Open-Source Prototyping of 5G Wireless Systems for Unmanned Ground and Aerial Vehicles

DESIGN DOCUMENT

Team 36

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Executive Summary

Development Standards & Practices Used

- 3GPP
- E-UTRAN
- EPC
- IEEE

Summary of Requirements

Primary Requirement:

- Ensure per-packet communication reliability while achieving high throughput/concurrency

Other Requirements:

- Low Latency
- High Throughput
- High Reliability

Applicable Courses from Iowa State University Curriculum

- CPRE 308 - Operating Systems
- CPRE 489 - Computer Networking and Data Transfer
- CPRE 430/530 - Network Security
- CPRE 543 - Wireless Network Architecture
- COMS 486 - Fundamental Concepts in Computer Networking

New Skills/Knowledge acquired that was not taught in courses

As a team we needed to learn about how network scheduling algorithms helped increase reliability and throughput and lower latency. To do this, we first needed to gain an understanding of the various tools needed to simulate the networks in various environments. For this project, we are studying how to meet the above listed requirements in highly mobile vehicular networks. So just to begin, two simulators are needed: one to simulate the network and another to simulate traffic conditions and positions of vehicles. The network simulation is done by software called Open Air Interface and the traffic/vehicle simulation is done by software called SUMO.

Both of these simulators need to interact with each other so the network stack has access to the vehicle positioning data from SUMO. Once this foundation for the project was acquired, to develop the algorithm two research papers were read on algorithms designed for high throughput, low latency, and high reliability. A proposed scheduling algorithm called PRKS was proposed to help meet the reliability requirements of the project, however, it needs to be fully implemented and tested in simulators to verify it's performance vs current solutions. PRKS is built on a scheduling algorithm called PRK and PRKS is the basis of a scheduling algorithm that can meet the requirements of this project. It provides a high level of reliability by coordinating nodes that are close to each other. Ensuring that the reliability between individual nodes is extremely high bubbles up to the network as a whole. This provides high network reliability for nodes in different network and environmental conditions without a prior knowledge of these conditions

To apply PRKS to ground vehicles, some extra work needs to be done because vehicles are highly mobile in most use cases. This is detrimental to the performance of PRKS because there is no way to do predictable interface control in a highly mobile setting. To combat this, cyber-physical scheduling (CPS) is applied to PRKS. This creates a geometric approximation of the PRKS scheduling algorithm. Applying CPS to PRKS allows vehicles to know of each other locality without dedicating large portions of network bandwidth to transport this information to and from each vehicle.

Table of Contents

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

OpenAirInterface (OAI) - Open source software that simulates 3G, 4G, or 5G communication between two devices.

SUMO - Open source software that simulates traffic patterns on a given part of the world.

Unmanned Ground Vehicle (UGV) - A mode of transport, such as a car or truck, that is controlled remotely.

1 Introduction

1.1 Acknowledgement

This project would not be possible without the technical advice, planning advice, and material support of our faculty advisor Hongwei Zhang, and his doctoral student Chen Ye Lim.

1.2 Problem and Project Statement

This project deals with the lack of modern 5G implementations that allow for low latency and high throughput and reliability. Current solutions for 5G networks do not guarantee any type of reliability between two nodes, especially in highly mobile environments like communication between ground or air vehicles. It involves developing and prototyping advanced 5G wireless solutions for unmanned ground and aerial vehicles, which have broad applications in domains such as connected autonomous transportation, smart agriculture, and advanced logistics. Furthermore, creating a highly reliable and low latency 5G network can allow self-driving cars to be safer and could potentially allow doctors to do surgeries from hundreds of miles away. This would keep people safer in more ways than one.

To create a solution to this problem, a new network scheduling algorithm needs to be developed that can help reorganize connections between nodes in highly mobile environments. Two proposed algorithms exist that can meet the requirements of this project, but they need to be implemented and tested in both simulation and real-world environments. These algorithms are called PKRS and CPS. PKRS is an algorithm that allows a network to achieve high reliability between two nodes that are close to each other. CPS takes this a step further and applies cyber physical scheduling (CPS) to extend PKRS to mobile networks, as it was originally intended for stationary nodes. CPS essentially extends PKRS to include data about the nodes positioning relative to each other without dedicating a lot of bandwidth solely to the transfer of positional information. This project will need to use a variation of the CPS algorithm in the MAC scheduling module of Open Air Interface to determine performance metrics associated with the new 5G implementation vs solutions that are currently available on the market.

1.3 Operational Environment

The operational environment for this project will be primarily in vehicles, which means the network will need to be able to operate under a variety of external conditions. However, this project does not deal with the hardware involved in the transfer of information, it is primarily the scheduling algorithm that allows the nodes to communicate with each other. However, we will need to ensure that things like storms, blizzards, and other natural disasters don't hinder the algorithms ability to reach high levels of packet reliability and throughput.

