

Open-Source Prototyping of Advanced Wireless Systems for Smart Agriculture and Connected Rural Communities

DESIGN DOCUMENT

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Client: ISU

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Executive Summary

Development Standards & Practices Used

Agile

Summary of Requirements

- Implementation of PRKS Algorithm
- Implementation of pktRT Algorithm
- Applying the above algorithms within the TVWS spectrum
- Developing a Proof of Concept application using the above implementations that relates to smart agriculture

Applicable Courses from Iowa State University Curriculum

CPRE 308, COM S 311, CPRE 430/530, CPRE 489, CPRE 548X

New Skills/Knowledge acquired that was not taught in courses

TVWS (TV-White Space), PRKS Algorithm, pktRT Algorithm, wireless kernel development, wireless networking protocols.

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List of figures/tables/symbols/definitions (This should be the similar to the project plan)

1 Introduction

1.1 ACKNOWLEDGEMENT

We would like to express our great appreciation to Prof. Hongwei Zhang and Dr. Matthias Sander-Frigau, for their patient guidance, enthusiastic encouragement and useful critiques of this senior project.

1.2 PROBLEM AND PROJECT STATEMENT

Rural regions are home to many industries such as agriculture, renewable energy and manufacturing, and they are major sources of food and energy for our society. For instance, the US agriculture and food sectors alone contribute more than \$750 billion to the national GDP every year. However, rural regions are subject to growing challenges such as population shrinkage and labor shortage, the need to feed a growing population and food demand while subject to climate changes, and the rural-urban education gap. One basic enabler for addressing these challenges and for ensuring the prosperity of rural regions and communities and our society in general is broadband rural connectivity. Rural broadband is the digital superhighway for the broad rural communities and industries, but 39% of the rural US lacks broadband access, and most farms are not connected at all. Through this project, we are going to develop and prototype advanced wireless solutions for smart agriculture and connected rural communities. We are going to use cutting-edge TV white space (TVWS) wireless platforms and advanced wireless algorithms. At the end of this project, we hope to accomplish a spiral evaluation and refinement of the aforementioned novel 5G wireless solution for smart agriculture and connected rural communities.

1.3 OPERATIONAL ENVIRONMENT

We will be using the Qualcomm Atheros QCA9533 chip. It is a highly integrated and feature-rich IEEE 802.11n 2x2 2.4 GHz System-on-a-Chip (SoC) for advanced WLAN platforms.

1.4 REQUIREMENTS

Functional Requirements: The basic of our wireless communication is based on TV White Space(TVWS). Then, for implementing this wireless solution to rural, we need algorithms to support. In which we are utilizing the PRKS and pktRT algorithms created by Prof. Hongwei Zhang. This ensures the reliability for the wireless communication and the time guarantee in real time packet transmit. Then for the software requirement, we are using the OpenWrt on top of QEMU which was designated to simulate MIPS embedded devices. By simulating the chip we are using, ensures us to test our code functionally before actually did the field test. Lastly, we will need physical hardware to apply our solution.

1.5 INTENDED USERS AND USES

Our major customer/user will be within the smart agriculture industry in rural communities. In the US, tons of industries are based in rural areas, as well as agriculture. A big number of them especially farms have a lack of broadband connectivity or have no reception at all.

So if these regions can have a reliable wireless network setup, there will be a big progress towards smart industry/ agriculture.

1.6 ASSUMPTIONS AND LIMITATIONS

Assumptions: Our prototyped solution will be work at rural regions who requires a reliable wireless connectivity;

Limitations: Limited to implementation of TVWS Spectrum; Any noise / interference in TVWS.

1.7 EXPECTED END PRODUCT AND DELIVERABLES

- By the end of the Project, we will be able to create a prototype of a reliable wireless solution for rural regions. This prototype will be a good starting point for future advanced rural wireless network development.
- The prototype is expected to be done by March 2020.
- If the prototype works fine, we might be able to have it applied on physical wireless devices. This will enable rural broadband for the region that is lack of connectivity. Which will enhance the prosperity of rural regions as well as the society as a whole.
- The solution enabled device might be delivered by April 2020.

