Exhibit A

<u>REQUEST FOR SPECIAL TEMPORARY AUTHORITY</u>
File No.: 0287-EX-ST-2007
Confirmation No.: EL297440

The Software Defined Radio Forum ("SDR Forum") requests Special Temporary Authority ("STA") to operate fifteen (15) to eighteen (18) student-built and -operated transceivers as part of its Smart Radio Challenge[1] event from November 3, 2007 to November 12, 2007 at its Denver, Colorado convention center.[2]

The Smart Radio Challenge consists of three Scenarios,[3] each requiring student participants to develop a smart radio solution. Exhibit 1, attached, details each Scenario. Technical limitations, where they exist, are summarized below.[4] The majority of testing will take place within the convention center. The radio terminals will be mobile within that space, but will remain stationary when in operation. In Scenarios 1 and 2 transmitters will be placed in close proximity on benches in order to communicate. In Scenario 3, some testing will take place immediately outdoors in the convention center parking lot.

Scenario 1: Detection of Available Frequencies

(1) The transceiver will be capable of detecting available 25 kHz bandwidth channels in the 462-467 MHz Family Radio Service (FRS) band.
(2) Two Quality of Service (QoS) settings must be demonstrated; further, tranceivers must be capable of switching between them during operation. The settings are:
   a. 16 kbps, QPSK, Reed Solomon channel coding, CVSD vocoded voice,
   b. computer to computer link at 19.2 kbps using 8-PSK and a rate one-half convolutional channel code.
(3) In establishing this channel, the system may operate in a master-slave mode, with one radio paging the other radio on an available channel to establish the communications, or in infrastructure mode, with the channel between the two transceivers assigned by a 3rd infrastructure radio.
(4) The demonstration shall show how the transceiver complies with FRS specifications as outlined in Part 95 of the Federal Communications Commission's Rules.

---

1 Further details for this event may be found at this address: http://radiochallenge.org/07Challenge.html.

2 According to the preliminary technical specifications submitted by the students, attached hereto as Exhibit 2, internal components of the transceivers may be off-the-shelf or student-assembled.

3 Four scenarios are outlined in the official description of the contest. However, because none of the student teams chose to participate in that event, the SDR Forum is **not** requesting that the "blanket" STA cover Scenario 4.

4 As explained below, full technical specifications are not available at this time.

Scenario 2: Develop an Interoperable, Single Channel Wireless Terminal

(1) Communications systems with which the terminal must be interoperable include:
   a. AM citizen's band radio (90% peak AM modulation, 10 KHz channelization between 26.965-27.405 MHz, using only the 40 numbered allowed CB channels, maximum power level of 1 watt),
   b. FRS narrowband FM radio (10 kHz deviation NBFM with a 40 HZ PL tone squelch, 25 kHz channelization between 462.5625-467.7125 using only the 14 numbered channels, maximum power level of 0.5 watt),
   c. Digital cordless phone operating in the 902-928 MHz ISM band (16 Kbps CVSD encoded voice, modulated +/- 8 KHz FSK with 50 KHz channelization between 902-928 MHz, with a maximum power of 0.1watt).

(2) The terminal must be adaptive to spectrum policies in administrations where it may be used.
(3) The terminal must be able to detect emissions from any of the three communications systems.
(4) The terminal must be able to bridge between the three systems.

Scenario 3: Traffic Management System

(1) The system must work with an off-the-shelf radio controlled vehicle.
(2) The control link must operate in either (a) the FRS band, or (b) the IEEE 802.11 ISM band.
(3) The radio tag must be software defined and the waveform modulation (phy), MAC and Link protocols must be reprogrammable.

Necessarily, this "blanket" STA must allow for some flexibility with regard to power levels and emission designators as student designs have not yet been finalized. Informal conversations with Federal Communications Commission ("Commission") staff yielded a maximum of 4 Watts peak power for each frequency band. SDR Forum recognizes that two of the bands chosen for testing are co-allocated for government use, and some lie close to restricted bands. Accordingly, SDR Forum understands if the Commission believes 4 Watts is not acceptable, and, in the alternative, proposes to constrain transceivers to a maximum of 1 Watt peak power.

Also as a result of informal discussions with the Commission staff, this application lists the A9W and F9W emission designators for each frequency band as *placeholders only* in lieu of finalized technical specifications, which the SDR Forum will submit to the Commission as soon as they are available.

Radio spectrum will continue to become more saturated as devices are invented to satisfy consumer demand for safety, convenience and entertainment. The competition enabled by this event will impact the advancement of cognitive radio technology, and, as a result, promote greater spectral efficiency. Accordingly, SDR Forum respectfully requests that the Commission grant this application as expeditiously as possible.

EXHIBIT 1

SDR Forum Smart Radio Challenge Written Qualification Submittal Preparation Instructions and Requirements

This document provides instructions for the creation of qualification submittals (Proposal) in Phase 1 of the SDR Forum Smart Radio Challenge. The goal of the proposal is to provide sufficient information so as to persuade the Phase 1 panel of judges that the team is qualified for advancement to Phase 2. Further, should more than 10 teams respond in any one topic area, the proposal will be utilized to down select from qualified teams to a maximum of 10. The Phase 1 panel of judges will evaluate the submitted proposal as follows:

- Overall technical approach (50%)
- Maturity of design process (10%)
- Use of materials provided by the corporate sponsors (10%)
- Feasibility and performance (10%)
- Commercial Viability (10%)
- Documentations and Deliverables (10%)

The quality of technical content of the proposal will be the principle basis upon which proposals will be evaluated. The proposed research and development must be responsive to the chosen Problem as selected from the Smart Radio Challenge Problem Set (Appendix 1), although it need not use the exact approach specified in the Problem. Each proposal must address only a single Problem.

Limitations on the Length of the Proposal

The Smart Radio Challenge is designed to reduce the investment of time and cost to student teams in preparing a written qualification submittal. Those who wish to respond shall submit a direct, concise, and informative research and development proposal of no more than 25 pages. Promotional or non-project related discussion is discouraged. In the interest of equity, pages in excess of the 25 page limitation, except as defined below, will not be considered or reviewed.

Format of Proposal

The proposal shall be submitted in English only. Pages shall be of standard 8.5” x 11” paper with one-inch margins. The type font shall not be smaller than 10 points. Engineering drawings, etc. may be provided on 11” by 17” (folded) paper should the team so choose, but these drawings will count as 2 pages in the 25-page count. Student teams shall choose a team name, and this name must be in the header of each page along with the Problem number. The footer must include the page number. Specific proposal sections that must be addressed are as follows.

Proposal Cover Sheet

The proposal coversheet shall include the team name as well as the names of the university, the team lead, and the technical advisor. Contact information for the team lead shall also be provided. The names of the other team members may also be included at the team's discretion. The Smart Radio Challenge Problem that the team has selected shall be stated, and a brief technical abstract shall be provided outlining key challenges in the Problem and the university team's proposed solution. The cover sheet is limited to one page in length, and counts as one page of the 25-page count.

Note that the information contained in the cover sheet of proposals selected for advancement to phase 2 will likely be published on the smart radio challenge website.

Problem Overview

In this section, the team must provide an overview of the Problem and the key challenges/risks they perceive in addressing the problem. The problem overview is limited to one page in length, and counts as one page of the 25-page count.

Technical Proposal

The technical proposal shall be limited to no more than 18 pages and counts as 18 of the 25 page count. It will include four subsections as follows:

- Proposed Solution - This subsection shall provide an explicit detailed description of the team's proposed solution to the problem. This section may include preliminary designs, analysis, simulations, etc. as defined by the team. Key elements that should be addressed in this section include, but are not limited to:

    - Trade-offs that were made in defining the proposed solution
    - Ability of the proposed solution to address the defined Problem
    - Technology readiness of the proposed solution
    - Size, weight and power of proposed solution
    - Constraints inherent in the proposed solution

- Risk Assessment - In this section, the teams shall identify the primary risks (cost, performance, schedule) in creating the proposed solution and what the plan is for mitigating those risks.

- Deliverables – In this subsection, the teams shall detail the proposed deliverables, including engineering notebooks, hardware and software documentation, source code, view cell presentations, papers, and demonstrations. Deliverables should include, at a minimum:

- Problem specific deliverables, as defined in the Smart Radio Challenge Problem Set, with supporting documentation
  - A one-page monthly status report detailing progress that has been made to date, as well as identifying issues that have come up, and how these issues are being addressed.
  - Engineering Notebooks, showing daily work entries, written in English, from each team member, detailing the work that was performed, the design process that was followed and the trade-offs that were made
  - Anticipated published papers, with proposed publication dates. A minimum of one publishable paper must be produced in Phase 2.
  - A “final report” detailing what was accomplished and what was learned.

- Materials - In this subsection, the teams shall identify the materials they intend to utilize in the creation of the proposed solution. This includes a description of the use of materials provided by the corporate sponsors, as well as materials from other sources as appropriate. It is recognized that additional sponsors may offer their products during the proposal development time, or even during the development phase. The SDR Forum will make additional sponsor product notification to all teams if additional products are offered. The total cost of the resulting design, including assembly costs, will also be outlined in this section.

Work Plan

In this section, an explicit detailed work plan for creating the proposed solution shall be provided. The work plan must detail the development process that will be followed and include a schedule that identifies key milestones with that development process. The planned role of each team member in achieving said milestones must also be identified, and a schedule of deliverables must be included. The Work Plan must not be more than 3 pages, and will count as three pages of the 25-page count.

Facilities

In this section, the student team will identify the physical facilitates that they will utilize in creating the proposed solution. This includes identifying laboratory space, test equipment, fabrication facilities, etc. Also state whether the facilities where work will be performed meet environmental laws and regulations of federal, state, and local governments for, but not limited to, the following groupings: airborne emissions, waterborne effluents, external radiation levels, outdoor noise, solid bulk waste disposal practices, and handling of toxic and hazardous materials. The facilities description shall be no more than 2 pages in length and will count as two pages in the 25-page count.

Intellectual Property

All information that is either provided in the proposal, or will be used in the creation of the proposed solution, and is considered the protected intellectual property of the university or 3rd party affiliate must be identified. This material does NOT count towards the 25-page count.

Curriculum Vitae of Team Members

A resume or Curriculum Vitae of no more than 2 pages shall be provided for each member of the team. This material does NOT count towards the 25-page count.

Proposal Section Markings

The proposal sections shall be marked as follows:

Cover Sheet – No marking
1.0 Problem Summary
2.0 Technical Proposal
- 2.1 Proposed Solution
- 2.2 Deliverables
- 2.3 Materials
- 2.4 Risk Assessment

3.0 Work Plan
4.0 Facilities
5.0 Intellectual Property
6.0 Curriculum Vitae

Smart Radio Challenge Terms and Conditions

The faculty advisor and a representative of each teams university must sign the "Smart Radio Challenge Terms and Conditions" included in Appendix 2. This signature is the confirmation of the team members that they will abide by all rules of the contest and of the sponsors, and that the faculty advisor will monitor and affirm that the team has done so. The signed document must be returned with each proposal in order for the proposal to be considered. The terms and conditions document does not count towards the 25 page limit.

Delivery

Electronic delivery of the proposal must be made no later than midnight GMT (8:00 PM US-EDT) 30 September 2006. Proposals should be in PDF format and should be emailed with the subject line "Radio Challenge Proposal from team <team name>_" to info@sdrforum.org. Teams may follow up with paper proposals should they so choose.

Questions during Phase 1

Student teams are encouraged to ask questions of the SDR Forum during the phase 1 development. Questions and responses will be posted on the Radio Challenge website in a Phase 1 FAQ.

SDR forum

Smart Radio Challenge '07

Appendix 1
The Problem Set

Problem 1: Spectrum Access for First Responders

The Scenario:

You are a first responder on the scene following a major earthquake. To effectively do your job, you need share significant amounts of data with other first responders including, for example, digital video, high-resolution pictures, high-resolution maps, and building floor plans. However, given the number of responders on the scene, the airwaves are clogged and you can't send or receive the necessary data in a reliable manner using your conventional radio technology, and communications is compounded by urban propagation conditions. You are very concerned that your inability to communicate information quickly to the proper recipient is costing peoples lives.

The Challenge:

Develop a smart radio system that will automatically find available spectrum within a pre-defined band, rendezvous with the intended receiver, and transmit data over that band with a pre-defined QoS, in urban conditions.

The Problem in Detail:

Students will develop a cognitive transceiver system capable of detecting available 25 kHz of available bandwidth in the 5 MHz FRS Frequency Band (462 to 467 MHz).

- The system must establish a data transmission channel supporting a QoS setting selected by the user. At least 2 QoS settings must be demonstrated: one with 16 kbps, QPSK, Reed Solomon channel coding, CVSD vocoded voice, and the other showing a computer to computer link at 19.2 kbps using 8-PSK and a rate ½ convolutional channel code. Protocols beyond the physical layer are not defined and will be proposed by student teams as appropriate.
- In establishing this channel, the system may operate in a master-slave mode, with one radio paging the other radio on an available channel to establish the communications, or in infrastructure mode, with the channel between the two transceivers assigned by a 3rd infrastructure radio (which would be mounted in, for example, a command vehicle) that is monitoring the spectrum, or in another mode proposed by the students. Radio source and destination must accomplish rendezvous with each other (and infrastructure when tested in that mode) without producing interference to any other active communications traffic. Student teams will propose how interference will be quantified within this context.
- It must be possible to switch between the two QoS settings while in operation, with the procedure for switching and switching speed to be proposed by the student teams.

- The demonstration must show how a legacy FRS user can become active in using the channel, and the voice or data transmission automatically moves to another available channel without loss of service, while managing delay, and delay jitter.
- The demonstration shall show that the spectral properties of the transmitter are FRS specification compliant. How this is to be demonstrated is to be proposed by the student teams.

Problem 2: Communications Interoperability

The Scenario

A major forest fire has occurred in Southern California. This fire has spread out of control and has forced a number of local communities to evacuate as the fire approaches their homes and offices. Fire fighters and other emergency responders from organizations and jurisdictions nation wide have responded to this emergency, with each group bringing their own equipment. Unfortunately, the radio equipments from the various jurisdictions are not interoperable with each other or with the civilian radio infrastructure, and this lack of interoperability is causing a huge problem in coordinating efforts. Without a way to allow these various radio equipments to interoperate, this lack of coordination has put the responders at risk, and has forced many front line responders to carry several radios to allow an appropriate level of inter-organizational communication.

