Open-Source Prototyping of 5G-and-Beyond Wireless Systems

DESIGN DOCUMENT

Team Number: 15
Client: Professor Zhang
Advisers: Professor Zhang
Team Members: Anh To, Bradley Norman, Elias Zougmore, Haan Zilmer
Roles: Lead Algorithm Designer, Meeting Facilitator, Lead Testing Engineer, Report Manager

sddec21-15@iastate.edu

http://sddec21-15.sd.ece.iastate.edu
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Executive Summary

Development Standards & Practices Used

- IEEE and SESC software development standards
- Continuous Integration/ Continuous Development

Summary of Requirements

- Learn about 5g
- Implementation of 5g algorithm on:
    - srsLTE
    - USRP
    - Powder
    - COSMOS
    - AERPAW
- Refinement of algorithm

Applicable Courses from Iowa State University Curriculum

- SE 329
- CPRE/EE 185

New Skills/Knowledge acquired that was not taught in courses

- 5g infrastructure

Table of Contents

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

1 Introduction

1.1 Acknowledgement

We would like to acknowledge Professor Zhang for the research resources he has provided us as well as the advice he will be providing us with for the remainder of the project.

1.2 Problem and Project Statement

Problem statement: Advancements in 5G technology have led to an increase in demand for qualified engineers with the ability to develop and prototype advanced wireless solutions. 5G wireless networks are expected to enable not only Gbps mobile connectivity but also machine-type communications for smart agriculture, connected and automated vehicles, smart grid, Industry 4.0, and AR/VR. 5G wireless is projected to reach a market size of $250 billion by 2025, and it has been attracting significant investment from industry and government worldwide.

Solution approach: Through this project, team members will get hands on experience with the development and implementation of advanced wireless 5G algorithms. As a part of the project, members will get to use platform technologies such as srsLTE, USRP software defined radios, and at scale wireless testbeds.

Project outputs: Experience with platform technologies and testbeds. Knowledge of advanced wireless 5G algorithms, and implementation of these algorithms through at scale wireless testbeds.

1.3 Operational Environment

Our project will operate in a software environment. We will have an open-source software platform and a testbed in which it will exist. If able to implement in a physical environment we will have to take into account environmental factors that could affect signal strength and propogation.

1.4 Requirements

Functionality

- Ensures schedule efficiency and must utilize an efficient time allocation process.
- RAN and Mobile core unity ensures communication between base stations and the mobile core.

User Interface: Users of our product must be able to access and use the modified algorithm for academic purposes.

1.5 Intended Users and Uses

The product will be used for research purposes and other areas of academia. Therefore, the users will be primarily researchers, educators, and students.

1.6 Assumptions and Limitations

- Assumptions:
  - Our research will be used by other researchers in the 5G systems field.
  - Our test environment will apply to real life situations
  - As a team we have the required skills or the ability to obtain the required skills to complete the project.
- Limitations:
  - Lack of time (need to be done by December)
  - Lack of access to physical RAN
  - Lack of knowledge in the field of advanced wireless algorithms and technologies.
  - This technology is very new so there is not much information or infrastructure for it.

1.7 Expected End Product and Deliverables

Deliverables: Wireless testbed setup, at scale testbed implementation of an advanced 5G wireless algorithm.

- The team will be implementing a simple wireless algorithm on an at scale wireless testbed to gain understanding of algorithm testing using at scale wireless testbeds. This will set the foundation for further analysis and testing of advanced wireless algorithms. To be implemented April 30, 2021
- With the testbed setup complete, the team will refine and test advanced dynamic algorithms. Expected implementation date, Nov 1, 2021.

2 Project Plan

2.1 Task Decomposition

- Complete Research
  - Cover given reference materials on 5g
- Tools Setup
  - Set up GitLab
    - CI/CD setup
  - Website setup
  - Testbed setup
- Implement/refine algorithm using srsLTE
  - Begin with simple implementation of wireless algorithm
  - Begin implementation of advanced wireless algorithms
  - Analyze testbed results
  - Refine the algorithm
  - Retest
- Refine algorithm using Powder

2.2 Risks And Risk Management/Mitigation

The nature of the project is purely/mostly software based as we are going to be developing algorithms. Therefore, our primary risk is code that does not work 100% of the time for all usage. This is most applicable to our dynamic design since not all UEs will behave as we expect them to. Some of the errors that can cause code to not function as expected are anomalies of the algorithm or user input.