2. Specifications and Analysis

2.1 PROPOSED DESIGN

During the process of virtualizing OpenWrt on local computers, we installed VirtualBox application on our computers and set up the network adaptor and SSH in order to provide a platform for the prototype to run. By implementing Agile model to this process, we can increase our efficiency during our workflow.

When it comes to understanding the advanced wireless algorithms, we have already understood the purposes, goals, approaches of the two algorithms - PRKS(Physical-Ratio-K scheduling) and pktRT(Probabilistic Per-Packet Real-Time). In the next few weeks, we need to list out the parameters which will be used in the two algorithms and provide the mathematical formulas related to them. The method we are using during the stage of understanding the advanced algorithms is the Agile mode. Since the algorithms have multiple branches and we need to look through other papers to help us to understand the PRKS and pktRT algorithms, so we used the agile model to solve the problem.

2.2 DESIGN ANALYSIS

For the group which focuses on OpenWrt, we installed VirtualBox application on our computers and set up the network adaptor and SSH. And now we are on the testing stage. This work worked as expected since we followed the instructions step by step. Based on our

observations, this is a good start of the project, we should build the project step by step in order to reduce redundant time on checking previous mistakes.

On the other side, the group tried to understand the advanced wireless algorithms, we have understand the purposes, goals, approaches of the two algorithms - PRKS(Physical-Ratio-K scheduling) and pktRT(Probabilistic Per-Packet Real-Time). This is an understanding part of our project. This is just a summary of the algorithms we are going to work with. Based on our observations, we will spend plenty of time on digesting the core ideas of the algorithms since none of us had previous experience with the wireless networks. Our idea about how to solve the problem is to do a detailed reading of the peripheral papers like ONAMA which could help us to understand the core ideas in PRKS and pktRT.

2.3 DEVELOPMENT PROCESS

For the whole project of Open-Source Prototyping of Advanced Wireless Systems for Smart Agriculture and Connected Rural Communities, we are following the Agile approach during the development processes.(We implement the Agile approach not only on software developing but all of our development strategies)

We break the project into different stages, we developed a Gantt chart which listed detailed deadlines for each of our objectives to different stages. For instance, we set up deadlines for OpenWrt virtualization, Algorithms understanding, Prototype development(the deadlines are often set at the end of the week because we have a fixed meeting time on Monday morning every week). For each single task, we create a corresponding card on our trello and synchronize the task to trello every week. So, team members who take responsibility to their jobs can publish some links or descriptions on the card. Therefore, for our project we are using the Gantt chart and trello to sprints and tracks the development process.

As mentioned before, we are using Agile approach in our development processes. For each task, we have several stages. For instance, when we are virtualizing OpenWrt, we first find out the requirement like which version we should install, and then after planning out the details we start to develop it. Moreover, the testing stage, deploy stage, and review stage is essential for a single task. Not only for OpenWrt virtualization, we implement Agile approach on all of our tasks. This is the development process for each of our single tasks.

2.4 DESIGN PLAN

Use case of the OpenWrt system: we receive videos from monitors in rural farms on the system.

Use case of advanced 5G wireless algorithm: we eliminates the delay and decrease package loss rate by applying advanced 5G wireless algorithm in the prototype.

Use case of Gantt Chart: we follow the schedule on the gantt chart during the process of the project.

Use case of trello: we use trello application to list out the tasks needed to be done and tasks had done and the deadline for each task.

3. Statement of Work

3.1 PREVIOUS WORK AND LITERATURE

Very few previous work has been done to our knowledge in implementing 5G advance algorithms within the TVWS. The 5G algorithms that we are implementing have been implemented before in order to test their feasibility and some of the documentation / results from those implementations are included in the algorithm research papers. (See references [1] and [2])

3.2 TECHNOLOGY CONSIDERATIONS

The current rural wireless connection are lack of efficiency, we are discovering a new solution that improve the channel usage. We were provided the TVWS platform that allow us to apply our prototype for testing. It will give us the opportunity to physically test out, rather than using the emulator.