The Challenge

Develop a smart radio terminal that can automatically provide interoperability between radios with different modulations, voice, and network protocols, and which knows how to forward messages to the proper network – be it commercial or civil.

The Problem in Detail

Develop a single channel wireless terminal capable of detecting and interoperating with any one of three types communications systems: An AM citizens band radio, an FRS narrowband FM radio, and a digital cordless phone operating in the 900 MHz ISM band (902 to 928 MHz):

- Means must be provided to define the allowed spectrum usage policies to each mode of the radio, as if it were done by the regulatory body of the country in which the radio is operated
- Means must be provided for the using organization's telecommunication manager to define the frequency channels used by that organization within the allowed usage bands (CB, FRS, 900 Mhz).
- The wireless transceiver must automatically detect when any of the three types of communications are "on the air" and the load the appropriate air interface standard onto the terminal to communicate on that channel.
- If more than one waveform channel is being available, the terminal must notify the user and allow the user to select which channel to communicate with. The student team will propose a concept of operation to address this contingency
- The system should demonstrate bridging between multiple available services, such as allowing 3 way calling between the CB, the FRS radio, or the cordless phone, according to a connectivity plan specified by the communication system manager
- The system must follow the modulation type, frequency channelization, and power level following regulatory policies appropriate for each band:

  Policy:

CB must use 90% peak AM modulation, 10 Khz channelization between 26.965 and 27.405, using only the 40 numbered allowed CB channels, with a maximum power level of 1 watt.
FRS must use 10 Khz deviation NBFM with a 40 HZ PL tone squelch, 25 Khz channelization between 462.5625 and 467.7125 using only the 14 numbered channels, with a maximum power level of 0.5 watt
The cordless phone must use 16 Kbps CVSD encoded voice, modulated +/- 8 Khz FSK with 50 Khz channelization between 902 and 928 Mhz, with a maximum power of 0.1watt.

- The demonstration shall show that all modes are compliant with the spectrum requirements corresponding to that mode.

Problem 3: Traffic Management

The Scenario

You are driving into work, and the freeway is a parking lot. You listened to the traffic report on the radio, but given that the weather is poor, there are a lot of accidents, and as such there wasn't really a lot of information you could use to choose an alternate route. As you sit there with your engine running, watching your gas gauge move towards empty, you think to yourself that there must be a better way to manage these kinds of traffic problems.

The Challenge

Develop a smart radio system that can, using available spectrum, accurately detect the location of many vehicles within the city and assess the velocity along common roadways. The system will then provide user specific route guidance from starting point to ending point which will minimize total fuel consumption. The system must be future proof, to allow new features and capabilities to be added over an expected 10-year life span of the vehicle without requiring a visit to the dealer.

The Problem in Detail

Develop a traffic management system using smart radio technology that can track and report the location and velocity of a large number of radio controlled vehicles (at least 6) on a defined test track (to be presented at test time). Vehicular velocity will be monitored to determine obstruction. Best route guidance will be provided to at least one vehicle to avoid traffic.

- The system must work with an off the shelf radio controlled vehicle. One example of such a vehicle is the following: http://www.radioshack.com/product/index.jsp?productId=2123167&tab=techSpecs,
- The on-board radio "tag" must be mounted to the vehicle in a manner that allows the vehicle to operate in a normal manner
- When the radio tag is turned on, it must "register" with the traffic management system's infrastructure. The control link must operate in either the FRS band, or the IEEE 802.11 ISM band and can use any air interface standard and protocol of the students choosing so long as it doesn't interfere with any existing FRS or 802.11 radio communications.
- The system must track each vehicle's position versus time, and report average velocity, for at least 6 simultaneous vehicles. The algorithmic mechanism for identifying position, and velocity is left as an exercise to the students.
- The system must automatically control at least one vehicle to maneuver it over a predefined course associated with the location of that vehicle. Each course will include a straight route and a twisty route, with the route taken selected by the user monitoring the infrastructure system. Demonstration of this capability will take place at the SDR '07 Technical Conference, where a route will be established using orange cones in a parking lot of suitable size.

- The radio tag must be software defined and the waveform modulation (phy) and MAC and Link protocols must be reprogrammable.

Problem 4: Rapid Application Development

The Scenario

You are the lead system engineer for a mobile radio terminal that is going to be used by an oil exploration team. The details of the communications link required by this team are in flux, and will not be finalized until after you arrive at the site. You know that you have developed the radio hardware specifically to support these types of quick response requests, including the use of programmable processing devices such as FPGAs and DSPs for implementing the air interface, but are concerned that you may not have developed the platform's software infrastructure sufficiently to support the tight time frame for this request.

The Challenge

Develop two smart radio terminals and demonstrate a process that will allow them to communicate using a new advanced air interface standard that is developed and deployed on the terminals in less than 24 hours.

The Problem in Detail

Develop two smart radio terminals that will communicate in the FRS frequency band.

- The terminals will incorporate processing devices capable of supporting transmitted data rates from 16 kbps to 6 Mbps
- Payload data ingress and egress for the terminals will be via an on-board 10/100 ethernet port.
- The terminal's architectural model must include a well defined operating environment with an application framework (such as the SCA core framework).
- In support of their development process, the student must develop a mechanism for standardizing the application interfaces of the various processing devices in the terminal (FPGA, DSP, GPP, etc.). The mechanism must support both intra and inter device communications and may be based on an industry standard such as CORBA, OCP, the IT-API, OpenClovis, etc. or it may be developed by the students teams to address their specific needs. As a part of this development, a trade-off analysis must be performed showing the impact on size, weight, power, cost and waveform portability in adopting the mechanism
- Students will develop and demonstrate a process that will allow them to create, download, and test a complex digital air interface onto the terminals in less than 24 hours. Possible parameters that may be required include:

    - Multiple Access – FDMA, CSMA
    - Multi Carrier: OFDM (128 Point FFT, 1 to 32 carriers modulated with traffic, 10% pilot channels, 10% cyclic redundancy,)
    - Carrier Modulation Types: BPSK, QPSK, 8PSK, 16QAM
    - FEC: Reed Solomon, Viterbi
    - Diversity selection, Optimal combining, MIMO

- Students will demonstrate their waveform development process efficiency, and the sophistication of the radio architecture infrastructure to be able to support a new waveform requirement.
- Demonstration of the terminals architecture and the efficiency of their waveform development process will be as follows: At the SDR ’07 Technical Conference, each student team will be handed an envelope containing a pre-defined “air interface specification”. The student teams will then have 24 hours to create, download, and demonstrate this waveform. This process will be timed, and once their development is complete they will contact a judge to have their completion time recorded. Final demonstrations will occur the next day.
- Student teams must propose a mechanism for validating that the waveform is running as defined during the demonstration process.

Appendix 2
Terms and Conditions

I / we certify that we agree to follow all rules of the Smart Radio Challenge contest, as described on the web page www.radiochallenge.org/rules.html,
And as further explained on www.radiochallenge.org/FAQ.html

I / we agree to all terms and conditions of license for all tools and products provided to our team from the sponsors of the Challenge. If we are unable to agree to the terms and conditions associated with any sponsor product, we will notify the SDR Forum of this condition, and will return the associated tool or product to the SDR Forum. At the conclusion of the contest, we agree to return tools or products and to remove these tools and products from the computers on which they were installed, if that is a condition of the sponsored product license.

I / we agree to identify all intellectual property used, to include references to publications by others used in this development, and to abide by international intellectual property rights, patents, and copyright law.

- - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - -
Printed name of teammate 1	Signature of teammate 1	date
- - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - -
Printed name of teammate 2	Signature of teammate 2	date
- - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - -
Printed name of teammate 3	Signature of teammate 3	date
- - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - -
Printed name of teammate 4	Signature of teammate 4	date
- - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - -
Printed name of advisor	Signature of advisor	date
- - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - -
Printed name of Team	Printed Name of University	date

EXHIBIT 2

SDR Test Procedure Specification

Spectrum Access Radio for First Responders

Table of Contents

1 Introduction

1.1 Description of Feature(s) to Be Tested

There are 3 layers of the design that were defined in the proposal. The Radio Frequency Layer (RFL) is responsible for upconversion, downconversion, and frequency scanning for open channels. The physical layer (PHY) is responsible for implementing the two quality of service (QoS) settings given in both modulation and demodulation. The protocol layer (PROT) is responsible for all upper level functions such as packet building, initial handshaking between radios, file handling, etc. Each of these layers will be tested individually for their key functional features, as shown below. The entire system (SYS) will then be tested for its functionality.

Layer	Key Features	Component(s)	Figures of Merit
RFL	Frequency Scanner Algorithm	FPGA, RF unit	Scan Time, False Positive Probability
PHY	Dual QoS Implementation	FPGA, RF unit	Conformity to FRS Specs. in Frequency domain, Time lag for switching protocols
PROT	Initial Handshaking, Situational adjustments for each of 3 implemented protocols, packet construction for data	DSP	Percentage overhead for each packet. Time required for initializing communications and adjustments for interference mitigation.
SYS	Ability to transmit data from one sender to other in various RF interference environments	FPGA, DSP, RF unit	Interference Detection and Adjustment time, effective data rate under interference scenarios defined in 3.

1.2 References

Document(s)	Location	Version
SDR challenge Proposal.doc		1.0

1.3 Time Estimates

Task	Duration (Number of Days)
Test Planning	45
Test Setup	14
Test Execution	45

NOTE: **Test Planning** includes all Review Design Document(s), Resource Allocation, Time-Line/Sequence of Events, Environment needs, Data needs, Tools, etc. as well as TPS Generation.
NOTE: **Test Setup** includes Installation only.

2 Test Organization

2.1 Test Environment

Hardware	Function	Notes / Special Setup
Windows XP PC	Running Matlab with Simulink and Code Composer Studio	Running Xilinx ISE IP version 8.2.2 and SP update 8.2.03i for Xilinx Simulink blockset

Xilinx Virtex-4 SX-35 FPGA	Physical Layer and intermediate frequency signal processing	This component Implements Modem functionality as well as the spectrum search routine to find open spectrum.
Texas Instruments DM6446 DSP Chip	Protocol Layer	This component implements all upper layers, packet building, and channel coding.
Lyrtech Custom RF transceiver unit	Radio Frequency conversion and amplification	Two of the Lyrtech boards containing FPGA, DSP, and RF upconversion units will be employed to verify all handshaking between the units.

2.2 Tools

Tool(s)	Role	Notes
Matlab Simulink w/ Xilinx System Generator Plugin	Employed to design and debug all FPGA Routines	
Code Composer Studio	Employed to design and debug all DSP Routines	
Agilent Signal Generator E4433B	Generates Interference signals for Testing Purposes	A baseband unit will be employed to produce channelized interference.
Tektronix TDS 210 Oscilloscope	Employed to test baseband modulated waveforms	
Rohde & Schwarz FS300 Spectrum Analyzer	Employed to test RF properties of signals and interference	

2.3 Testers

Tester(s)	Responsibilities
Travis Axtell	Application testing, RFL development and document creation
Joel Simoneau	Application testing, PHY development and document creation.
Brandon Bilinski	Application testing, PROT development and document creation

3 Test Approach, Strategy and Cases

3.1 Feature(s) to Be Tested

3.1.1 Physical Layer

3.1.1.1 QoS 1 implementation: 16 kbps, QPSK, Reed Solomon channel coding, CVSD vocoded voice.

3.1.1.2 QoS 2 implementation: 19.2 kbps, 8 PSK, rate ½ convolutional channel code.

3.1.1.3 Switch Time between the two QoS.

3.1.1.4 Each of these QoS settings will be tested both at baseband and at Radio frequency to ensure FRS specification compliance.

3.1.2 Protocol Layer

3.1.2.1 Test basic functionality (handshaking, packet building, and interference adjustment) for each of 3 protocol modes (Master-Slave mode, Infastructure Mode, and Reserved-Channel Mode).

3.1.2.2 During Reserved Channel mode, a certain number of channels can be set as rendezvous channels. The numbers below will be tested to see how the radios respond. A resulting tradeoff between speed of acquisition and the handshaking radio capacity will be formed.

Percentage of Channels	Number of Rendezvous Channels
5%	10 Channels
10%	20 Channels
15%	30 Channels
20%	40 Channels

3.1.2.3 Test the difference between putting radio silence in each packet to sense interference versus every few packets. This will develop a tradeoff between packet overhead and ability to adapt to a quickly-changing RF environment.

3.1.3 RF Layer

The FPGA frequency scanning algorithms will be simulated under various radio frequency environments.

Description	Technical Description
Low-level RF interference	>100 Open channels
Mid-level RF interference	10-100 Open channels
High-level RF interference	<10 Open channels

Each algorithm will be tested under scenarios where various groups of channels go into use to determine if the algorithms detect and respond appropriately. These scenarios will include:

- Block of lower-channels being used (channels 0-20)
- Block of higher-channels being used (channels (180-199)
- Block of middle-channels being used (channels (90-110)
- Blocks of random amounts of channels being used for each interference level listed above in the table.

The algorithms will be marked as successful upon completion of the above tests.

3.1.4 System Functionality

3.1.4.1 Verify that a *.jpeg image that is 300x300 pixels with color 0xFF0000 (primary red) sent from one unit to the other in QoS 1 is received with all pixels intact at that color for all three protocol modes.

3.1.4.2 Verify that a heavily multicolored *.jpeg image (such as one taken with a digital camera) can be sent from one unit to the other in QoS 1 for each protocol mode will be received without error.

3.1.4.3 Verify that a Vocoded voice signal sent over QoS 2 for each protocol mode will be received without error.

3.1.4.4 Send the Vocoded voice file interspersed through the jpeg image to demonstrate switching between QoS settings.

3.1.4.5 Repeat steps 1-4 for each of the interference settings listed below.

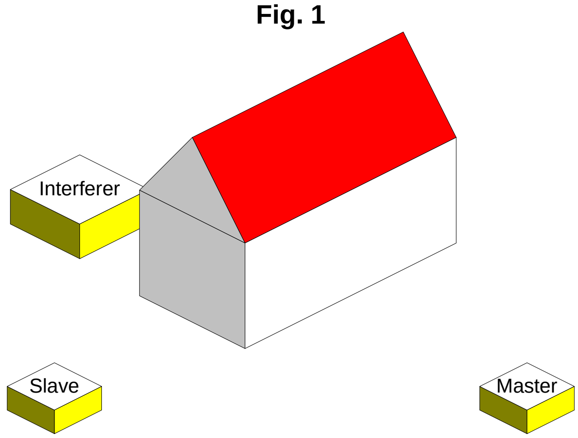
(a) Primary Channel Interference: System must rendezvous at 1 of 2 backup channels and continue communication.