1.4 Requirements

Functional Requirements:

- Low Latency
- High Throughput
- High Reliability
- Interoperability with current solutions

Economic Requirements:

- Easy to simulate to avoid expensive hardware testing and implementations
- Code written to be maintainable (i.e. does not require days of work for simple changes, costing money)

1.5 Intended Users and Uses

This project can have multiple types of end users, as it is an extension of the Internet that almost everyone uses today. Some examples of these are:

- Surgeons - With low latency and high reliability, surgeons would be able to operate on patients from hundreds of miles away, giving everyone more access to better healthcare.
- Self Driving Cars/UGV's- Meeting the requirements of the project will also allow cars to communicate safety information between each other in near real time.
- Military Applications - This project would also allow for the control of ground vehicles from a distance. Transport trucks and scouting vehicles could be controlled in near real time by an operator far from the site of the vehicle, increasing the safety of those involved.

1.6 Assumptions and Limitations

Limitations:

- 5G signals are low range and degrade quickly
- May apply for ground vehicles or air vehicles, but not both due to environmental differences

Assumptions:

- Supports networks where there is fairly flat ground between nodes (i.e. no mountains).
- Supports vehicle networks where vehicles (i.e. nodes) aren't extremely sparse.

1.7 Expected End Product and Deliverables

Algorithm Simulation/Extension (January - Febuary 2020)

This is the primary deliverable associated with the project. To achieve the requirements of the project, the algorithm needs to be implended in Open Air Interface and tested by using SUMO to deliver traffic data and vehicle positions which Open Air Interface will use to simulate the network scheduling algorithm. To ensure that this deliverable meets the requirements listed above, the new scheduling algorithm will be tested and its performance measured to allow us to compare it to current solutions.

Report / IEEE article <IEEE Communications Magazine>

Because this project deals with a fairly new and upcoming technology, it would be extremely valuable to report our work done on the 5G communication between mobile nodes so others have access to our research on the subject. This work would be in parallel with the algorithm design and simulation. The plan is to try and have something published to further the research on low latency, high throughput and reliability mobile networks.

2. Specifications and Analysis

2.1 Proposed Design

Our proposed solution is to integrate a 5G algorithm written by Hongwei Zhang and his team into Open Air Interface and to simulate the implementation using with SUMO. We will do this by spending two months preparing and learning about the software needed,writing the software and integrating it, and the rest testing with the hardware and working on a final report.

All of our code is following standards set by 3GPP, including E-UTRAN and EPC. We are modifying the code rather than changing the stack completely, so it should follow those standards before and after.

2.2 Design Analysis

Due to the scope of the project focusing heavily on scheduling algorithms and using the Open Air Interface/SUMO, the team will need to research and understand some of the requirements that would need to be met.

As a team we have yet to see the algorithms of our design implemented and through our own research are currently gaining an understanding of how to utilize, OAI, SUMO, and other 5G utilities.

As it stands, we are all still learning about OAI and SUMO, so there haven't been any reasons to modify or change the scope of our project. A strength is that using OAI and SUMO we will be able to continuously test/debug any problems we have with the algorithm we are trying to implement. However, the raw content is new to each member to the time to learn the material will be large.

2.3 Development Process

We will be using the Waterfall model for our project. We were looking at Agile initially but we don't have a specific customer and our project cannot have continuous updates since it relies on a lot of research beforehand. We also cannot meet in person every day due to conflicts in schedules for team members. Waterfall lends itself to individual stages, which is the only real way we can do our project.

2.4 Design Plan

The emphasis of the packet scheduling algorithms currently being used in Open Air Interface is throughput in a non-mobile network. The plan for our design is to replace the scheduling algorithms already in Open Air Interface with a new algorithm provided by our faculty advisor. This implementation must fit within the existing architecture of Open Air Interface. Then, using SUMO we will be able to simulate a network of vehicles to feed data into Open Air Interface to simulate how the scheduling algorithm will perform. Using the metrics from these simulations, we will be able to compare to the previous benchmarks for other algorithms and determine if we've met our requirements as outlined in section 1.4.

3. Statement of Work

3.1 Previous Work And Literature

3.2 Technology Considerations

3.3 Task Decomposition

3.4 Possible Risks And Risk Management

3.5 Project Proposed Milestones and Evaluation Criteria

3.6 Project Tracking Procedures

3.7 Expected Results and Validation

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

4.2 Feasibility Assessment

4.3 Personnel Effort Requirements

4.4 Other Resource Requirements

4.5 Financial Requirements

5. Testing and Implementation

5.1 Interface Specifications

5.2 Hardware and software

5.3 Functional Testing

5.4 Non-Functional Testing

5.5 Process

5.6 Results

6. Closing Material

6.1 Conclusion

6.2 References

6.3 Appendices