3.3 TASK DECOMPOSITION

1. Algorithm understanding
 - a. pktRT
 - b. PRKS
 - c. ONAMA
2. Algorithm Parameter mapping for each of the algorithm
3. Hardware emulating

Emulating MIPS 24K devices with Althero 9K chip

4. Apply algorithm parameters to the emulator
5. Testing

Task are in the order of interdependencies. The task requires the finish of its previous task.

3.4 POSSIBLE RISKS AND RISK MANAGEMENT

Throughout our project, we have encountered some concerns which costs us a lot of time and slows down our efficiency. In the first stage of our project, there are some algorithms which we need to spend a lot of time to understand and implement them in our code. However, it may be risky for us

to spend unexpected time on learning new knowledge. To deal with that, we plan to separate the task to each of the team members and set up a knowledge exchange meeting to teach others the key points in each algorithm and how to implement in the project.

Moreover, we are worried about the potential accuracy issues in the project. Since our project is to build a prototype which can establish a stable and fast wireless network system. We need to make sure that our system meets some requirements such as a certain package loss rate less than 5%. However, this is highly complicated and to measure the accurate result of the test for the package loss rate.

3.5 PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

There are several milestones we set up for the project. For the team which focuses on platform. We have OpenWrt virtualization on local computers, cross compilation, emulate hardware on QEMU, read and document Linux Wifi system. For another team with algorithms understanding, we have milestones such as design parameter form, mapping parameters to the Linux system. These milestones we created are closely relates to the development of the project, and will benefit for us to take the progress of our project.

For some milestones are based on knowledge understanding, we just write down some notes and explain our understandings to our instructor to make sure we are on the right path. On the other hand, for code based milestones, we will carry out test cases strictly to confirm that our code works without any problem.

3.6 PROJECT TRACKING PROCEDURES

We carried out a weekly meeting and use Trello to keep track on the same page and make sure we are on the correct path of the project. Every Monday morning, we have a regular meeting with instructor to show them our weekly goal and we make a week plan as a team about what kinds of objectives we are going to do for the following week. During the meeting, our instructor will point out the problems with our project and give us appropriate advice so we can fix them.

During the week, we use Trello to keep track on the same page. In the beginning of a new week, we create some blocks containing the information of new tasks need to be done in the following week and label the team member who are taking a lead on that task. Then, our team members can clearly see the rate of the progress of the task.

Before the end of the week, we usually have another team meeting to discuss some confusing point, summarize for a weekly report. etc. These meetings are usually flexible based on the actual circumstances for our project for certain weeks.

3.7 EXPECTED RESULTS AND VALIDATION

A well-designed 5G wireless solution for smart agriculture and connected rural communities.