(b) Catastrophic Interference: All three selected channels contain interference and the search routine must be repeated.
(c) Single-user Interference: Only one of two units experiences interference, leaving the second unit unable to communicate with the first (shown in figure 1 below).

3.1.4.6 Allow each of the interference settings above to occur in the acquisition stage of protocol and the stage in which communication has been established.

3.1.4.7 Determine the response of the system to changes between each of the three interference settings.

Fig. 1



SDR Forum Smart Radio Challenge 2007

University:

SUPELEC

Team name:

MENHIR
Multi-standard ENHanced Interoperable Radio

<u>Team lead:</u>
Hongzhi WANG

hongzhi.wang@supelec.fr
+33 2 99 84 45 36

<u>Team members:</u>
Loïg GODARD
Fabien LABORDE

<u>Technical advisor:</u>
Prof. Christophe MOY

Problem #2:
Communications interoperability

Test Plan

1. Test plan

Each problem (1 through 4) will require a Test Plan to evaluate the objectives of each problem's solution. The test plan should cover any evaluation criteria not submitted as part of the Phase 2 documentation which is due September 30 2007. The Test Plans are due from each team to the SDR Forum by May 1 2007; comments will be returned to teams by June 15.

Each team may have a different test plan due to the unique solution for their chosen problem. But each problem's test plan must cover the problem objectives below, no matter what type of solution is proposed.

Problem 2

The test plan must show:

1- Interoperability between N air interface standards

   a. N is chosen number of interoperable air interface standards that will be demonstrated

Number of standards N: at least N=2 (CB and FRS), and if possible N=3.

The demonstration will be based on 2 transceivers systems: SystemA and SystemB. Interoperability means that each system is able to communicate with any of the N standards. Two main aspects are connected to standard: the modulation (FM, AM, digital FM) and the carrier frequency band.

We recall that to each standard, a set of pre-defined channel couples exist for transmission from SystemA to SystemB at a given frequency, associated with transmission from SystemB to SystemA at another given frequency.

The number of channel couples for each standard is P. At least, P equals 2.

The following table gives an example for N=2 and P=2

standard 1	channel α_{A1}	SystemA Tx for standard 1 SystemB Rx for standard 1 coupled to channel α_{B1} for “reverse” link
	channel β_{A1}	SystemA Tx for standard 1 SystemB Rx for standard 1 coupled to channel β_{B1} for “reverse” link
	channel α_{B1}	SystemB Tx for standard 1 SystemA Rx for standard 1 coupled to channel α_{A1} for “forward” link
	channel β_{B1}	SystemB Tx for standard 1 SystemA Rx for standard 1 coupled to channel β_{A1} for “forward” link
standard 2	channel α_{A2}	SystemA Tx for standard 2

		SystemB Rx for standard 2 coupled to channel α_{B2} for "reverse" link
	channel β_{A2}	SystemA Tx for standard 2 SystemB Rx for standard 2 coupled to channel β_{B2} for "reverse" link
	channel α_{B2}	SystemB Tx for standard 2 SystemA Rx for standard 2 coupled to channel α_{A2} for "forward" link
	channel β_{B2}	SystemB Tx for standard 2 SystemA Rx for standard 2 coupled to channel β_{A2} for "forward" link

Table 1: SystemA and SystemB channels for N=2 and P=2

This means that for each standard, SystemA has P possible transmission channels (α_{A1}, β_{A1} for standard 1, α_{A2}, β_{A2} for standard 2) which correspond to the P possible reception channels of SystemB.
This means that for each standard, SystemB has also P possible transmission channels (different from those of SystemA: α_{B1}, β_{B1} for standard 1, α_{B2}, β_{B2} for standard 2) which correspond to the P possible reception channels of SystemA.

Note that we are not sure yet to manage communications for each standard in the allocated frequency bands (27 MHz for CB, 465 MHz for FRS and 900 MHz for Cordless Phone).
Moreover, considering our proposal of September 2006, as our approach is full-duplex, channels α_{A1}, β_{A1}, α_{B1}, β_{B1} (respectively α_{A2}, β_{A2}, α_{B2}, β_{B2}) are supposed to be in the same band of standard. On the one hand, α_{A1}, β_{A1} (respectively α_{A2}, β_{A2}) have been declared to be located in the lower band of standard 1 (respectively standard 2), on the other hand α_{B1}, β_{B1} (respectively α_{B2}, β_{B2}) have been declared to be located in the upper band of standard 1 (respectively standard 2).
Maybe some adaptation will be done because of RF issues, but without any loose of generality concerning the interoperability issue. The coupled channels may require to be more spaced in frequency than the original proposal.

2- Where interoperability software is loaded in the new terminal
   a. Or state the assumptions regarding loading of interoperable software

Each system is initially configured with its own standard: SystemA runs with Standard1 if it for instance belongs to the police, and SystemB runs with Standard2 if it is for instance belongs to the firemen.
But each system integrates here capabilities to switch to other bands and other standards by construction. The corresponding reconfiguration code is stored in the host-PC memory and the DSP memory.

The interoperability phase (described hereafter at question 3) is manually launched by the user of a system and then automatically operates the scanning scenario.

Note that there is no plan to change a normal system to an interoperable system. The system is interoperable by construction.

3- What initial conditions are assumed or demonstrated to establish initial communications across different air interface standards

This is the procedure for interoperability operation.
One system, SystemA, starts operating. It consists first in listening to signals in each of the P bands of each of the N standards by round robin, starting in its own default standard. Dynamic reconfiguration is planned to support this procedure. When all the P bands of the N standards have been processed in vain (no signal detected), SystemA changes to transmitting mode. This means that SystemA continuously transmits a beacon in its own default standard and assigned band. Two reasons may stop it:

- case 1: either a timeout (that can be fixed at 1 minute) expires,
- case 2: or another system connects to it (SystemB),

In case 1, SystemA comes back at the beginning of the procedure and listens again to all bands and standards by round robin.
In case 2, discussion begins with SystemB: the connection is done, as SystemB obtained the connection with SystemA while applying the same procedure. SystemB detected SystemA's beacon in one band of one standard and automatically transmitted its own signal in the corresponding coupled band that Rx of SystemA is listening to.

4- Show the capability of forwarding messages from one type of network to another type of network
  a. State any assumptions made for this interoperation to be accomplished

As only two systems are available, the forwarding or translating operation can only be run this way:

- SystemA transmits in one standard towards SystemB that demodulates this standard,
- SystemB answers to SystemA in another standard.

This implies new requirements to our framework. It particularly means that the couple of transmit/receive frequencies (given in Table 1) associated to SystemA on the one hand and SystemB on the other hand have to be changed. This implies a new assignment of frequency couples as given in Table 2. This is a different mode from interoperability mode of question 3. The mode the demo should run has to be previoulsly specified.

standard 1	channel α_{A1}	SystemA Tx for standard 1 SystemB Rx for standard 1 coupled to channel α_{B2} for inter-standard "reverse" link
	channel β_{A1}	SystemA Tx for standard 1

		SystemB Rx for standard 1 coupled to channel β_{B2} for inter-standard “reverse” link
	channel α_{B1}	SystemB Tx for standard 1 SystemA Rx for standard 1 coupled to channel α_{A2} for inter-standard “forward” link
	channel β_{B1}	SystemB Tx for standard 1 SystemA Rx for standard 1 coupled to channel β_{A2} for inter-standard “forward” link
standard 2	channel α_{A2}	SystemA Tx for standard 2 SystemB Rx for standard 2 coupled to channel α_{B1} for inter-standard “reverse” link
	channel β_{A2}	SystemA Tx for standard 2 SystemB Rx for standard 2 coupled to channel β_{B1} for inter-standard “reverse” link
	channel α_{B2}	SystemB Tx for standard 2 SystemA Rx for standard 2 coupled to channel α_{A1} for inter-standard “forward” link
	channel β_{B2}	SystemB Tx for standard 2 SystemA Rx for standard 2 coupled to channel β_{A1} for inter-standard “forward” link

Table 2: SystemA and SystemB channels for N=2 and P=2 for forwarding mode

Test Plan

for

Traffic Management

prepared by

Universiti Putra Malaysia Team

Updated Team Members:

- Chong Jin Hui (Leader)
- Vahid Solouk
- Shola Aderuji
- Ahmed Mohamed
- Samaneh Rastegari

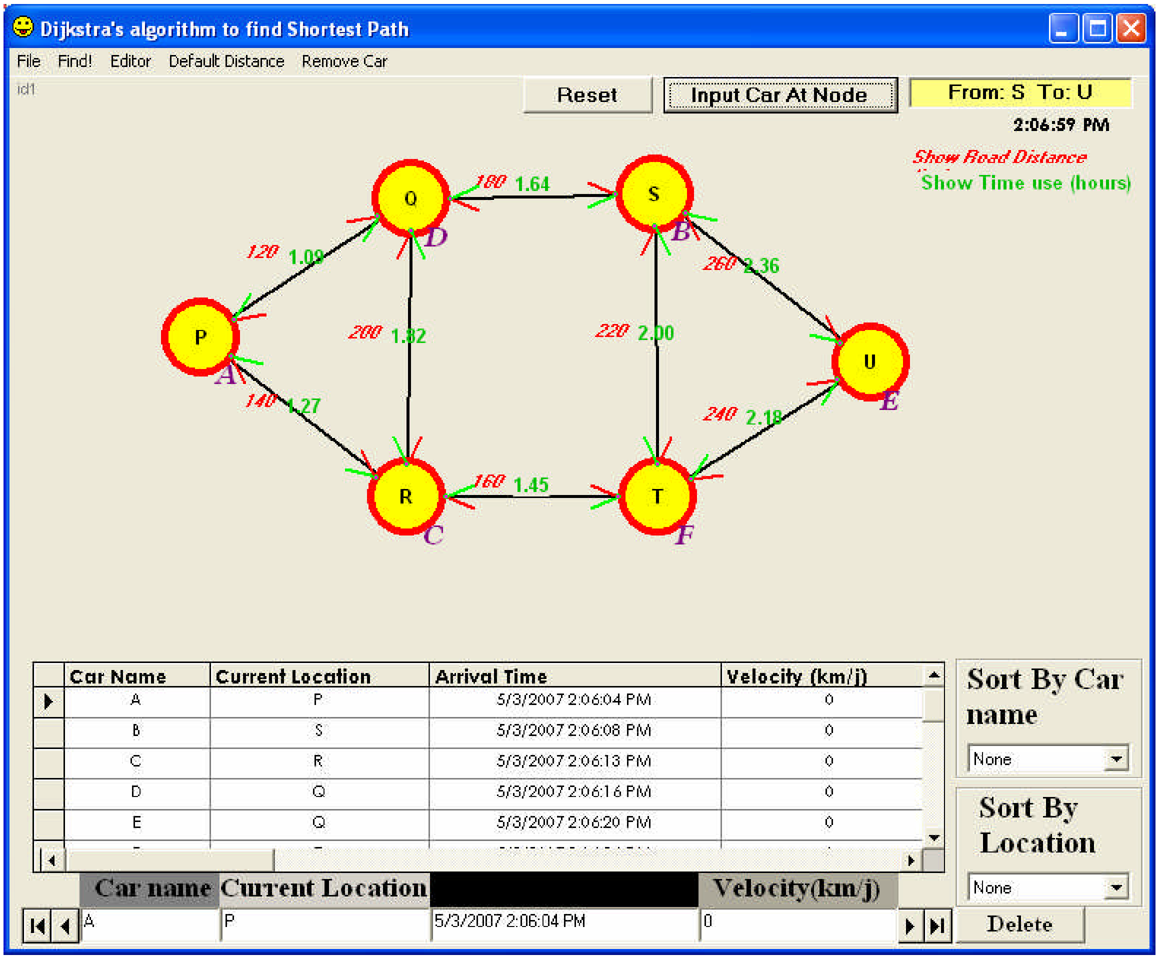
Updated Technical Advisor:

Associate Professor Dr. Sabira Khatun

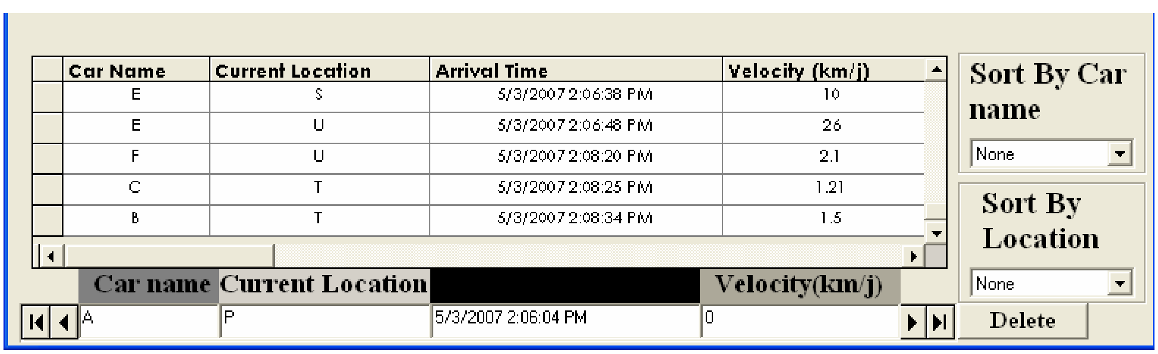
Department of Computer and Communication Systems Engineering,
Faculty of Engineering,
Universiti Putra Malaysia (UPM),
43400 UPM, Serdang,
Selangor,
Malaysia.
*Email: jinhui@eng.upm.edu.my
Tel: +603-8946 6446
Fax: +603-86567127

1. The required spectrum it uses/needs
The required spectrum is 433MHz and 315MHz

2. The solution detects where “many” (N) vehicles are located
The solution is able to detect 6 cars (A, B, C, D, E and F) simultaneously as shown below

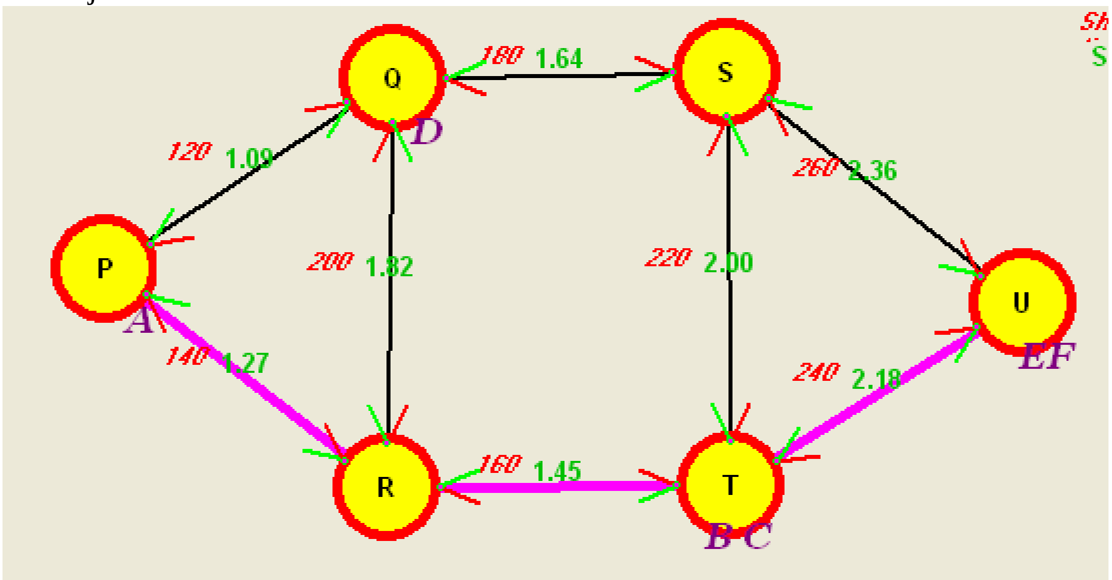


3. The solution assesses the velocity of the N vehicles
The solution shows that it can calculate the average velocity of 6 cars.