The probability of our code not fitting all scenarios is 1.00 as it is almost impossible for our algorithm to cover everything that 5g can be provided. An obvious mitigation of this is to include as much code testing as possible or at least till we deem it satisfactory.

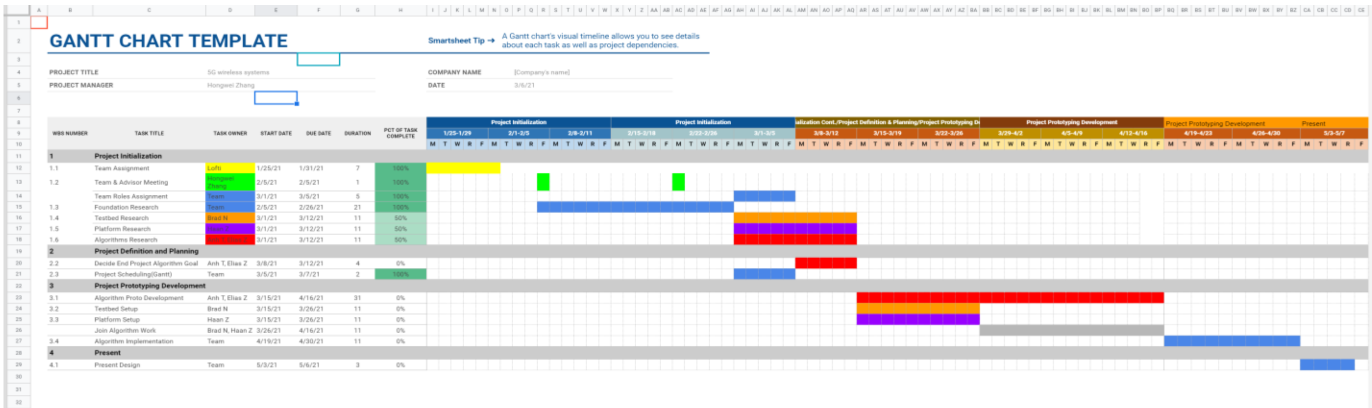
2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Milestones:

1. Complete research
2. Finish tools setup
3. Implement simple code on platform
4. Prototype of algorithm
5. Finished algorithm

Progress metric will be time spent on the given task.

2.4 Project Timeline/Schedule



2.5 Project Tracking Procedures

GitHub, MS Team, Gantt Chart (Google Excel)

2.6 Personnel Effort Requirements

Members	Anh To	Brad Norman	Hann Zilmer	Elias Zougmore
Time (Coding/Testing) Hours/Week	9hr	9hr	9hr	9hr

2.7 Other Resource Requirements

- Internet access
- Personal computers
- SrsLTE
- Reference Materials
- At scale wireless testbeds
- Powder

2.8 Financial Requirements

NA

3 Design

3.1 Previous Work And Literature

There are similar products everywhere in 5G wireless systems as each system needs a scheduler in order to function. For example IEEE put out an article about a scheduler used with time reversal theory and downlink user selection algorithm.

We will also be following a paper on scheduling written in part by our professor for base theory for our scheduler.

3.2 Design Thinking

Detail any design thinking driven design “define” aspects that shape your design. Enumerate some of the other design choices that came up in your design thinking “ideate” phase.

Through this project, team members will get hands on experience with the implementation of advanced 5G algorithms. We decided to work on srsLTE source code through powder technologies. This decision came up with implementing the static part first. We also though about working on the mobile aspect of the transmission, which will bring more interference between base stations. We have planned out what we will do throughout the semester and we have a Gantt chart that help us follow up on what to do or when they are due.

