the cordless phone signal and responded by emitting a jamming signal at the same frequency and power level with white noise modulation. The Uniden phone is designed to detect a loss of signal between cordless phone base station and handset and responds by hopping to another one of 20 channels. The nodes would again detect this new frequency and emit a corresponding jamming signal. This resulted in a "chase" between cordless phone and Smart Carpet nodes of detection and jamming which sequenced through all 20 channels and repeated. As the chase occurred at a rate of 100 microseconds per frequency hop, no DTMF tone was successfully received by the Uniden base station. Hence the Smart Carpet system deterred transmission of the threat sequence.

FUTURE WORK

AFRL will continue to develop, design and test unique techniques and features to be used in "Smart" software defined radio. This research will prove the usefulness of SDR and eventually lead to "true" cognitive radios.