AC 2010-1377: EXPERIENCES WITH STUDENT-DEVELOPED SOFTWARE-DEFINED RADIOS IN THE SMART RADIO CHALLENGE

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Experiences with Student-developed Software-Defined Radios in the Smart Radio Challenge

Abstract

This paper discusses our experiences of participating in the Wireless Innovation Forum's Smart Radio Challenge, which was established to promote the learning of software-defined radio (SDR) systems and techniques at educational institutions. As part of the challenge, each student team must build and demonstrate an SDR that addresses the problem(s) defined by the Wireless Innovation Forum and supporting the target waveform(s). The SDR domains provides a method to tie together many of the subjects in a typical electrical engineering and computer science and engineering undergraduate's curriculum. Although student teams may choose to use whatever development environment they wish, we have had success with the GNU Radio development environment as well as the MATLAB Simulink environment. Simulink allows a model-based design approach, which allows students to take a systems approach to designing the overall SDR transceiver, which provides them with exposure to this important aspect of project development. In this paper, we discuss the overall structure of the Challenge and our experience with it; lessons learned and recommendations; and how we used various development tools to develop the resulting SDR systems.

Introduction

Starting with the 2007 Challenge, the Wireless Innovation Forum (previously called the SDR Forum) has sponsored the Smart Radio Challenge (SRC) annually. The SRC is an international competition in which student engineering teams design, develop, and test software-defined radio (SDR) or cognitive-radio (CR) technologies to address relevant, real-world problems in the advanced wireless communications market.

The Challenge is performed in several phases, beginning with a qualifying round and progressing through one or more development rounds. As part of the Challenge, each student team must build and demonstrate an SDR that addresses the problem(s) defined by the Wireless Innovation Forum and supporting the target waveform(s). For example, in the 2007 Challenge, one of the problems had student teams attack the problem of "communications interoperability". Their task was "to 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 Challenge culminates in a competition in which teams compete against each other in their problem category. A complete set of rules, details on problems from previous years, and a listing of current teams and past winners may be found at the Challenge's website (http://www.radiochallenge.org).

One of the primary drivers for the Challenge is that it addresses a need in the education of SDR engineers. SDR is a rapidly growing field that is driving the development of and innovation in communications technology and promises to significantly impact both the consumer and government communications sectors. Companies and government agencies developing these SDR systems require a trained workforce that has been prepared with the mindset, knowledge, skills, and tools required to address both the systems and technical aspects of SDR system development. Indeed, the defining aspect of SDR is its extremely multidisciplinary nature, requiring a tremendous breadth of knowledge and background in a wide variety of subjects. Successful SDR development is contingent on the successful integration and synthesis of material taught across the entire electrical engineering (EE) and computer science and engineering (CSE) undergraduate curricula. The Challenge allows the students to develop the skills and mindsets they will require in their careers, regardless of whether or not they work in the SDR domain.

Smart Radio Challenge Affecting the Learning of SDR Design

As stated above, the SDR design domain employs many different aspects of telecommunications and design tools, covering antennas and EM environment simulation to filters, equalizers, up/down converters, decision-making procedures, coding, protocol design, etc. SDR is also an enabling technology in many areas of communications. It has been, or is being, examined for a very wide range of applications, including military communications, civilian mobile communications, and introduction of new technologies in legacy frequency bands, to name but a few.[1]

These aspects of SDR are greatly exploited in the educational goals of the Challenge because it allows students to apply their often newly acquired knowledge of communications, signal processing, electronics, coding, etc. to a real-life, complex problem. This allows them to become familiar in dealing with real problems before graduating and prepares them in using their theoretical knowledge of communication in those problems. In addition, hands-on experience is always one of the best methods to learn what is learned theoretically.

Student Experiences and Observations of the Challenge

In the three years of participating in the Challenge, the Penn State students involved feel that they have gained significantly from their participation. Working on several different problems has provided them solid grounding in concepts that were pure theory to them before.

To give an example, the Penn State students designed a tree structure for a modulation-classification (MC) process (Figure 1) for part of their solution to the 2008 Challenge.[2] The students had elected to work on problem to “develop a smart radio terminal and a rapid development model defining sufficient software and firmware infrastructure so as to allow new air interfaces to be added to the terminal very quickly.” During the Challenge, teams were given a specification for an air interface standard that was transmitting a secret message. The first team to decode this message was declared the winner. To retrieve a modulation and derive data from the arrived signal involves many different techniques that they had studied previously in their courses. In designing this solution, they employed their theoretical knowledge and came up with a solution. However, they found that to apply this to a real signal was a far greater challenge than they thought it would be.

