Design Document

Open-Source Prototyping of 5G Wireless Systems for Smart Ag, Autonomous Vehicles and Beyond

sdmay19-04

Team Member

- Hye-Sung Moon (LTE-5G Researcher)
  Email: mhss5458@iastate.edu
- Jaime Zetina (OAI Researcher)
  Email: jzetina@iastate.edu
- Anthony Benson (OAI Researcher)
  Email: anthonyb@iastate.edu
- Khanh Luu (OAI Researcher)
  Email: kdluu@iastate.edu
- Jared Gorton (LTE-5G Researcher)
  Email: jmgorton@iastate.edu
- Theodore Miller (LTE-5G Researcher)
  Email: tgm@iastae.edu

Team Website: http://sdmay19-04.sd.ece.iastate.edu/team.html

Adviser/Client: Prof. Hongwei Zhang

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List of Acronyms

AV (Autonomous Vehicle)

BS (Base Station)

CPS (Cyber Physical Scheduling)

dBi (decibel Isotropic)

ER (Exclusion Region)

ETG (Electronic Technology Group of Department of Electrical and Computer Engineering at Iowa State University)

eNB (eNodeB)

HW (Hardware)

IoT (Internet of Things)

OAI (Open Air Interface)

PRK (Physical-Ratio-K)

PRKS (Physical-Ratio-K Scheduling)

SNR (Sound to Noise Ratio)

SUMO (Simulation of Urban Mobility)

SW (Software)

TRaCI (Traffic Control Interface)

UCS (Unified Cellular Scheduling)

UE (User Equipment)

USRP (Universal Software Radio Peripheral)

V2V (Vehicle to Vehicle)

VM (Virtual Machine)

1 Introduction

1.1 ACKNOWLEDGEMENT

Our team would like to thank Professor Zhang Hongwei, who is our adviser as well as client. We also would like to thank PhD student Yuwei Xie, who has assisted us with his research on using the PRKS algorithm over OAI.

1.2 PROBLEM AND PROJECT STATEMENT

The general public is in need of a wireless network that will allow information to be received, processed, and sent at a minimum reliability, while maximizing concurrency and throughput. These requirements will allow an autonomous vehicle to operate safely in urban areas. Current 3G and 4G wireless technology does not provide a solution for these requirements. Reliability is one of the biggest problems with current networks. The current network scheduling protocols are unable to overcome interference from other nearby vehicles also trying to communicate either at the same time or same bandwidth.

Our goal is to provide a network that is capable of providing the maximum reliability. Through the implementation of the Cyber Physical Scheduling (CPS) algorithm in OAI we will create a network that can guarantee predictable reliability. This will be a step towards allowing autonomous vehicles to operate safely in urban areas, where there is a high potential for interference.

1.3 OPERATIONAL ENVIRONMENT

The operating environment is ideally everywhere and anywhere IoT's can be found. IoT's include fully autonomous devices such as autonomous vehicles (AVs) and autonomous agricultural tractors on the roads and farms in every city. The network must work in every location, from the most dense city to the most rural of county sides, with the same low latency and most importantly the highest predictable reliability.

Specifically, we are focusing our main efforts on applications that require real time data processing to make decisions as fast or faster than that of the human mind. The AVs will be our main focus. We must ensure their communication maintains the promised low-latency and predictable reliability to make the split second decisions required for safe autonomous operation. AVs will be operating under extremely congested areas of communication. The network will need to perform adequately in these environments and the implementation of CPS over OAI 5G simulation will deliver this.

1.4 INTENDED USERS AND USES

Our project has limited the scope of our design to be about self driving cars. The way the project intends to work is by reducing interference when vehicles are communicating. The main use of our project will be to facilitate better communication between AVs. While this will more than likely be a necessary component in most AVs, our focus will be in areas with traffic. As a result, the use of the project will be reduced interference in communication between AVs.

The main users of this product will be the automotive industry. Normal people will most likely never even hear of what we are making. It will be the people in the automotive industry who are building autonomous vehicles that will inevitably use our software. They will use it to have the AVs communicate and schedule transmissions. This will be done in order to stop interference that would result from multiple vehicles transmitting to different base stations at the same time.