3.3 Proposed Design

Include any/all possible methods of approach to solving the problem:

- Discuss what you have done so far – what have you tried/implemented/tested?
- Some discussion of how this design satisfies the **functional and non-functional requirements** of the project.
- If any **standards** are relevant to your project (e.g. IEEE standards, NIST standards) discuss the applicability of those standards here
- This design description should be in **sufficient detail** that another team of engineers can look through it and implement it.

In order to approach this problem, we are thinking about working on the static part first and then we will work on a mobile one. We are trying to implement the source code for the srsLTE mac so we can know what to modify or not. The source code only works with Linux, so we are using a virtual machine to run the code. We are also using Powder to test the code and see how fast the signal can travel with all the interferences that might occur.

3.4 Technology Considerations

We will be using Powder as our testbed for this project and while it gives us the ability to edit the source code directly in the testbed it does remove some of the flexibility that comes with editing the source code in our own environment. Overall, the benefits outweigh the consequences as we will not have to worry about the implementation of the source code into the testbed being an issue. The alternative would be working on the source code in an environment outside of the testbed and as discussed before that solution would bring more negatives than positives. Another limitation of technology we have is a lack of radio to use in testing. Our solution to this problem is to simulate the radios in the testbed as well. With this comes the positive of the ability to run a full test and simulation, however, we will not have the ability to test and adjust our system for real life signal propagation. For this problem there are no existing solutions outside of obtaining radio to use.

3.5 Design Analysis

– Did your proposed design from 3.3 work? Why or why not?

– What are your observations, thoughts, and ideas to modify or iterate over the design?

3.6 Development Process

We will be using an Agile development process. For our project we will need to have the ability to adapt our planning and code to the results of our tests. The waterfall method would not work for us as it does not allow us to adjust our algorithm to meet the test requirements, and the TDD method does not apply as our testing outcomes will be an analysis of the system functionality.

3.7 Design Plan

Describe a design plan with respect to use-cases within the context of requirements, modules in your design (dependency/concurrency of modules through a module diagram, interfaces, architectural overview), module constraints tied to requirements.

4 Testing

For srsLTE, we will just test if its functional and leave the details to the srsLTE team since its their code.

The algorithm we write will be tested for compilations and goes through our own test cases to ensure that it works for values within our chosen domain.

Our algorithm design with srsLTE will be tested using POWDER's test suites.

1. Define the needed types of tests (unit testing for modules, integrity testing for interfaces, user-study or acceptance testing for functional and non-functional requirements).
2. Define/identify the individual items/units and interfaces 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 have determined.

4.1 Unit Testing

Our algorithm will be tested separately within our own test cases.

Our platform, srsLTE, will be tested for basic functionality after setup.

The platform with our algorithm will be tested together using POWDER.

Base-station resources

Each Powder base station site includes a collection of software defined radio devices from National Instruments (NI) connected to Commscope and Keysight antennas. A handful of sites include massive MIMO equipment from Skylark Wireless. Each device has one or more dedicated 10G links to aggregation switches at the Fort Douglas aggregation point. These network connections can be flexibly paired with compute at the aggregation point or slightly further upstream with Emulab/CloudLab resources.

- **Antennas (connectivity defined in SDR equipment section)**
  - **1 x 10-port Commscope VVSSP-360S-F multi-band**
    - **360 horizontal beamwidth, ~20 degree vertical**
    - **8.2 dBi gain from 2.3 - 2.69 GHz**
    - **4.9 dBi gain from 3.4 - 3.8 GHz**
    - **4-port MIMO-capable Cellular elements (1695 - 2690 MHz)**
    - **4-port MIMO-capable CBRS elements (3400 - 3800 MHz)**
    - **2-port 5 GHz elements (5150 - 5925 MHz)**