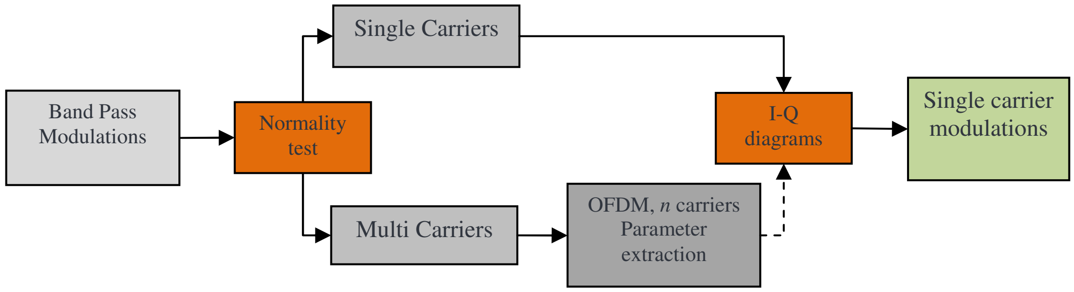

Figure 1. Tree structure of modulation classification

This simple diagram then involved working on different Gaussianity tests (which involved consulting with statisticians), applying different wireless channel models into their simulations, and solving many different aspects in working with an OFDM signal such as synchronization, carrier recovery, sampling clock offsets, carrier frequency offsets, peak-to-average-power ratio, and phase noise. It showed them how complicated a problem can be when applied to real life.

Additionally, the students feel that the Challenge lets them see how different electrical and computer engineering subfields come together to solve a design problem. As an example, in the same problem during 2008 Challenge, for single-carrier MC, we were able to apply an image recognition technique to a MC process to come up with a novel method for solving that problem.

How Design Tools Are Used in the Challenge

The Penn State students have employed and examined various tools in their three participations in the Challenge to determine the configuration that allows the optimal vector toward solving the problem. Each year, due to their different approaches to the different Challenge problems, they have used a wide variety of tools but MATLAB has remained the consistent part of their problem-solving methods. It has proven to be very useful to test the different ideas rapidly in early stages of the design. In latter stages, its various tools and toolboxes have helped them to easily make the different configurations in our simulations.

In the 2007 Challenge, working on "communication interoperability" the student team employed three USRP boards and used GNU Radio/Python to program them and connect them together. The architecture included a three-way, single-channel radio bridge capable of interoperation in the following three bands: AM CB radio, narrowband FM FRS radio, and the 900-MHz digital cordless phone band.[3] The USRP and GNU Radio platform were chosen for this solution because the team leader had significant familiarity with the Linux environment and Python. The block diagram for solution is given in Figure 2.

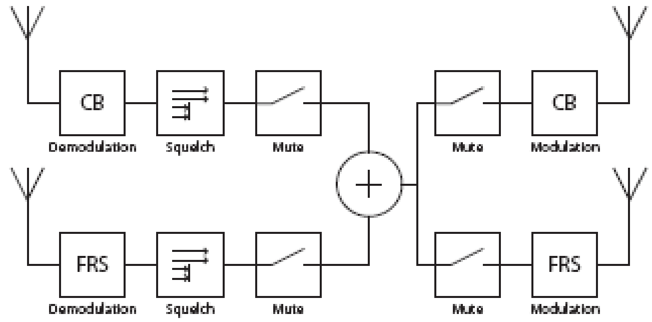

Figure 2. Radio bridge system block diagram

For the 2008 Challenge, the students tackled a very different topic. They developed a smart radio terminal and a rapid development model defining sufficient software and firmware infrastructure to allow new air interfaces to be added to the platform very quickly.[2] The terminal communicated in the 2.4-GHz ISM frequency band and incorporated processing devices capable of supporting transmitted data rates from 16 kbps to 6 Mbps. The terminal's architectural model included a well-defined operating environment with an application framework. The platform was able to support Multiple Access methods of TDMA, FDMA and CSMA. Modulation techniques such as OFDM, BPSK, QPSK, 8PSK, 16QAM were also implemented into the software to provide MC. The system had the ability to receive data structures with a standard preamble, header, and protocol format.

In developing their solution, the students employed a model-based design architecture. Throughout the process, they used MATLAB and Simulink for simulating their design. They used a Lyrtech/TI platform and Xilinx ISE 9.0 for implementing their design in hardware. This was beneficial in the way that they were able to directly translate and transfer their Simulink blocks into Lyrtech board's FPGA (a Xilinx Virtex-II in this case) using Xilinx's block set in Simulink. This greatly facilitated the configuration and testing of our architecture with real signals.

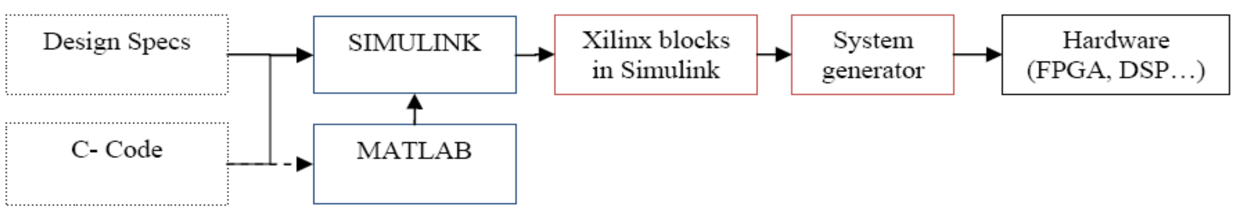

Figure 3. Model-based design block diagram

For the 2009 Challenge (their third competition), the students are developing a cooperative sensing system that will create and maintain a database of public safety emitters in a region, including the emitter location, physical layer parameters such as modulation type and transmit frequency, and an association to which emergency team is using this frequency and waveform. At least 20 different emergency response teams will be trying to coordinate their activities.[4,5]

The tools the students are using for this Challenge are a combination of what they have used in their first two Challenge solutions. They are using MATLAB for the initial design simulations and later, during the design phase, they plan to implement it in hardware using USRP boards, transferring their codes from MATLAB to Python to program the boards.