4. Project Timeline, Estimated Resources, and Challenges

4.1 PROJECT TIMELINE

OpenWrt Kernel Development 9/1/19 - 11/1/19

Virtualize OpenWrt 9/8/19 - 9/15/19

Cross Compile Hello World 9/16/19 - 9/27/19

Hardware Virtualization with QEMU 9/28/19 - 10/5/19

Hello World Kernel Module 10/6/19 - 10/13/19

Algorithm Understanding 9/1/19 - 11/1/19

Define Algorithm Parameters 9/1/19 - 10/1/19

Map Algorithm Params to OpenWrt 10/8/19 - 10/23/19

Design 11/1/19

Implementation Initial 11/2/19 - 11/14/19

Proof of Concept Design Concept 11/2/19 - 12/1/19

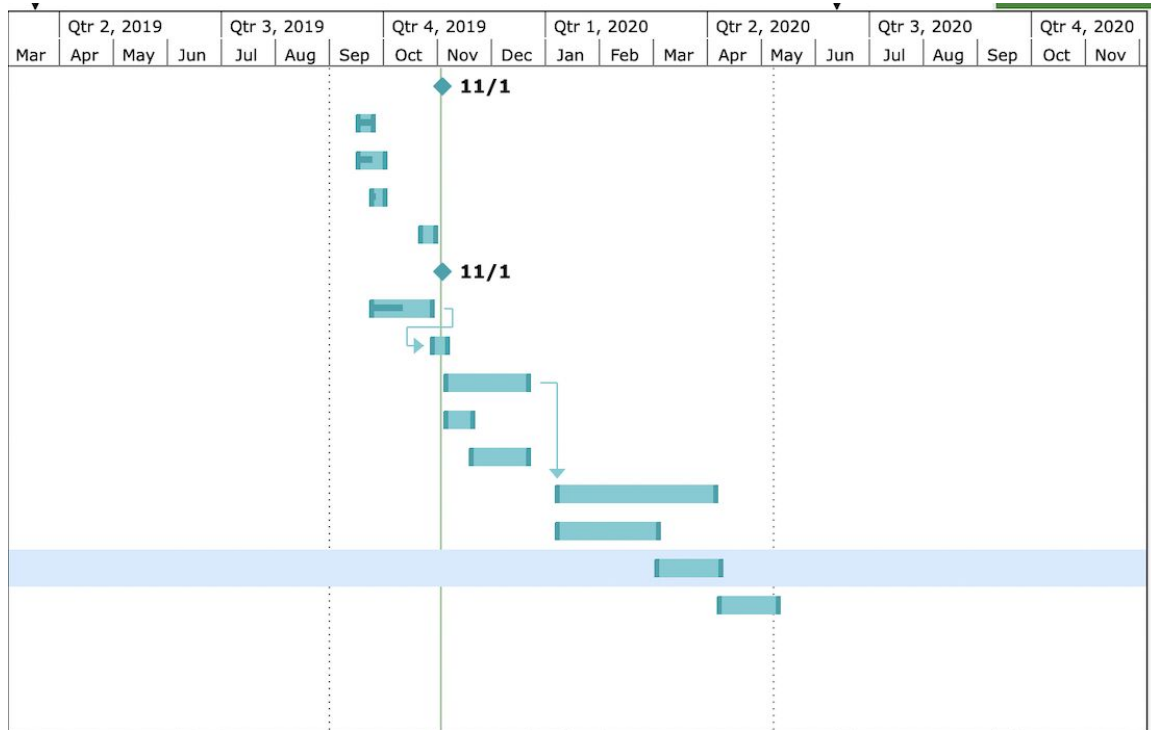
Implementation and Testing 1/6/20 - 4/3/20

Kernel Implementation 1/6/20 - 3/2/20

Proof of Concept Implementation 3/2/20 - 4/6/20

Final Report and Demonstration 4/6/20 - 5/8/20

	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	✚	OpenWrt Kernel Development	46 days	Sun 9/1/19	Fri 11/1/19		
2	✓	Virtualize OpenWrt	6 days	Mon	Mon		
3	✚	Cross Compile Hello World	11 days	Mon	Mon		
4	✚	Hardware Virtualization w/ QEMU	6 days	Mon	Mon		
5	✚	Hello World Kernel Module	6 days	Mon	Mon		
6	✚	Algorithm Understanding (Learning)	46 days	Sun 9/1/19	Fri 11/1/19		
7	✚	Define Algorithm Parameters	26 days	Mon	Sun		
8	✚	Map Algorithm Params to OpenWrt	6 days	Mon	Mon	7	
9	✚	Design	35 days	Mon	Fri		
10	✚	Implementation Initial	11 days	Mon	Mon		
11	✚	Proof of Concept Design Concept	25 days	Mon	Fri		
12	✚	Implementation, Testing	65 days	Mon 1/6/20	Fri 4/3/20	9	
13	✚	Kernel Implementation	41 days	Mon 1/6/20	Mon 3/2/20		
14	✚	Proof of Concept Implementation	26 days	Mon 3/2/20	Mon 4/6/20		
15	✚	Final Report and Demonstration	25 days	Mon 4/6/20	Fri 5/8/20		



4.2 FEASIBILITY ASSESSMENT

Realistic projection of what the project will be. State foreseen challenges of the project.

Complicated knowledge about Algorithm, we all have little background and experience about the network system.

Time Consuming for all of us to fully understand three Algorithm.

Hardware setup: OpenWrt malta with QEMU, the software requires hundreds of dependencies and the biggest challenges for us is to find an environment that both support the hundreds of dependencies and the software itself.