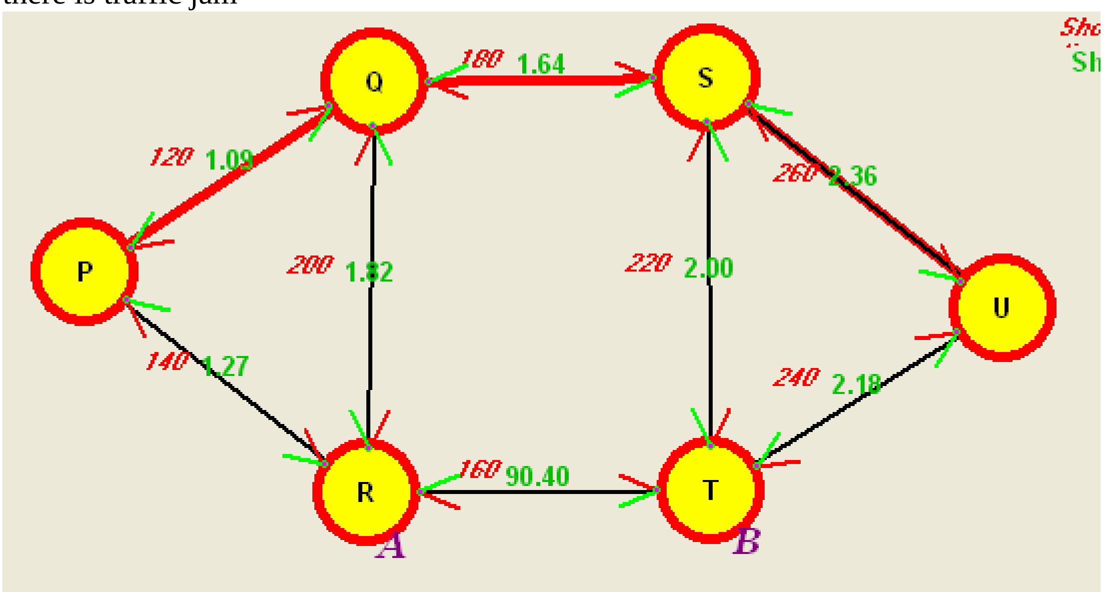


4. The solution can determine choices of routes available to minimize fuel consumption

The solution shows shortest path from P to U to minimize fuel consumption if there is no traffic jam



The solution shows shortest traveling time from P to U to minimize fuel consumption if there is traffic jam



5. The solution must have a way to determine how a route is selected

The solution shows the shortest path with 540 km via P, R, T and U.

The path is: U <- T <- R <- P

The total path distance is : 540 km.

The solution shows the shortest time with 540 km via P, Q, S and U

The path is: U <- S <- Q <- P

The average time use is: 5.09 hours.

6. How dynamics of the traffic and the user interact
There are some bugs on the program, we are still troubleshooting it currently

7. A demonstration of adding future capability (or capabilities)
Still in the process

SMART RADIO CHALLENGE

The Pennsylvania State University

Eric Menendez, *team lead*
213N Hammond Bldg, University Park, PA 16802
(610) 731-8350, eMenendez@psu.edu

Ken McKeever

Michael Sudick

Kenny Tang

Gaurav Vaidya

Sven Bilén, *advisor*
213N Hammond Bldg., University Park, PA 16802
(814) 863-1526, sbilen@psu.edu

SYSTEM TEST PLAN

System Test Plan

- ☐ Start radio bridge software via command prompt
    - Specify desired CB channel
    - Specify desired FRS channel
    - Specify desired system squelch setting
    - Specify desired CB receiver gain
    - Specify desired FRS receiver gain
- ☐ Wait until both radio channels are silent for several seconds
- ☐ Test the bridge at close range (standing in the same room)
    - While using a handheld CB radio to monitor the specified CB channel, broadcast a test message on the specified FRS channel with a handheld FRS radio. Verify that the message is received on the CB radio.
    - Using the handheld FRS radio to monitor the specified FRS channel, broadcast a test message on the specified CB channel with the handheld CB radio. Verify that the message is received on the FRS radio.
- ☐ Continue to test the radio bridge at increasing range until the maximum system range is determined.

Team MPRG Test Plan: Software, Hardware, and Dynamic Spectrum Access (MPRG-SRC-TestPlan_0.0.1)

contact: caguayog@vt.edu

May 1, 2007

Executive Summary

This document describes the master test plan for the Cognitively Intrepid Radio Emergency Network (CIREN) system developed by the MPRG Team for the Smart Radio Challenge. The scope of this test plan includes all testing activities in all developments areas: hardware test and characterization, software verification, and system validation.

The plan is organized in three chapters:

- Quality of Service and Dynamic Spectrum Access Test Plan
- Analog RF and Digital IF Hardware Test Plan and
- Master Software Test Plan

The first one describes the approach to validate system performance in terms of quality of service and spectrum access. It treats the system as a whole and describes test cases, scenarios, and assumptions used to validate the behavior of our system. In terms of quality of service, measurements will be taken to characterize the performance of our system against channel conditions. These measurements include data rates and critical delays that affect the overall connection time, latency, and jitter. As for spectrum access, test cases are developed to demonstrate correct operation from a regulatory perspective. These scenarios are designed to measure the impact of the CIREN system to licensed users of the FRS band.

The second chapter includes a description of scenarios and measurements designed to characterize and evaluate the performance of our digital and analog hardware modules. Different characteristics of our analog Tx and Rx hardware that have an impact on the overall performance of the system are measured. The interfaces between different subsystems are validated as well. This chapter describes the instruments and setups required to perform these measurements. For those required instruments not currently available in our facilities (e.g. anechoic chamber for antenna pattern measurements), we will try to borrow them from other laboratories in our university.

The last section describes the master software test plan. This includes the general approach to verify the correctness of our software artifacts and components. Major emphasis is placed on test automatization to speed up regression testing and to facilitate development and debugging. Because our software architecture follows the SCA, JTAP and WTT are required to test architectural compliance of our framework and waveforms. Another tool, oTest, is being developed along the rest of the system to automate the tests tasks not covered by JTAP and WTT. Besides automatic testing, regular peer reviews are followed to improve software quality in this development effort.

Given the experimental nature of the project, the approach and scope of this plan may change as development moves forward. When required, changes to this test plan will be executed and properly documented after being authorized by senior members of the team in coordination with faculty advisors.

Contents

List of Figures

Chapter 1

Dynamic Spectrum Access and Quality of Service Test Plan

1.1 Introduction

This section describes the general approach to validate and demonstrate the capacity of our system to meet the required Quality of Service (QoS) goals and its Dynamic Spectrum Access (DSA) abilities. Included in this section are test and measurement techniques, applicable and expected scenarios, and the underlying assumptions upon which the testing environment is based.

1.2 Attributes to test

In order to demonstrate that the CIREN radios are capable of meeting the proposed goals, the team will need to test a number of attributes of the radio protocol. The following sections describe the tests necessary to validate the performance of the CIREN system.

1.2.1 Quality of service requirements

Error rates; packet-level, bit-level While operating in data mode, erroneous packets will be retransmitted repeatedly until they are decoded correctly. This effectively results in a reduced throughput. While operating in voice mode, erroneous bits cannot be retransmitted without resulting in unacceptable delays. For this reason, a specific average BER will be targeted. The resulting bit errors will be apparent as audible degradations, however if the BER is kept sufficiently small (on the order of 1%) the quality should be sufficient, particularly for the CVSD codec. The error rates of decoded bits as well as packets will be tested to ensure the system operates within tolerable limits.

Packet re-transmission rate Packet re-transmission in data mode results in a degraded throughput. The CIREN system shall incorporate a logical closed-loop power control channel that should allow for minimal packet re-transmissions.

System throughput The two operational modes of the radios – voice and data – provide two different data rates. This chapter proposes a method for testing this metric to ensure these rates are achieved. There are several factors affecting throughput including modulating scheme, coding rate, TDD timing loss, excess bandwidth (pulse shaping), transition time loss, and spectrum sensing quiet time loss.

1.2.2 Dynamic spectrum access performance

Successful link rendezvous probability Successful link rendezvous is contingent upon many factors, including separation between master and slave nodes, the number of available FRS channels, and link quality.

Link rendezvous time The initial link rendezvous latency is defined as being the time between when a CIREN user presses the push-to-talk button and when the link is established (see Figure 1.6). This initial delay directly impacts the system's boot up time.

User detection capabilities Detection of incumbent primary FRS users (IPU) is of great importance to this system, and cognitive radio systems in general. Furthermore, detection of other secondary users is significant as well. Coexistence of heterogeneous radio protocols relies on the ability for devices to systematically and accurately detect and classify proximal radios in order to avoid causing harmful interference to one another. Furthermore, policies for shared spectrum techniques strictly define protocol for channel evacuation when IPUs are detected, and therefore evaluation of such capabilities must be a priority.

Link switching time If an FRS radio is detected on the current radio link, the CIREN radios must vacate the channel quickly to avoid causing significant interference to the primary user link. This comes at the risk of a service quality degradation to both the FRS users and CIREN radios and therefore shall be given particular emphasis while testing. A graphical representation of link switching time can be found in Figure 1.7.

Frame/Packet timing jitter Frame and packet delay associated with a TDD system results in potential timing jitters that can affect both system throughput and service quality. If the platform supporting a CIREN radio does not support real-time scheduling (a probable scenario) then the radio must rely on a coherent reception of a packet before transmitting a reply. In this event the time between frames might be inconsistent (see Figure 1.4).

Interference tolerance In addition to noise, the system will need to be robust to interference. In the event that all channels are occupied by both FRS users as well as other CIREN devices it might be necessary for several secondary users to share spectrum. For this reason it is necessary to test the performance of CIREN radios in the midst of digital RF interference.

1.3 Approach

The execution of this test plan is based on a set of different scenarios designed to exercise and demonstrate the different features available in the radio. The test methodology is based on a system approach and is designed as a form of acceptance testing. Due to the looseness in system specifications, some of the scenarios are designed to characterize the performance of the radio rather than to demonstrate compliance with specifications. However, for the specifications that are clearly defined (e.g. data rates), it is the intention to validate the performance of the system and provide a set of conditions that are required for the system to meet the specifications.

1.3.1 QoS Test Scenarios

The goal of these scenarios is to demonstrate that the CIREN system is capable of providing the required quality of service given the appropriate conditions.

The first and simplest scenario is designed to show the basic operation of the system and to provide baseline performance metrics. This scenario, shown in Figure 1.1, is used to demonstrate system throughput (as a function of channel conditions), interference tolerance, and spectrum efficiency. In this scenario a CIREN transmitter is connected directly to the receiver via a variable attenuator. Known data are transmitted and used to obtain error statistics for the system. This way the maximum rates for both voice and data are demonstrated. From this scenario an estimated signal to noise ratio is calculated based on the measured noise power during a silent transmission period. Using an arbitrary waveform generator and an analog mixer we can measure the response of our system to interference, as described in Figure 1.2. Using this approach in combination with systematic increments in the attenuation values, we can obtain a data rate vs SINR curve similar to the one shown in Figure 1.3 (Note that this Figure is only a depiction of the expected behavior of our system and does not contain meaningful data).

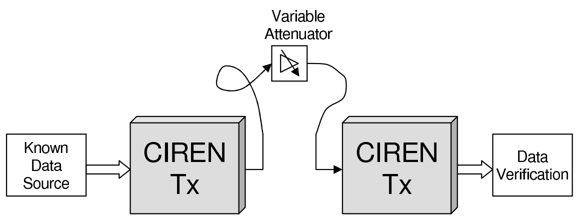


Figure 1.1: Simple QoS test scenario

An even simpler scenario is required to measure spectrum efficiency. To this end, the direct con-

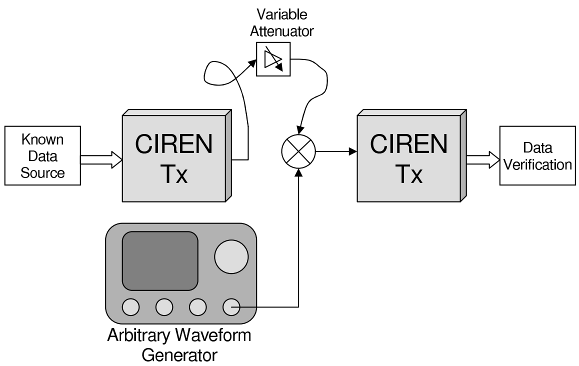


Figure 1.2: QoS test scenario to measure interference tolerance

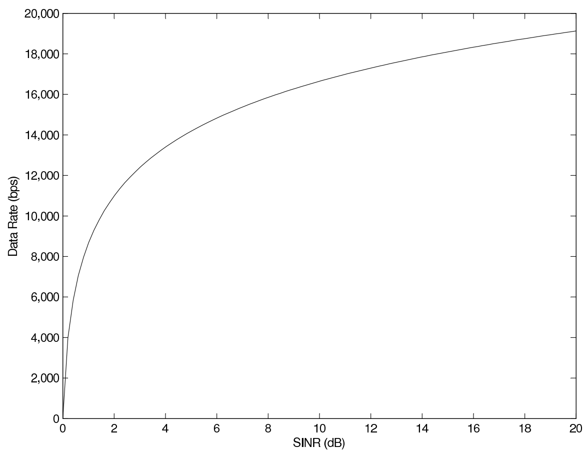


Figure 1.3: Expected data rate behavior as a function of SINR

nection between Tx and Rx is removed and replaced with dipole antennas. A spectrum analyzer is then used to validate the integrity of the transmitted signal and its compliance with spectrum policies.