1.5 ASSUMPTIONS AND LIMITATIONS

We assume the autonomous vehicle and the IoT industries will grow exponentially. The importance of high speed, low-latency, and predictable reliability network systems are emphasized. One of the most promising options is the 5G network. The 5G network will provide a data rate that is 20 times faster than that of the 4G network. In addition to this, the error rate and latency will be near zero. We are expecting that our simulation will fulfill the high reliability as well as low latency required to operate a successful V2V network.

One limitation we are bound by is the availability of hardware for testing our algorithm. We have the ability to use five nodes in our system during testing. We will also be able to test the algorithm using software simulations. In this area, we are limited by the computational abilities of our machines. However, we will be making the assumption that these tests and simulations will be representative of larger and more complex systems.

Given the fact that we are designing a communication algorithm that focuses on reliability, there is still the factor of latency. However given the scope of our project we will be mainly focusing on reliability instead of latency.

1.6 EXPECTED END PRODUCT AND DELIVERABLES

The expected end product of our project is a CPS algorithm implemented using OAI. OAI will run the basic code for communications between vehicles. Our job is to create a program that works in tandem with OAI to reduce interference in vehicle to vehicle communication. What we develop will be an add-on to OAI that schedules communications between vehicles to minimize interference. The range will be limited to the vehicles in the immediate vicinity. Each vehicle will be running both OAI and our developed CPS add-on.

2. Specifications and Analysis

2.1 PROPOSED DESIGN

Our project is divided into two major components: virtual simulation and physical implementation. First, we will run the simulation of the CPS algorithm over OAI and SUMO. In the software simulation, we will be able to run multiple UEs and check the reliability when the system has at least 75 UEs. However, when it comes to the hardware implementation, we are limited by how many units are available for use, so we are going to use 5 SDRs during the physical testing process to verify the CPS algorithm for correctness.

Figure 1: V2V Communication [10]

2.1.1 Software Simulation:

Our proposed software simulation will be based on OAI. For V2V wireless channels, we will implement in OAI a channel model based on the real-world.

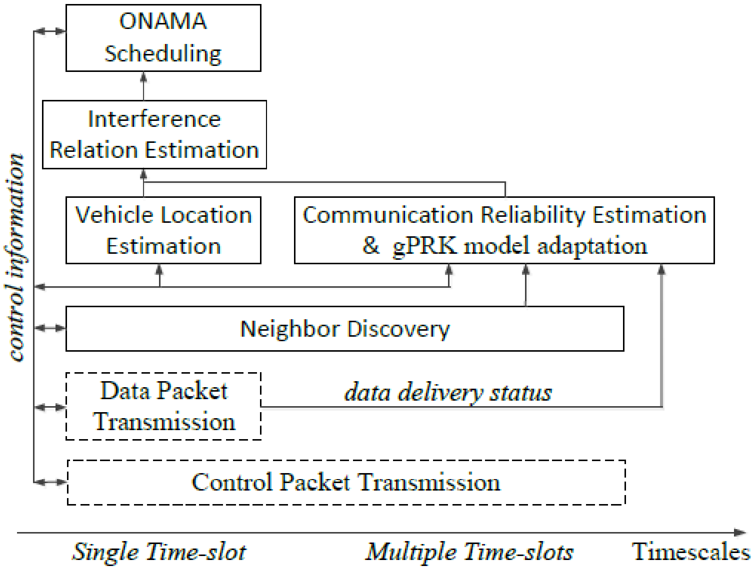

Figure 2: Cyber Physical Scheduling (CPS) Framework [8]

Unlike conventional communication systems, the advantage of the CPS algorithm is that it does not need the base station, because each UE can communicate with the others to overcome the interference and maximize the reliability of overall communications. The CPS algorithm we will be implementing is based on the PRKS algorithm. The number of UE nodes that we will be using is dependent on our processing power, but should be at least 75.

The AV data packet contains the information of the vehicle's status for the surrounding vehicles. However, in our simulation, the required information that is needed to build the PRKS will be included, so that the CPS algorithm can schedule the transmission and avoid co-channel interference.

For vehicle mobility dynamics, we use the SUMO simulator that simulates vehicle traffic flow dynamics at high-fidelity based on real-world road and traffic conditions of Ames, Iowa, USA. To integrate these two systems, we will use the TraCI (Traffic Control Interface) of SUMO.