4.3 PERSONNEL EFFORT REQUIREMENTS

Task	Effort Required	Explanation
Algorithms understanding	5hrs/week, 8 weeks	The algorithms are the base of this project. They are PRKS, PKTRT and ONAMA. Every concept and function are from these.
Hardware emulating	3hrs/week, 4 weeks	QEMU is a platform of emulating. All the code will be running and testing on this platform after setting up.
Linux wifi system research	3hrs/week, 2 weeks	The system will be a guide of our work.
Prototyping and testing	5hrs/week, 8 weeks	To create the actual code. Also, we will keep testing and improving for the early prototype to get achieve all the requirements.

4.4 OTHER RESOURCE REQUIREMENTS

The following additional resources are required:

- Legal Access to TVWS Spectrum
- Physical ChipSet and Antenna

Access to the TVWS is required and has been fulfilled as our advisors have gotten us legal access to the spectrum around ISU. Our advisors are also providing us with the Qualcomm Atheros QCA9533 rev 2 ChipSet for the application.

4.5 FINANCIAL REQUIREMENTS

Most of our tasks will be understanding the algorithm references and physical device driver, creating code to achieve the related requirements and finally run everything on the virtual machine. From a financial point of view, besides the certain chip, everything else will be created and run them on our own computer. The instructor will help to provide the chips we need, so actually there is no financial requirements for this project.

5. Testing and Implementation

Testing is an **extremely** important component of most projects, whether it involves a circuit, a process, or a software library

Although the tooling is usually significantly different, the testing process is typically quite similar regardless of CprE, EE, or SE themed project:

1. Define the needed types of tests (unit testing for modules, integrity testing for interfaces, user-study for functional and non-functional requirements)
2. Define the individual items to be tested
3. Define, design, and develop the actual test cases
4. Determine the anticipated test results for each test case
5. Perform the actual tests
6. Evaluate the actual test results
7. Make the necessary changes to the product being tested
8. Perform any necessary retesting
9. Document the entire testing process and its results

Include Functional and Non-Functional Testing, Modeling and Simulations, challenges you've determined.

5.1 INTERFACE SPECIFICATIONS

- Discuss any hardware/software interfacing that you are working on for testing your project

5.2 HARDWARE AND SOFTWARE

- Indicate any hardware and/or software used in the testing phase
- Provide brief, simple introductions for each to explain the usefulness of each

5.3 FUNCTIONAL TESTING

Examples include unit, integration, system, acceptance testing

5.4 NON-FUNCTIONAL TESTING

Testing for performance, security, usability, compatibility

5.5 PROCESS

- Explain how each method indicated in Section 2 was tested
- Flow diagram of the process if applicable (should be for most projects)

5.6 RESULTS

- List and explain any and all results obtained so far during the testing phase
 - - Include failures and successes
 - - Explain what you learned and how you are planning to change it as you progress with your project
 - - If you are including figures, please include captions and cite it in the text
 - This part will likely need to be refined in your 492 semester where the majority of the implementation and testing work will take place
- Modeling and Simulation:** This could be logic analyzation, waveform outputs, block testing. 3D model renders, modeling graphs.
- List the **implementation Issues and Challenges.**

6. Closing Material

6.1 CONCLUSION

Summarize the work you have done so far. Briefly re-iterate your goals. Then, re-iterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

6.2 REFERENCES

This will likely be different than in project plan, since these will be technical references versus related work / market survey references. Do professional citation style(ex. IEEE).

[1] Y. Chen, H. Zhang, N. Fisher, L. Y. Wang, and G. Yin, "Probabilistic Per-Packet Real-Time Guarantees for Wireless Networked Sensing and Control," January, 2018. [Online]. Available: <https://www.ece.iastate.edu/~hongwei/group/publications/pktRT-TII.pdf>. [Accessed: November 3, 2019].

[2] H. Zhang, X. Liu, C. Li, Y. Chen, X. Che, L. Y. Wang, F. Lin, and G. Yin, "Scheduling with Predictable Link Reliability for Wireless Networked Control," January, 2018, [Online]. Available: <https://www.ece.iastate.edu/~hongwei/group/publications/PRKS-TWC.pdf>. [Accessed: November 3, 2019].

6.3 APPENDICES

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar that does not directly pertain to the problem but helps support it, include that here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc. PCB testing issues etc. Software bugs etc.