The next scenario for QoS is intended to measure the frame/packet timing jitter. This is a measure of the delay variations each CIREN transceiver experiences during the transition between transmission and reception. In the CIREN protocol after the master node has completed transmitting a frame, it has to empty the channel and prepare to receive the reply from the slave node. These transitions will be measured with help from a modified software waveform in the master node that initiates transmitting a new frame as soon as the reply from the previous one is received. This operation is depicted in Figure 1.4 with the delay from transmission to reception in the master node represented by Δ_1, and by Δ_2 in the slave node.

Link rendezvous time is the time required to initially establish a connection. This will usually happen at startup, but it could occur after a period when no channels were available for use. The

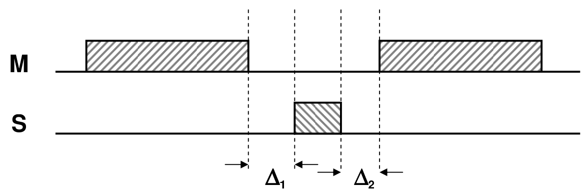


Figure 1.4: Frame/Packet timing jitter measurement operation

time required depends on the occupancy distribution of the FRS band, in the extreme it could go to infinity if the all the channels are occupied by incumbent users without interruptions. To measure this time, we will use the scenario shown in Figure 1.5. Here, an arbitrary waveform generator is used to dynamically emulate primary users occupying channels. The sequence of events in this scenario is described in Figure 1.6. The link rendezvous time is measured from the moment both radios are enabled until the connection is established and data is transmitted.

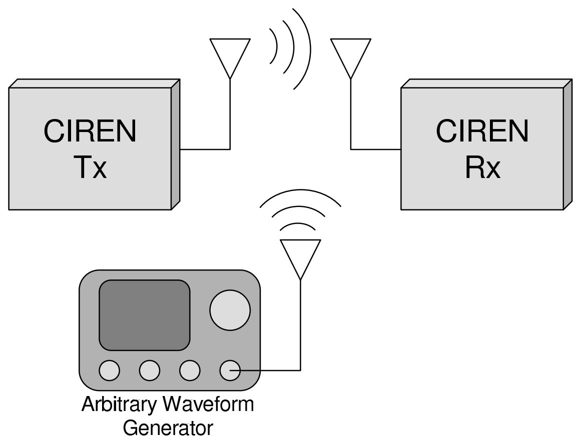


Figure 1.5: Link timing measurement scenario

The primary user channel occupation distribution is assumed to be normal and the probability of a given primary user to occupy a given channel is assumed uniform.

The same setup described in Figure 1.5 will be used to measure the link switching time, which is defined as the time required to switch the link from one channel to another after an initial connection had been established. This action will be usually triggered by the appearance of a primary user in the channel occupied by a CIREN link. This event will force the CIREN system to switch to the preestablished backup channels. The link switching time is measured from the moment the primary user starts interfering with the link until the connection is reestablished in a backup channel. This operation is shown in Figure 1.7. The link switching time is also dependent on the channel occupation conditions of the FRS band.

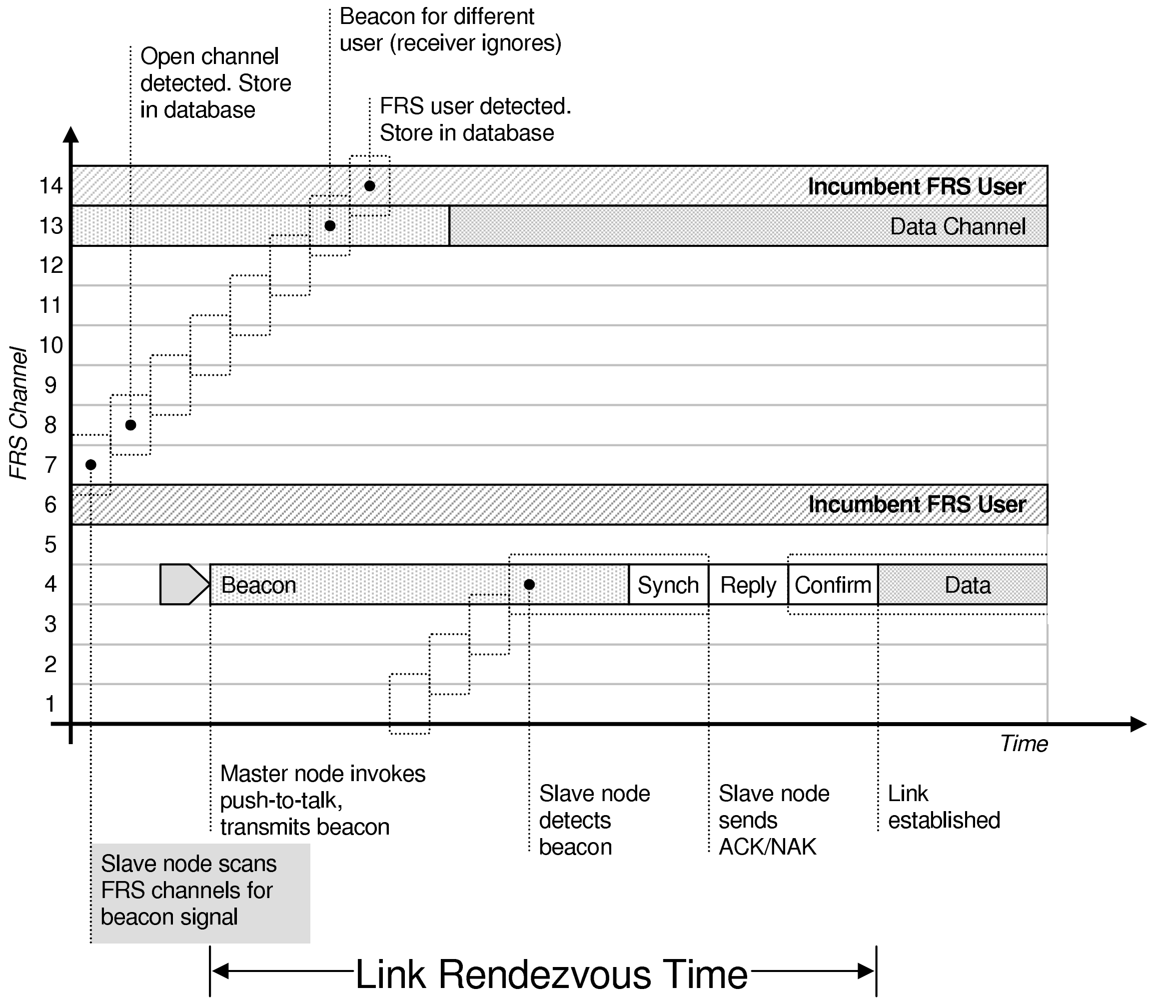


Figure 1.6: Link rendezvous event description

1.3.2 DSA Test Scenarios

From a regulatory perspective, the most important aspect to validate in a radio with dynamic spectrum access capabilities is the reduction of interference to primary or incumbent users of the spectrum. A very important metric is the vacation time which is defined as the time a secondary user takes to evacuate a channel that has been occupied by a primary or licensed user. The sequence of events that trigger a channel switch in the CIREN system was shown in Figure 1.7, indicating the vacation time.

To measure the vacation time of the CIREN system we will use the setup described in Figure 1.8. Here, an arbitrary waveform generator is used to emulate FRS incumbent users among which the CIREN system operates. A primary user transmission is then triggered by means of a sequence change in the AWG sequence or by an actual FRS legacy radio. A real-time spectrum analyzer with

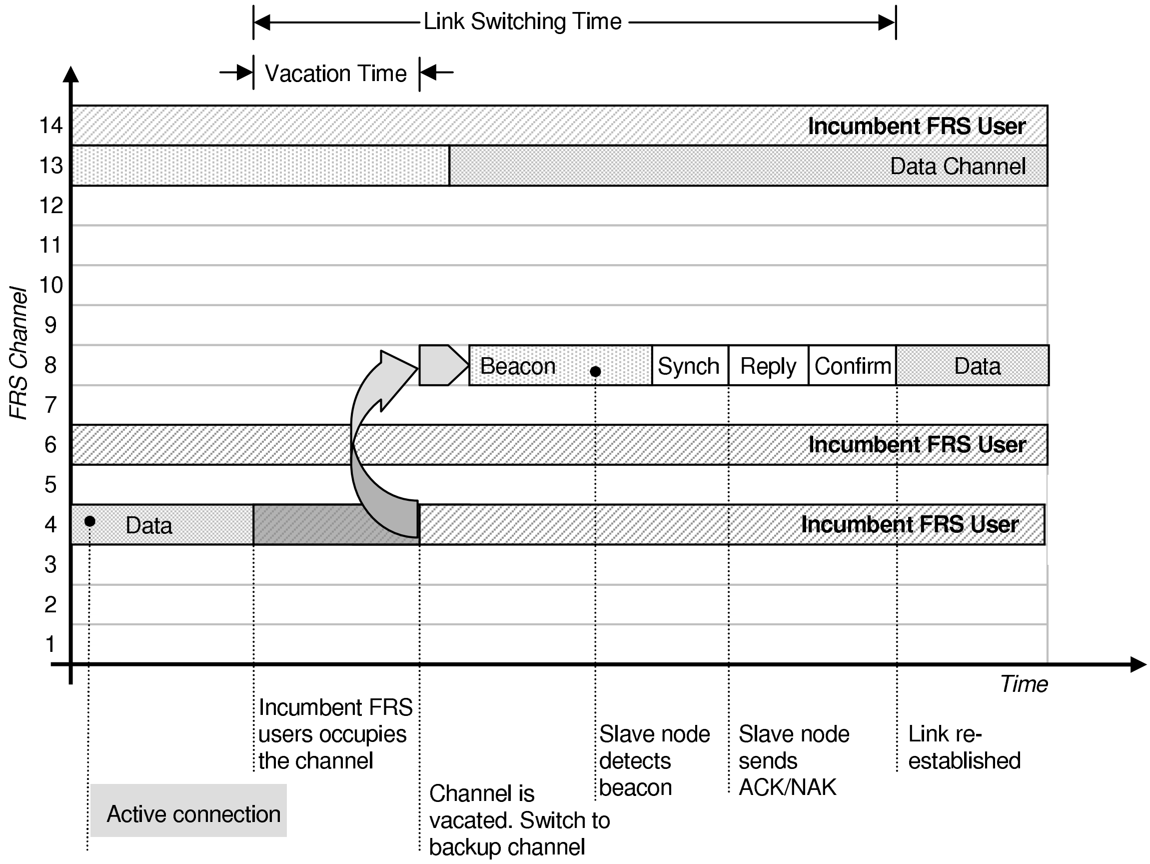


Figure 1.7: Link switching event description

the appropriate spectrum mask is then used to measure the time it takes to the CIREN system to vacate the channel.

1.4 Item pass/fail criteria

For QoS, the CIREN system is expected to achieve the maximum data rate only on perfect conditions. However, given the experimental nature of the system, not achieving these rates is not considered a failure and the maximum data rate achieved will be published.

In term of DSA behavior, the expected vacation time is 500 mS, following the number picked by the XG program. Again, not meeting this deadline does not necessarily represent a catastrophic failure. In this case, the achieved vacation time will be published.

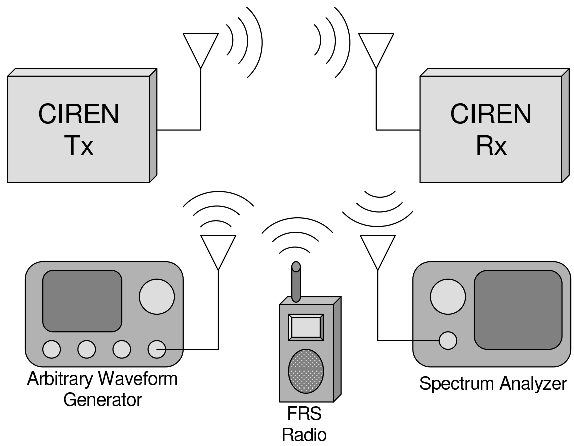


Figure 1.8: Dynamic Spectrum Access Test Scenario

1.5 Risk areas

The major risk areas that may affect the success of this plan are:

- Lack of personnel resources when testing is to begin.
- Lack of availability of required hardware, software, data or tools.
- Late delivery of the software, hardware or tools.
- Delays in training on the application and/or tools.
- Changes to the original requirements or designs.
- Complexities involved in testing the applications

1.6 Test deliverables

As a result of this test plan we will present detailed reports containing the results of the scenarios described in this test plan. In case important test cases and scenarios are ommited from this plan, they will be described, implemented, and the results published as well. The final demonstration scenario will be shown during the SDR Forum Technical Conference.

1.7 Environmental needs

At least two CIREN radios will be designed and constructed. The necessary hardware to complete this task are listed below:

- Lyrtech SFF SDR radio platform
- Personal computer with USRP

In order to execute the tests described in this document, the following pieces of equipment will be necessary:

- Tektronix 3408A real-time spectrum analyzer
- Tektronix 710 arbitrary waveform generator
- Miscellaneous components, including cables, attenuators, mixers, filters, and amplifiers
- At least two FRS radios

1.8 Responsibilities

As the senior member of the team in charge of developing the CIREN protocol, Joseph Gaeddert will be responsible for coordinating and evaluating this test plan.