Also, the 2009 Challenge has provided a new experience and opportunity for students. Due to the change in the timing of the Challenge, the team membership has been more stable. This has allowed the team to divide the project in components and have different task groups that operate independently and gather every week to discuss their progress and coordinate their efforts. The benefits of this new format are discussed below.

Benefits and Issues of the Challenge

As perceived by the students, the benefits of the Challenge include, but are not limited to, the following:

- Gaining excellent hands-on experience working on a real-life problem;
- Gaining valuable experience in working as a team and learning to use different expertise in different areas for achieving the final result;
- Working with a range of software and hardware, some of which are provided by the sponsors; and
- Understanding how broad knowledge of various electrical engineering subfields and even with fields outside electrical engineering can significantly help in developing a project, bringing powerful tools together.

Experience from our participation in 2009 Smart Radio Challenge under the new format shows that having a group consisting of a mix of graduate and undergraduate students can be beneficial in multiple ways. A few of advantages with this method include:

- For undergraduate students:
    1. Dealing with real problems and implementing algorithms that show their results on real signals in real life situations right away. Despite this being on a smaller scale most of the time, the impact on students having hand-on experience with such a project is significant.
    2. Students who take the undergraduate SDR course have the opportunity to put that knowledge into practice immediately.
- For graduate students:
    1. Most of the graduate students will have two different career paths in their future: they will either follow an academic career supervising and advising future graduate students, or will find a career in a company or government lab, involved in projects as members if project groups. They will first participate and eventually lead these groups. In the way this Challenge is organized at Penn State, it gives them a valuable experience in both paths. They get the chance to supervise undergraduate students and divide different tasks of the project into smaller parts that are suitable for undergraduates to work on.
    2. Discussing the project idea amongst themselves and teaching these topics to junior members of the group helps them learn topics at a level deeper than generally achievable through course work alone.

From an educator's standpoint, the Challenge provides an excellent venue for the students to implement what they have learned in class and to work on a complex problem. The nature of the Challenge, however, does result in several issues that have been noted in the first two Challenges, some of which are:

- Most, if not all, of the problems require a graduate level of knowledge to solve them and it is difficult to find graduate students who work in different areas and are willing to spend a year working on a very demanding problem such as the problems of the Challenge. We have had success including undergraduates on our team, but these have typically been honors students. We have sought out Challenge problems that allow us to advance the research work of our lab and graduate students, at least in part.
- Team members can change after each semester and keeping the team together for a year-long project has proved difficult at times.
- There is limited interaction with the other teams, especially before the final project demonstration. It would be a very valuable experience for everyone to talk about their problems with colleagues in other universities and find out about their problems and what ways they have used to tackle those problems. Although the Challenge is a competition, the fact that it is meant to be educational should allow for the development of a mechanism for this interchange.
- Because the sponsors have often wanted to make sure the students are working with the latest and greatest hardware (and the problems generally require this), vendors have pledged hardware that does not arrive until later in the development process, which causes delay in solving the Challenge problems. Hence, teams need to ensure that their institutions have backup hardware to use.

Recommendations for the Future

In the 2007 and 2008 Challenges, there was a timing issue for the Challenge that did not allow teams to use the valuable time during the semesters to work on their problems. This issue has been solved for the 2009 Challenge. Unfortunately, the on-site judging of the teams will now occur via a webinar presentation. The changed timing maps better to the academic year, but the interaction with colleagues on other teams at the competition will be lost.

Because of the complexity of the current Challenge problems, the number of universities that can field a team is somewhat limited. Some universities have fairly large SDR research groups, and can fairly readily field a team. Still, these teams are often only comprised of graduate students, so it is felt that there is room for a simpler Challenge problem that could be addressed by teams of undergraduates. Currently, there are some discussions underway in the WIF's Education Working Group on providing such a challenge.

References

1. Kenington, P.B., *RF and Baseband Techniques for Software Defined Radio*, Artech House, 2005.
2. Azarmanesh, O., and S. G. Bilén, "The Pennsylvania State University Technical Proposal: Next Step … Elbonia," 2008

3. Menendez, E., and S. G. Bilén, "The Pennsylvania State University Technical Proposal: Communications Interoperability," 2007.
4. Azarmanesh, O., P. Desale, R. Gupta, S. Bilén, "PSU Technical Proposal for Smart Radio Challenge 2010," 2009.
5. Azarmanesh, O., and S. G. Bilén, "A Novel Modulation-Classification Technique for Software Defined Radio Applications," SDR Technical Conference Proceedings, 2008.