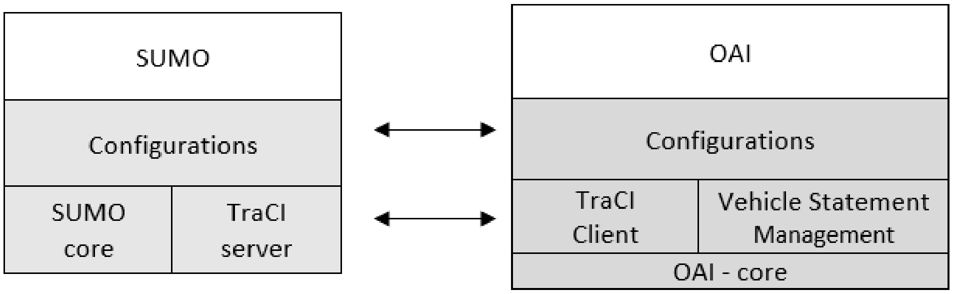

Figure 3: Integration of SUMO with OAI

After integrating OAI with SUMO, we will be able to check the reliability of the communication when considering the dynamics of a system with 75 mobile UEs. This environment can reflect the real-world road condition.

2.1.2 Hardware Implementation:

Due to the limited number of SDRs that we have available for use, we will be unable to run physical tests of the same magnitude as the virtual simulation. However, the fundamental mechanics of the scheduling algorithm should be the same regardless of the size of the network. The proposed hardware implementation will be performed in Iowa State's campus with five vehicles mounted with SDRs. The SDR B210s will be mounted on each vehicle, OAI's UE with our CPS addition will be uploaded into SDR. With the VERT 2450 antennas, each vehicle will communicate and check the transmission and receiving signals from the surrounding UEs.

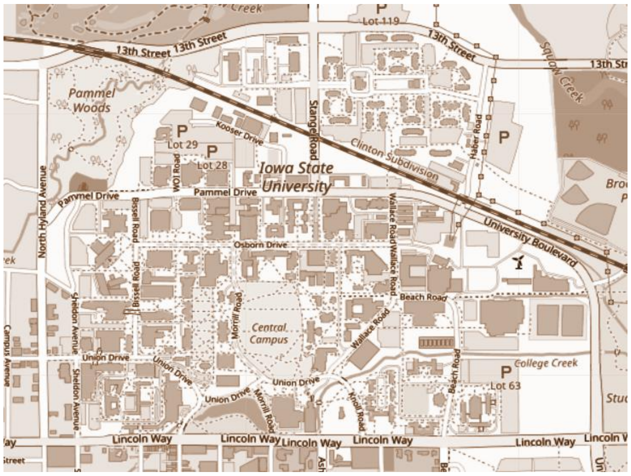

Figure 4: Map of Iowa State Campus. [12]

Figure 5: VERT 2450 Antenna[13]

Figure 6:SDR B210 (Board Only)[11]

2.2 DESIGN ANALYSIS

The proposed design will present a solution to interference between V2V communication. Integrating with SUMO, the simulation can provide a more realistic V2V communication environment. The algorithm built over OAI is highly compatible with SDRs, and as a result, this project can provide a more realistic platform.

The CPS algorithm over the OAI framework will be heavily based on the software simulation, therefore the following strengths and weaknesses are expected:

2.2.1 Design Strengths

1. The advantage of using OAI is that OAI can implement the full protocol stack to run on a real execution environment respecting frame timing constraints. As a result, it is a more realistic platform (even in simulation) and has high compatibility with a SDR.
2. Our design is integrated with SUMO, so we can provide the mobility dynamics of a moving vehicle to UEs. As a result, it can reflect the real-world communication environment.
3. Our implementation will achieve reliability figures well beyond what other implementations have been able to achieve.

2.2.2 Design Weaknesses

1. The algorithm, at this stage, will not consider obstacles such as buildings, terrain, weather, or other possible physical obstacles that exist in the real world. The

parameter-K can take these factors into consideration, but that is outside the scope of our implementation.

2. Because the algorithm is mostly focused on reliability, latency is a secondary priority in this project. In more advanced implementations, this issue will need to be resolved in order for V2V communication to be safe.
3. Our project is using a platform (OAI) that is currently being modified regularly, and as a direct result, our product depends heavily on updates to OAI. When OAI receives an update, our project may possibly need to be updated as well, depending on the backwards-compatibility of the update.