1.9 Approvals

Due to the inclusion of system and acceptance testing aspects, the completion of this test plan will be determined with the participation of all senior members of the team and the faculty advisors. Up to the legal extent, the input from external colaborators such as the SDR Forum and Challenge sponsors will be considered for the final acceptance of the test plan completion.

Chapter 2

Analog RF and Digital IF Hardware Test Plan

2.1 Introduction

This chapter describes the general test and characterization strategy for the analog radio frequency (RF) and digital intermediate frequency (IF) stages that will be used as part of the Smart Radio Challenge. According to our proposal we will use the SFF SDR boards supplied by Lyrtech. It consists of an RF front end, with superhet-based receiver and direct-launch transmitter, and an FPGA board for performing the IF stages. The RF stage will act as the preliminary frequency conversion stage to convert the incoming RF signal to IF signal and vice versa. On the other hand, a digital IF stage will translate this IF signal to baseband and vice versa.

2.2 Test Items

Receive (Rx) chain including antenna, low-noise amplifier (LNA), frequency conversion stages (e.g. mixer), and filters.

Transmit (Tx) chain including power amplifier (PA), frequency conversion stage, filter, and antenna.

Local Oscillator (LO) to distribute required frequencies to multiple mixers.

Digital IF including digital down–converter, digital filter for decimation and interpolation.

BUS interface between digital IF and processor.

2.3 Analog RF and Digital IF Hardware Risk Issues

Our ability to test and characterize Hardware (HW) depends on the availability of probe points and the overall accessibility of the components of interest on the boards. Because we are not developing the HW in-house, the success of our measurements depends on the "facilities" provided with the boards. In case we cannot measure some characteristics, we will resort to approximate them or to provide a generic value based on existing documentation. For the digital–IF and BUS interface, HDL–level simulation may be used for the characteristics.

Due to limited resources in our lab, we will request some facilities and equipment, described in section 2.9, from our sister organization: the Virginia Tech Antenna Group (VTAG). If such facilities are not available for us to use, we will not be able to complete this test and characterization plan.

2.4 Features to be tested

For this project, the following parameters of the analog RF and digital IF stages will be measured and characterized:

Analog RF part:

- Receiver Measurement:
  - Gain-Frequency Characteristics
  - Input 1dB Compression Point
  - Receiver Image Rejection
  - Receiver Bandwidth
  - Noise Figure
- Transmitter Measurement:
  - Transmitter Output Power vs Frequency
  - Output 1dB Compression Point
  - Transmitter Image Rejection
  - Transmitter Bandwidth
- Antenna:
  - Pattern/Gain(f)
  - Impedance-Frequency Characteristics($Z(f)$)
  - Voltage Standing Wave Ratio (VSWR)
- Local Oscillator Frequency Accuracy/Stability

Digital IF Part:

- Functionality of data–path or Tx/Rx.
  - Cascade integrator comb (CIC) filter for decimation and interpolation.
  - Quality of signal from direct digital synthesis (DDS).
- Validation of handshaking protocol for BUS interface.

2.5 Approach

2.5.1 Analog RF part

Most of the Rx and Tx chain measurements will be performed using a simple setup similar to the one described in Figure 2.1. Gain, 1-dB compression point, bandwidth, Tx power, and LO will be measured using similar setups with the spectrum analyzers that are currently in house (Tektronix RSA3408A and R&S FSH3).

For antenna measurements, we will require an anechoic chamber and the corresponding instrumentation. These facilities and equipment will be borrowed from the Antenna Group of Virginia Tech (VTAG), and used to perform measurements for antenna gain and impedance, VSWR, and noise figures.

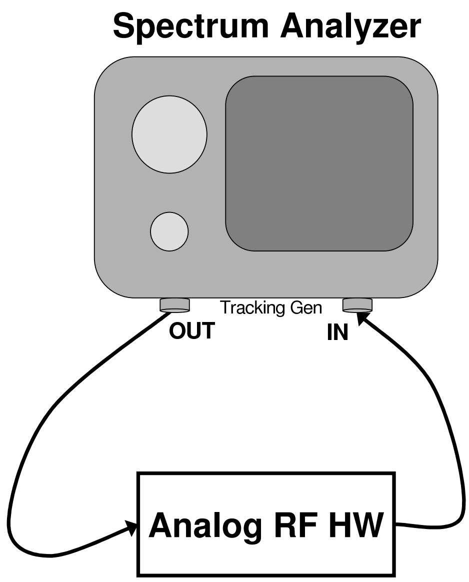


Figure 2.1: Generic Analog HW Test and Measurement Scenario

2.5.2 FPGA(Digital–IF and BUS interface) part

For FPGA design, we have to verify its functionality and logic timing. The logic timing, including pin–in/out timing, will be verified with help from the synthesis tools. According to the functionality, the function of FPGA generally consists of two blocks: data path and BUS interface.

The functionality associated with data path are down–conversion, decimation, and interpolation. To verify the FPGA implementation of these functions, HDL and MATLAB simulations will be compared, as shown in Figure 2.2(a). If the delivered boards allow access to the internal signals of the FPGA, the input pattern in simulation will be used in the test to compare its output with the output from HDL–simulation.

The BUS interface has several Finite–State Machines (FSM). The main FSM is the one responsible for data transfer from FPGA to host (DSP) and vice versa. This FSM must consider the timing protocol of BUS, the pre–defined handshaking protocol with a host, and the status of an available data or buffer in FPGA. The function of FSMs will be verified with HDL–simulation first, as shown in Figure 2.2(b). However, we expect this simulation to missr various real–world conditions. Therefore, for the debugging the BUS interface, we will combine real–world test and HDL–simulation as follows:

1. Do real–test with a test data which we can control
2. If there is a problem in the test, regenerate the problem in HDL–simulation, and
3. Update a design to fix the problem and redo the real–world test

2.6 Item pass/fail criteria

Because of the experimental nature of this project, we do not have specific requirements for this hardware. The purpose of these tests and measurements is characterization only. In case that we detect a defective component or one with poor performance that risks the success of the project, we will replace the part if possible or look for a workaround.

2.7 Test deliverables

As a result of the test and characterization efforts, a complete report describing the RF and FPGA data–path characteristics of our system will be provided.

2.8 Remaining test tasks

There are no extra test and characterization tasks envisioned for after the completion of the first, and only, phase of this project.

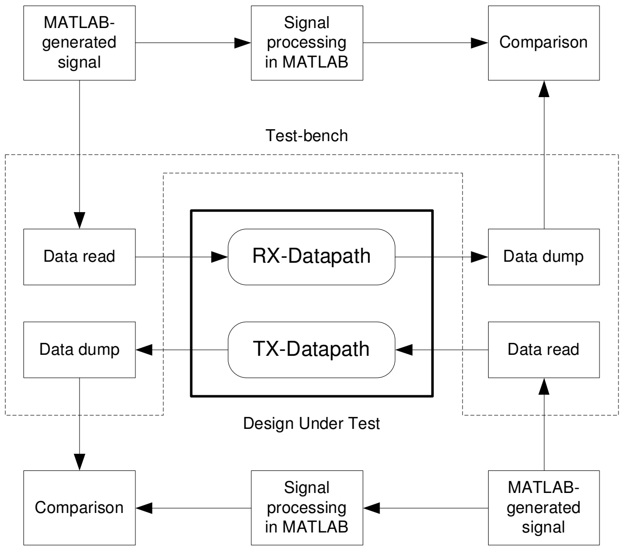
2.9 Environmental needs

To complete this test plan we need the following material and equipment:

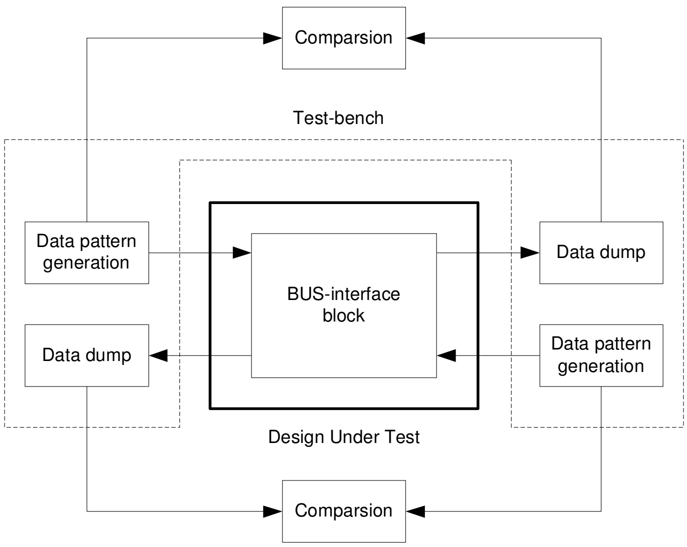
- Spectrum Analyzer (Tektronix RSA 3408A and R&S FSH3)
- Arbitrary Waveform Generator (Tektronix AWG430)
- Wide Band Arbitrary Waveform Generator (Tektronix AWG710)
- Anechoic RF Chamber, network analyzer, and related instrumentation
- Logic Analyzer
- Oscilloscope

2.10 Responsibilities

Being the person responsible for RF hardware section, S. M. Hasan will be in charge of coordinating and evaluating the tests regarding the analog RF front end. On the other hand, Kyehun Lee will perform the tests concerning the FPGA section.



(a)



(b)

Figure 2.2: FPGA HW Simulation Scenarios. (a) Simulation strategy for Data–path. (b) Simulation strategy for BUS interface

Chapter 3

Master Software Test Plan

3.1 References

The following documents are referenced within this document or used as reference or guidance materials . They may also contain provisions or requirements which by reference constitute requirements for this test plan:

1. Software Communications Architecture Specification (SCA) version 2.2. Joint Program Executive Office (JPEO) Joint Tactical Radio System
2. OSSIE Developer's Guide
3. Lyrtech's SFF board reference guide

3.2 Introduction

Software development for the CIREN system will be performed following the Software Communications Architecture (SCA) specifications. The Open-Source SCA Implementation Embedded (OSSIE) [1] is the specific framework used in this project.

In order to provide an agile software development environment and deliver quality software, Team MPRG will follow an efficient test methodology based on automatic unit, integration, and regression tests. Major emphasis will be placed on automating the majority of the tests, with test cases derived from functional analysis of the corresponding component description. For critical software components like the cognitive engine and control mechanisms, complimentary test cases will be derived from the structural analysis of their implementations.

Although complete SCA compliance is not a priority for this project, software components must be tested for SCA compliance, at least to the extent where they are operable within the OSSIE framework. Besides SCA compliance, components and waveforms must be validated for logical correctness, making sure they comply with timing and performance restrictions.

Because the bulk of the development will be made for an x86 processor running Linux, most of the logical correctness validation will be performed on this platform. However, given that the final target platform is Lyrtech's SFF board, performance and regression testing must be performed on the ported waveforms.

The purpose of the software test plan is to specify the scope, approach, artifacts, and deliverables for the software validation of Team MPRG Smart Radio Challenge developments.

3.3 Test items (functions)

The following software components are to be tested within the scope of this plan:

- Modulator/Demodulator (BPSK, QPSK, 8-PSK)
- Packetizer/Depacketizer
- FEC Encoder/Decoder (RS, Conv)
- Channel Sensor
- Cognitive radio control
- REM Database
- I/O Functions and User Interface
- USRP Device
- SoundCard Device
- Related OSSIE framework modules
  - Application
  - Application Factory
  - Domain Manager
  - Device Manager
  - File System

3.4 Software risk issues

We have identified the porting to the Lyrtech SFF board as a risk factor. We are completely dependent on the timely delivery of the board, board support package, and documentation. The fixing of almost any bug in the received software is beyond our expertise. This includes, but is not limited to: configuration routines, transport protocols, and ORB support.

As for the SCA Core Framework, the main area of concern is the file system, because we are going to be dealing with an embedded, distributed platform.

Some of the software components may require special attention due to their complexity. In particular: Cognitive Radio Control, Packetizer/Depacketizer, Spectrum Sensor, and Synchronizer.

Performance in general is an area of concern because of resource constraints in our platform.

3.5 Features to be tested

From the user perspective, the software features to be tested are:

- QoS selection
- Data I/O capabilities
- Display features (spectrum usage, current configuration,

3.6 Features not to be tested

So far, this plan considers all software functionality exposed to the user to be tested. At this time there is no second release planned for the system. Therefore, all functional features must be implemented and tested by the first and final release.

In terms of configuration management, some of the components and artifacts that have been developed and extensively used in the OSSIE framework, such as GPP Device or StandardInterfaces, will not be exhaustively tested as part of this plan. however, they will be included as part of integration and regression testing.

Only the minimum required interfaces from the SCA specifications to ensure correct operation from the framework perspective will be tested. Interfaces such as AggregateDevice and services such as Log and Event service will be excluded from this test plan.

3.7 Approach (strategy)

The overall test strategy is risk-based, with more attention being payed to critical components (e.g. Synchronizer, cognitive radio control, channel sensor) than the ones that have a limited impact (e.g. display)

As mentioned before, complete SCA compliance is not a priority. Therefore, we will use JTAP and WTT only to the extent of supporting this challenge. However, all the software components and artifacts are to be developed following the SCA specifications and are expected to operate on different SCA Core Frameworks.

For unit, regression, and integration testing, custom tools and scripts will be developed to automate the process. For unit testing, cxxTest will be used to provide automatic execution of functional test cases to help assuring functional correctness. Each developer is responsible for performing the corresponding unit test before committing a final release version of the component to the repository.

In order to exercise CORBA interfaces in the unit, integration, system, and regression levels, a specific test artifact is being developed: oTest. It is envisioned as an integrated test tool that reads XML Test Configuration Descriptors (TCD) to obtain test configuration, similar to the SCA SAD files. This descriptor contains the component(s) involved in the test, the respective connections (if any), as well as the location with the Test Configuration Table (TCT). This table contains a relation of the component configuration, as well as the input test vector and the expected outcome for each particular test. oTest parses the TCD, instantiates the required components, and establishes the connections. It then reads the TCT and executes one by one the test cases specified: sets up each component with the required configuration, enters the appropriate test vector, and compares the output of the system to the expected outcome (Oracle). Even though the full features of oTest may not be ready for this project, a primitive version of the tool with limited functionality will be used to support integration and regression tests.

Results from MATLAB simulations will be used as oracles to evaluate the performance of our signal processing components at all testing levels. A similar behavior is expected from our components compared to the MATLAB scripts after considering the effect of fixed point arithmetics.

There will be two hardware-software configurations for this project. The same software is supposed to be executed in both: a Linux PC with a USRP board, and a SFF board with its corresponding RF module attached.