        - 1 x 1-port broadband Keysight N6850A omnidirectional
            - 50 - 6000 MHz
- NI SDR Equipment
    - 2 x USRP X310 with UBX160 daughtercards
        - Channel 'A' TX/RX and RX2 ports of device 1 through a frontend to a Cellular port of VVSSP-360S-F
        - Channel 'A' TX/RX port of device 2 on a CBRS port of VVSSP-360S-F
        - RF front-end for Band 7 cellular providing FDD, reduced noise figure and 4W maximum (saturated) power
        - No add-on RF front-ends for gain/functionality yet in CBRS
        - 2 x 10 Gbe backhaul links
    - Keysight (broadband) antenna currently unavailable.
- Skylark Wireless Massive MIMO Equipment

- Skylark equipment consists of chains of multiple radios connected through a central hub. This hub is 64x64 capable, and has 4 x 10 Gbe backhaul connectivity. Powder provides "big iron" compute (Dell d840 nodes, see compute section) for pairing with the massive MIMO equipment.

    - Note: Available at Merrill Engineering Building site
    - 32 x IRIS-030-D 2x2 transceiver radios
        - Includes IRIS-FE-03-CBRS front-end modules
        -
            - BRS and CBRS capable: 2555 - 2655, 3550 - 3700 MHz
            - 26 dBm, 2 x 2 TDD
        - Connected to dual-polarized antenna elements
            - 100 degree beamwidth, 5.5 dBi
    - 1 x FAROS-ENC-05-HUB aggregation hub
        - Provides power and connectivity to all IRIS SDRs
        - The 32 SDRs are connected in six chains to hub
            - 4 chains have 4 Iris devices each
            - 2 chains have 8 Iris devices each (extended chains)
            - 13.2 Gbps connectivity across individual chains
        - Trenz TE0808 SOM with XC7U9EG MPSoC

Fixed-endpoint resources

Each Fixed Endpoint (FE) installation in POWDER contains an ensemble of software defined radio (SDR) equipment from national Instruments (NI) with complementary small form factor compute nodes. There is no wired backhaul, though the platform does provide seamless access via cellular/WiFi to resources in an FE installation. Endpoints are mounted at human height level on the sides of buildings.

- Antennas
    - 1 x Taoglas GSA.8841 wideband I-bar antenna
        - 698 - 6000 MHz frequency range
        - Approximately -2 dBi average gain across range
- NI SDR Equipment

- **1 x NI USRP B210 SDR on nuc1**
    - **Channel 'A' RX2 port connected to dedicated GSA.8841 antenna**
    - **Connected via USB 3.0 to NUC host (described below)**
  - **1 x NI USRP B210 SDR on nuc2**
    - **Channel 'A' connected to Band 7 FDD frontend**
    - **RF front-end provides FDD, reduced noise figure and 4W maximum (saturated) power**
    - **Connected via USB 3.0 to NUC host (described below)**
- **Intel NUC Compute**
  - **1 x Intel NUC8i7BEH small form factor PC**
    - **Intel Core i7-8559U**
    - **32 GB RAM (2 x 16GB Corsair Vengeance 2400 MHz DDR4 SODIMM)**
    - **250 GB NVMe storage (Kingston)**

4.2 Interface Testing

Interfacing with srsLTE is done through linux's command lines and the team have decided to trust that it'll work. Same with the POWDER's testing interface as well. As we did not write code for Linux or POWDER, we'll leave the testing to their src code author and just use the lattest upadated version.

4.3 Acceptance Testing

The algorithm's functional requirement is that it outputs the correct results that we can verify. The main requirement is that our algorithm functions at a faster rate than the base srsLTE source code.

4.4 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 the design iteratively as you progress with your project
- If you are including figures, please include captions and cite it in the text

5 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3.

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

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

Z. Wu, B. Wang, C. Jiang and K. J. R. Liu, "Downlink MAC Scheduler for 5G Communications With Spatial Focusing Effects," in *IEEE Transactions on Wireless Communications*, vol. 16, no. 6, pp. 3968-3980, June 2017, doi: 10.1109/TWC.2017.2690432.

Yuwei Xie, Hongwei Zhang, Pengfei Ren, "Unified Scheduling for Predictable Communication Reliability in Cellular Networks with D2D Links," https://www.ece.iastate.edu/~hongwei/group/publications/UCS.pdf

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 data that does not directly pertain to the problem but helps support it, include it 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.