Timing and performance testing will be executed with the use of emulators and profilers. After porting our waveforms to the SFF board, performance will be evaluated based on the slowest configurations detected in the GPP version.

Basic metrics will be kept to evaluate test efforts: test execution time, total system test hours, number of test cases executed, and number of errors detected and eliminated. Because of our automatic testing approach, most of the derived test cases and vectors will be stored along with the components and waveforms. For the time being, and due to the lack of time and experience, no attempt will be made to collect other metrics such as code coverage.

The regular peer review procedure used for other projects in the group will be followed in this challenge. A review will be conducted for the requirement specification phase and another one when the initial version of the component is completed, along with the corresponding unit tests.

3.8 Item pass/fail criteria

Test pass-fail criteria will be decided by senior members of the team depending on the criticality of the components and the test level.

3.9 Entry & exit criteria

All system features will be implemented and all must begin their testing process as soon as their development starts. Due to the experimental nature of this project, there is no specific criteria to complete the testing process. Testing will be continuous until the correct operation of the system is guaranteed (not likely) or until we run out of time (most likely).

3.10 Suspension criteria & resumption requirements

Test efforts are expected to be continuous during the whole development process. Testing will only be suspended if external issues prevent us from performing it.

3.11 Test deliverables

As a result of this test plan all derived test cases will be stored and documented as part of the component and waveform packages. Test progress will be presented regularly as part of the weekly status report meeting to other developers and faculty advisors.

3.12 Remaining test tasks

There are no remaining test tasks for this project because all the development is to be made in house in a single development stage. There are no iterations, spirals, or other versions of the project envisioned at this time.

3.13 Environmental needs

In order to complete these test plan we need the following software and hardware:

- cxxTest
- oTest
- JTAP
- WTT
- OProfile
- OMAP Simulator
- SFF board signal processing board and board support packages

Except for oTest, the remaining test tools and packages are already available in-house.

3.14 Responsibilities

Being the senior members of the team, Philip Balister and Carlos Aguayo are responsible for the execution and evaluation of this test plan. These responsibilities go from component validation to tool and testbed development.

3.15 Planning risks and contingencies

In the event that oTest is not completed on time for this project, manual execution of test cases will be required. If necessary, a simple spread sheet will be used to keep track of the tests passed and the respective dates. This manual approach has been used previously in our research group. Even though it is inefficient and slow, it provides enough evidence of correctness in the implementation.

Appendix A

Glossary and Acronyms

AWG Arbitrary Waveform Generator

BER Bit error rate/probability

BPSK Binary Phase-Shift Keying

CIC Cascade Integrator Comb

CIREN Cognitively Intrepid Radio Emergency Network

CORBA Common Object Request Broker Architecture

CRC Cyclic redundancy check

CVSD Continuously variable slope delta audio compression

DDS Direct Digital Synthesis

DSA Dynamic Spectrum Access

DSP Digital Signal Processor

FEC Forward Error Correction

FPGA Field-Programmable Gate Array

FRS Family Radio Service

FSM Finite State Machine

GPP General Purpose Processor

HDL Hardware Description Language

HW Hardware

IF Intermediate Frequency

IPU Incumbent/Primary User

JTAP JTRS Test Application

JTeL JTRS Technology Lab

JTRS Joint Tactical Radio System

Link rendezvous time Time required to initially establish a connection

Link switching time Time required to switch the link from one channel to another after an initial connection had been established

LNA Low Noise Amplifier

LO Local Oscillator

Master node CIREN radio for which the majority of the radio communication is transmitting

MPRG Mobile and Portable Radio Research Group

ORB Object Request Broker

OSSIE Open-Source SCA Implementation Embedded

PA Power Amplifier

QoS Quality of service. This generally refers to the cumulative measure of BER and latency at the application layer

QPSK Quadrature Phase-Shift Keying

REM Radio Environment Map

RF Radio Frequency

RS Reed-Solomon

Rx Receive

SAD Software Assembly Descriptor

SCA Software Communications Architecture

SDR Software-Defined Radio

SFF Small Form Factor

SINR Signal-to-Interference-plus-Noise Ratio

Slave node CIREN radio for which the majority of the radio communication is receiving

SNR Signal-to-noise ratio

SU Secondary User

SW Software

TCD Test Configuration Descriptor

TDD Time divisional duplexing describes a communications systems where the master and slave nodes take turns transmitting on the same spectrum at the same time

TCT Test Configuration Table

Tx Transmit

USRP Universal Software Radio Peripheral

Vacation Time Time a secondary user takes to evacuate a channel that has been occupied by a primary or licensed user

VSWR Voltage standing wave ratio

WTT Waveform Test Tool

XG neXt Generation Program

XML eXtensible Markup Language

Bibliography

[1] "OSSIE website." [Online]. Available: http://ossie.mprg.org/

Smart Radio Challenge
Spectrum Access for First Responders

Test Plan

Peiman Amini, Ehsan Azarnasab
Xuehong Mao, Salam Akoum, Harsha Rao, Shafagh Abbasi

Team Leader: Peiman Amini
Team Advisor: Dr. Behrouz Farhang-Boroujeny

Electrical and Computer Engineering Department
The University of Utah

May 1, 2007

Introduction

As described in our proposal, meaningful cognitive radio network operation requires a system of two leaf nodes and one base station. In addition, at least one node is required to act as a primary user to generate interference under laboratory conditions. Hence, a total of at least four SDR SFF platforms are necessary. Unfortunately, as of the time of writing of this document (May 1, 2007), no hardware in functional condition has been delivered to us. Hence, the following describes our test plan on a system design level only, based on the hypothetical availability of two SDR SFFs to demonstrate the capabilities of our system design. Note that our test plan can be changed easily in the future if more SDR SFFs are being made available to us.

The test plan is defined in two different sections:

I. Channel sensing

II. Operation of the cognitive radio system

Section I: Channel Sensing

We denote our two nodes as nodes A and B. Node A chooses 1 or more out of the 200 overall carriers and starts transmitting a stream of data. The test is split up into two parts:

a. *Determining the sensitivity of the RF front-end:* Node A sweeps the range of the SDR SFF boards' output power starting from the maximum power level. Node B monitors the spectrum and reports the presence of the transmitted signal as long as it can be detected.

b. *Spectral dynamic range:* In a cognitive radio system, SUs should be able to detect primary users which are at different locations and different power levels. In addition, wireless channels suffer from channel fading. Therefore, in order to reliably detect the available spectrum holes, the channel sensing mechanism needs to feature a high spectral dynamic range. If this is not the case, SUs may either interfere with low-power PUs or not be able to best harness the wireless resources. Furthermore, in order to increase the bandwidth efficiency, receivers need to have acceptable out-of-band rejection capabilities. It is shown that FFT has low dynamic range and thus it cannot detect low power users. We proposed using filterbank multicarrier for our sensing. Filterbank in contrast to FFT provides high dynamic range thus it is able to detect different users at different power levels. In this part of our test plan, we will measure the dynamic range of our filterbank sensing mechanism.

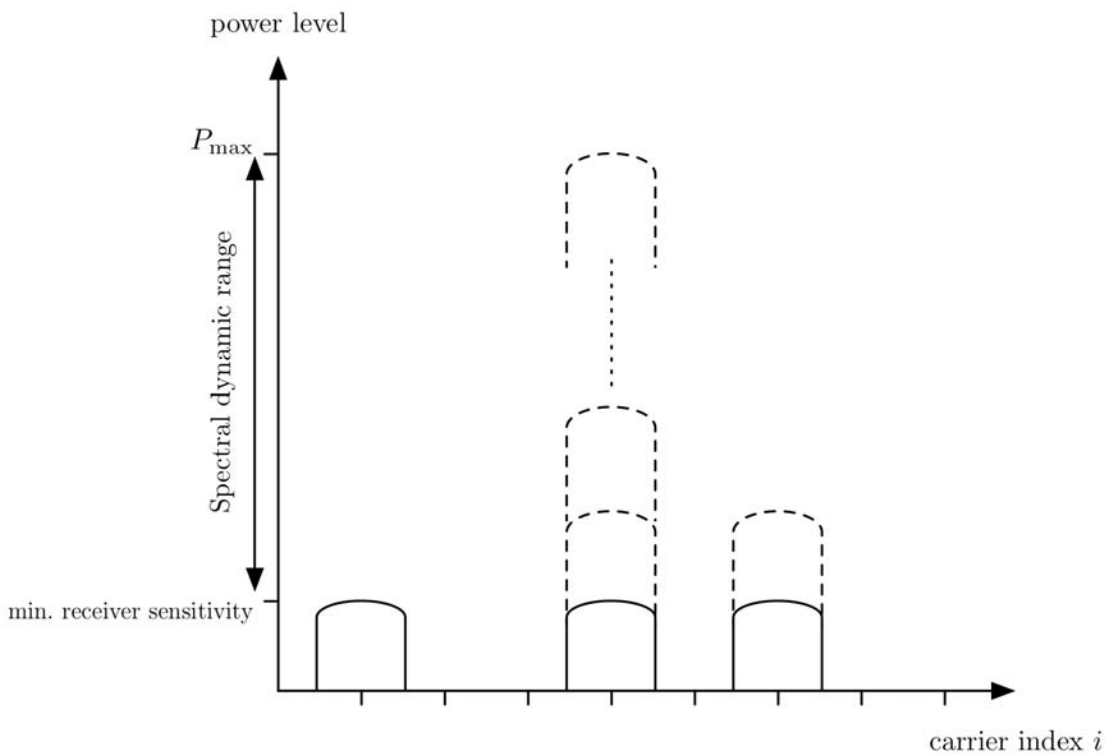


Figure 1: Spectral dynamic range measurement: $P_{\max}$ is the maximum power in which the low power user can be detected

Starting from the boards' sensitivity threshold, node A transmits a stream of data over a random number of subcarriers while node B senses the channel. Next, the output powers of some of the carriers are increased gradually until node B cannot detect the low-power carrier anymore. We expect this measurement to be limited by the 14 bit A/D with a resulting dynamic range of 84 dB, rather than by our filterbank spectral estimator. See Figure 1 for more details of how the measurement is performed.

Section II: Operation of the Cognitive Radio System

a. *Channel sensing and signaling:*

In this mode, both nodes, A and B, act as transceivers and in lack of a third development board, node B also acts as a base-station. In order to emulate interference from primary users, nodes A and B also transmit over a randomly chosen set of carriers out of the 200 available ones which are otherwise not used for actual secondary users (SUs) payload transmission. While the performing node is of course aware of the location and activity level of those "virtual" PUs, the other one is not, and hence will signal its channel observations to the base-station. Since node B is base-station, node A sends its channel observation to node B. In addition, node B also tests the channel and detects node A's simulated PU activities. Node B compiles the channel state information and sends it back to node A. The total number of carriers as well as the imposed traffic load is varied to study the dependency of our QoS estimation algorithms with respect to the available spectrum. According to our proposal, node A stops transmitting and senses the entire channel periodically. If the current sensing information differs from the last compiled channel state information, following a random delay, the channel state data is transmitted to the base station (node B) over the uplink control channel. In addition, node B also tests the channel and detects node A's simulated PU activities. We show that if there is activity on the carriers that are used by either node A or B, the nodes are able to change the carrier.

b. *Monitoring the level of QoS*

Quality of Service (QoS) on an active carrier is measured constantly as described in Section 2.2.2 of our proposal. QoS is characterized by three metrics: delay, jitter, and packet loss. To facilitate measurements, all packets are time-stamped before transmission, and delay is determined as the moving average of instantaneous packet delay. From here, jitter is calculated over a window of time by subtracting the maximum delay from the minimum delay. The rationale here is that the maximum jitter may not exceed the playout buffer at the receiver. Packet loss measurements can be done in a long period of time which will results in a long delay in our QoS measurements. Therefore, SNR is measured instead. In order to avoid excessive packet loss, SNR needs to be above a to be defined threshold. We transmit a preamble at the beginning of each packet for synchronization, timing, and carrier recovery. This preamble can also be used to measure SNR. The SNR is calculated over a few consecutive packets.

As soon as the observed level of QoS approaches a set limit, either node A or node B initiates a channel change request. The base-station (here node B) purges its memory of past channel observations and reassigns a new carrier. Carriers are ranked inside the base-station for their recent activity levels and are chosen from the lowest to the highest. This algorithm allows minimizing the risk of oscillation between different carriers, none of them able to provide the required level of QoS.

c. *Determining the dependency of QoS on available channel resources*

As mentioned previously, nodes A and B also emulate the behavior of primary users. Increasing the amount of traffic generated on those “virtual” PU carriers as well as the bandwidth of the emulated PUs and their “carrier hoping frequency”, enables us to investigate the degree to which the achievable level of QoS depends on the activity and the behavior of the primary users.

KTH Information and
Communication Technology

The ABSOLUT Team

Test plan for the Traffic Management Problem proposed by The SDR Forum Smart Radio Challenge

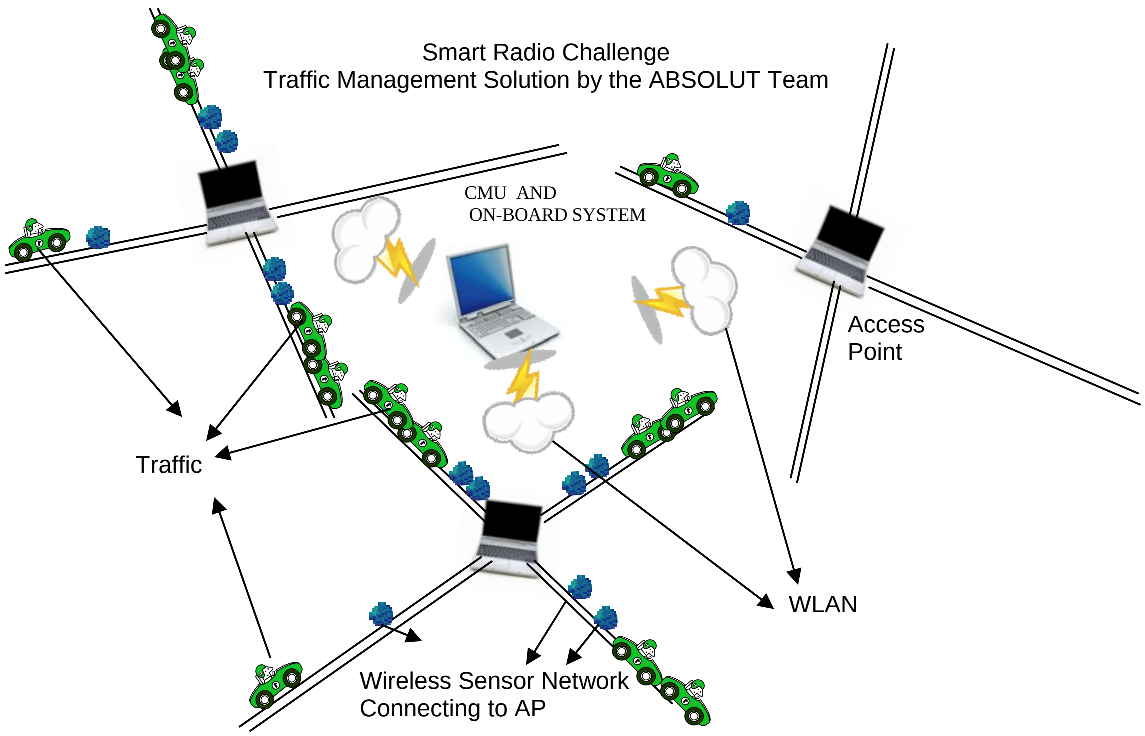
Team leader:
Delia Rodríguez de Llera González
Royal Institute of Technology (KTH)
School of Information and Communication Technology (ICT)
Box 229 SE-16440 Kista
Sweden
Email: delia@kth.se

Technical advisor:
Dr. Ana Rusu

Team members:
Chithrupa Ramesh
Sandeep Kowlgi Srinivasan
Georgios Panagiotou
Liu Xin
Abdullah Mansoor

Introduction

We propose to follow a test procedure with a 'bottom up' approach, validating first all the components of the system separately to continue with the full system validation in order to ensure that the desired traffic management is achieved. Beginning with the sensing system, we try to ensure that all vehicles in the area of interest are correctly detected for every position in the network and their velocity correctly determined. Once this is ascertained, we propose to test the effectiveness of the communication systems between the sensors and the central management unit (CMU) and also between the CMU and the on-board processing of the vehicle receiving the traffic information. The navigation and decision making algorithms will be rigorously tested in simulation environments created in Matlab. Since most of the wireless equipment is on board notebook computers, a GUI system might be employed to simplify debugging. The procedure and test setup are highlighted in the following sections.



1. Required spectrum

For our test plan we have to discriminate between two different situations, where we have:

1.2 Sensors Accumulative Point (SAP) to Central Management Unit (CMU) communication

In this case an RF24L01 RX/TX chip, managed by a ATMEGA 162V 8PI MCU will accumulate traffic signals from [5~10] ultrasonic sensors (the exact number of sensors that are going to be handled by a single CMU is under consideration, and is one of the parameters that the test plan will derive). Each sensor is connected through a wire with its corresponding CMU. Each accumulative point (from now on called an ATX point) will communicate with the CMU directly. The CMU's RF front end is going to be an other nRF24L01 RX/TX chip (from now on called PRX point). Each PRX point can receive data from up to six (6) different ATX points all of them using the same physical interface (a single channel). The band of operation for the SAP 2 CMU communication is going to be the 2.4GHz ISM band. Both ATX/PRX points are going to be configured for operating at the lowest configurable data rate (that is 1Mbps) in order to keep the use of spectrum at the lowest available level (<2MHz @ 1Mbps). Thus, we have a plethora of different channels to use for achieving high SNR, in the congested band of 2.4GHz.

Regarding the communications area of the test plan, both simulations and practical trials are scheduled. On the simulation side we will assume a non-ideal transmission medium (the RF channel), with various SNR and BER scenarios. Then we will simulate the usage of a spread spectrum technique, so as to derive a scheme that will help us minimize the actual BER in the test plan. After determining the «pre-coding» spread spectrum technique we will feed the PRX-ATX test topology with «training» bit-vectors so as to derive the performance of our communication system Furthermore this combination of simulations and test plans will provide us a closer look on the expecting conditions of a real environment, where our solution is going to be evaluated.

1.2 Car Control Unit (CCU) to Central Management Unit (CMU) communication

As described in the project solution proposal, the communication between the CCU and the CMU (computer to computer) is going to be operated at the 2.4GHz ISM band with the use of IEEE 802.11b protocol, using commercial off-the-shelf components. Since the data rate between the CCU and the CMU does not need to be larger than the 11Mbps (theoretical, for a half-duplex link) 802.11b can provide, there is no need to search for an alternative, and more spectrum inefficient, communication protocol. IEEE’s mask for an 802.11b operational link is set to be 22 MHz. This spectrum can be further reduced if we use high quality components. A test bed consisting of a wireless Access Point (AP) and two communicating wireless enabled PC’s is going to be set up. The required settings for a working topology will be extracted.

The required spectrum that our test plan needs is the minimum allowable in order for our hardware to operate in the 2.4 GHz ISM band.

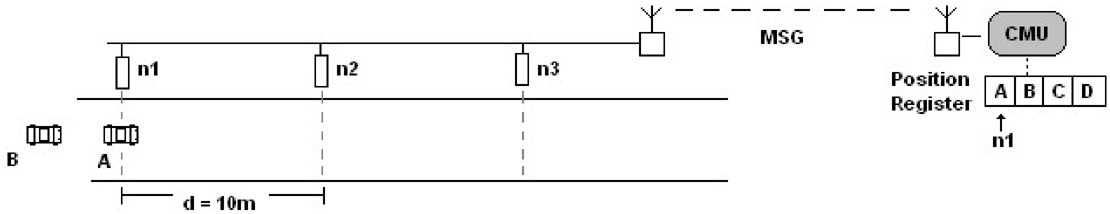
2. Vehicle location

2.1 Sensing Method

We use a pair of ultrasonic sensors in each sensor node which transmits and receives a 40KHZ burst to detect the presence of a vehicle. When a vehicle passes through the ultrasonic transmitter, the reflection of the burst will produce an echo on the receiver, which converts it into a proper voltage signal through a conditioner. The on-board processing translates it into meaningful data and transmits it to the CMU using the onboard RF device operating on the Zigbee protocol.

2.2 Position Awareness

The vehicle also needs to be aware of its position on the road. As the location of the sensors are fixed and hence the messages they send to the CMU are ‘tagged’ i.e. they contains the node’s position information in the data packet, with each sensor being allocated a unique identification tag. By analyzing the messages from the sensor which detected a vehicle nearby, the CMU could determine N vehicles’ position on the road.



Vehicle position & velocity detection

In our test plan, the model is a single-way road, so no overtake is allowed between vehicles. A register in the CMU is used as position register. By analyzing the information of the position register, the CMU could determine N vehicles' position on the road.

For this part, first of all, we will make sure that the Sencera UTT4010 ultrasonic sensor node could detect the model car passed by precisely and timely. In this phase, the detect range r_d , detect response time t_{rsp} and maximum & minimum detectable velocity $v_{\max}$ & $v_{\min}$ of the sensor node should be determined. After these tasks are completed, we could step into the second phase in which a cluster of sensor nodes are connected together and able to communicate with the CMU with the wireless network, in this phase the ability to detect the vehicle position for one to six cars with different velocities will be validated. Finally we will integrate the clusters of sensor nodes into the sensor network with 50 sensors. All the vehicles will be placed within the sensor network to test the overall reliability and robustness.

3. Velocity Detection

As we have described in the Sensing Method paragraph, when a vehicle passes through a ultrasonic sensor node, the sensor detects its presence and sends a message to the CMU with the node's tag. As the vehicle moves on and is detected by an adjacent sensor, it sends another message with its tag. By communicating the time when the two messages were sent, the CMU can calculate the average velocity of the vehicle.

When a vehicle passes through an ultrasonic sensor node (n1), it detects its presence and sends a message to the CMU with the node's tag. As the vehicle move on and is detected by an adjacent sensor (n2), n2 sends another message with its tag. When each message form a sensor node is received in the CMU, a time stamp (t_n) is preserved, since the distance between sensors is a constant, d, the average velocity of the vehicle could be produced in the following equation:

$$v_{ave} = \frac{d}{(t_n - t_{n-1})} = \frac{10}{(t_n - t_{n-1})}$$

For this part, we will first test a simple node network consisting of 2 Sencera UTT4010 ultrasonic sensor nodes connected with an Altera FPGA board, which could test the velocity of a single car. Then we may increase the number of cars on the road as well as the number of nodes in the sensor network, validate if the system functions properly with 50 nodes and more than 5 cars. During the test, we will also determine the velocity detect range and the maximum and minimum test response time of the full scale system.

4- The solution can determine choices of routes available to minimize fuel consumption

The system will determine which route choices are available by querying the CMU about traffic conditions of upcoming roads in the map. In addition to minimize fuel consumption, additional preferences are also taken from the user to increase the efficiency of the system, as discussed in the proposal.

Thus the choices of routes are determined on the basis of one of the following preferences:
1. Lowest fuel consumption preferred (default)
2. Shortest path preferred
3. Fastest path preferred
4. Multi-lane preferred over single-lane roads

The system will be then tested for each one of these preferences using simulation and real time operation. Lowest fuel consumption will be tested in terms of battery consumption of the car. As we don't have any empirical relationship for finding the power consumption of the toy cars, therefore approximate value will be determined on the basis of average values of travel time and speed.

Shortest Path preference is tested by measuring the distance covered by car when it will move from point A to another point, B under different traffic conditions. Ideally, the car will follow the same route in order to achieve shortest path.

Fastest Path preference will be tested by measuring the time taken by the car to move between two points under varying traffic conditions. Initially traffic will be kept low on the shortest path and the same route must be selected by the car. Secondly, traffic will be increased on the shortest path so that time taken to follow this path is more. Therefore, car will be supposed to follow longer path but with minimum time.

We have supposed single lane problem, hence no testing is required in this case.

5- The solution must have a way to determine how a route is selected

The system will determine the optimal route using the Shortest Path (SP) algorithm. As discussed in solution, Dijikstra's algorithm will be used to solve this problem.

In order to test if the system determines the correct route, a test car will be moved from given point A to another one, B. Five other cars will be introduced in the arena in such a way they will create different traffic conditions for the testing environment. The route adopted by the test car will be monitored and checked against the set preference.

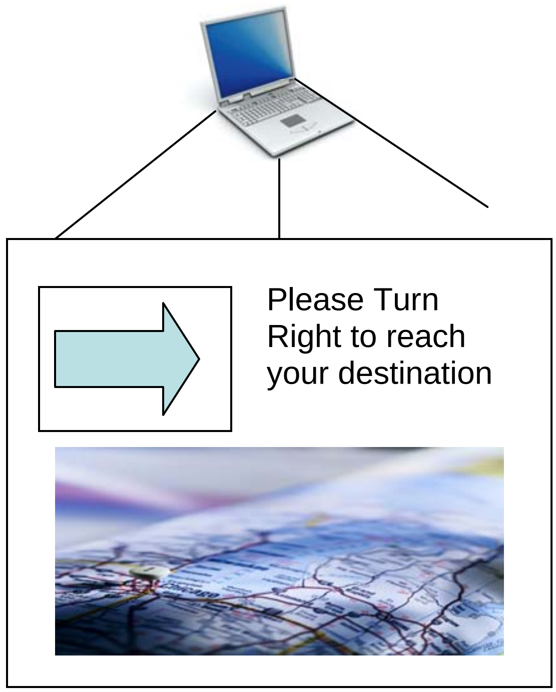
First of all, test will be carried out by setting same destination and different starting points. Every time car will be supposed to reach that destination. Test will be repeated by changing traffic conditions.

Secondly, the system will be tested by choosing same source and destination. However, tests will be carried out by changing the preference each time. If the route will be determined properly, car will arrive at the destination under different traffic conditions.

6. Interaction between the dynamics of the traffic and the user

The system will provide the user with directions every time it is approaching an intersection, that is, the road to take after the intersection among all the possible ones that minimizes fuel consumption.

As was discussed in the project proposal, the on-board system performs a best route recalculation after one of these events is triggered:
1. A certain number of intersections have been crossed.
2. A certain distance has been traveled.
3. A certain amount of time has passed since the last update.
4. A broadcast message indicating a sudden change in the conditions of the road has happened.



For our test system we will test separately each of these conditions. In test mode, the on-board system will display in its standard output the condition that triggered the recalculation, the time, the possible paths, and the selected one. This test will be performed:

- When all conditions but one are “turned off”.
- With all conditions “on”.

for different traffic conditions. These traffic conditions will be first produced as test vectors generated using computer simulations and, then using the real system. In order to reach a high coverage in the simulation phase, the test vectors will be static in the first steps, then dynamic but deterministic, and dynamic and random for the last simulations. When performing these tests in the demonstration system we will go from having only one extra car in the track to having all 5 extra cars in the track. We will create situations similar to the ones treated in simulation (have a clear road, have several cars deliberately slowing down a road and checking that the controlled car choose an alternative path, creating “random traffic” etc). Thus, we will be able to size the parameters that determine the triggering of a best path recalculation considering the maximum speed of the RC cars employed for our demo and the track size.

7. A demonstration of adding future capabilities.

Future capability is a broad term, but we limit ourselves to a few scenarios:

a. Increased traffic – The challenge here lies on two fronts; communications and CMU. The sensor network can be increased to cope with multi lane traffic, etc. The communication solution can be broken down to further levels of operation, as indicated in the main project plan. To facilitate a smart expansion from demonstration solution to application solution, we propose to standardize a general frame format and query procedure. The CMU challenge involves filling in larger data structures with more dynamic data.

b. Larger geographic areas – An expansion in the communication solution hierarchy should provide a solution for this problem as well. Sparse-traffic roads will have some sort of prediction algorithm to fill in data gaps.

c. Expanded user services / options – User convenience will be improved by making the solution multi-standard and adaptable to the user’s preferred mode of communication. This inter-convergence will be built into the software of the system. An increase in data sent to the user, or replies to more detailed traffic queries will be made possible as the system advances. These are purely software, and will be isolated from hardware requirements.

d. New Technology – Sensor technology may advance, but so long as the data packets maintain the same format, the solution will remain backward compatible. Additional sensor network solutions, including mobile GPS sensors onboard the cars themselves may be roped in to provide traffic updates. But, this should have no effect on the user equipment.

More than demonstrations of future capabilities, the points listed above are precautions to ensure a backward compatible system. These will be built into our solution.