3. Testing and Implementation

3.1 HARDWARE AND SOFTWARE

Hardware:

The hardware implementation will be performed with a number of SDRs equipped with antennas. OAI with the CPS algorithm implemented into it will be installed onto the SDRs and will communicate with each other via antennas.

- USRP B210 SDR - Several USRP B210 SDRs will be used for real world testing of the CPS algorithm. The reason we will need to utilize these SDR's is because they are currently the most affordable radio devices that are compatible with OAI and capable of short and long range transmission, which is needed for our UE to UE communication.
- Antenna - VERT2450 Dual Band 2.4 to 2.48 GHz and 4.9 to 5.9 GHz omni-directional vertical antenna, at 3dBi Gain.
- Ubuntu ETG Server - Our laptops are not able to perform the simulation. This server will make up for the limitation of computing power that we currently have. The server will be given to us by Iowa State. It is currently our best option.

Software:

Listed softwares are the most important parts of our project. CPS algorithm will be built over OAI network simulator. To provide the vehicle dynamic, we will use SUMO and integrate with OAI. Both softwares are operating over Linux OS, we will use an Ubuntu virtual machine to run these softwares.

- OAI - OAI's built-in simulator will be used for software testing and simulations. OAI can implement the full protocol stack to run on a real execution environment respecting frame timing constraints which make the algorithm built over OAI compatible with the SDRs.

- SUMO - SUMO will be used for simulation of traffic and to provide vehicle dynamics to UEs.
- Ubuntu - Ubuntu Version 16.04 LTS with low-latency kernel v4.8.15 which is required to run the OAI.

3.2 FUNCTIONAL AND NON-FUNCTIONAL TESTING

The main purpose of our algorithm is to reduce the communication interference between vehicles to maintain the high reliability of communications.

1. **Reliability:** The reliability is the essential part of V2V communication. Conventional network system scheduling protocols are unable to overcome the interferences between vehicles. Theoretically, we can obtain high reliability with the CPS algorithm, and we will test through simulation with OAI and SUMO.
    a. **Test Method:** Tests will be implemented by sending the certain number of data packets (Rx) and checking the successfully received data packets (Tx). The reliability will be measured as, Tx/Rx * 100.
    b. **Expected Results:** We expect that we can obtain more than 90% reliability over simulation ((Tx/Rx * 100) > 90) or packets lost less than 10%.

2. **Delay:** Delay is the other factor that we need to consider for simulations. In fast moving vehicles, a tiny amount of time delay can be a tremendous difference. The latency for 5G is conceptually around 1 ms. However, we will not be able to obtain this goal. The delay level will be as same as 4G network.
    a. **Test Method:** We will timestamp events and then calculate the time difference between events.
    b. **Expected Results:** Current 4G network has a delay of 50 ms. Although it is not good enough for AVs, due to practical limitations, we expect that delay will be similar to the 4G network. In a crowded region, we expect more than 50 ms.

3. **Concurrency:** The number of simultaneous non-interfering transmissions in the same time slot is one part we should consider.
    a. **Test method:** In each time slot, we will count the number of active transmissions between nodes.
    b. **Expected results:** We expect to have high number of non-interfering concurrency with the CPS algorithm to ensure high reliability, high throughput, and low latency.

4. **Throughput:** The rate of successful packet transmission with respect to time should be maximized, but is a low priority than concurrency.
    a. **Test method:** We will measure the number of the packets per unit time for each communication. Each packet is 1kB.
    b. **Expected results:** Using the CPS algorithm, we expect to retain high throughput representing a high successful packet delivery ratio.

3.3 IMPLEMENTATION ISSUES AND CHALLENGES

The first challenge we faced as a group was having to learn how to install and operate OAI. OAI is needed as our simulation platform, it will allow us to run a simulated real time prototype 5G network using eNBs (base stations) and UEs (our autonomous vehicles). The issue of this particular challenge is that OAI software is very particular to what operating system it will properly function within. OAI is difficult to set up with no prior experience. It requires an advanced understanding of the Linux Ubuntu operating system.

Secondly, we faced a challenge of understanding the algorithms PRKS, UCS, and CPS, at a fundamental level. We must be able to manipulate the algorithms to work for our desired purpose of simulating a congested urban area with multiple UEs communicating with each other while overcoming the co-channel interference and providing an average package delivery rate of 90% reliability.

Thirdly, hardware has become an issue; in the beginning, our laptops had proven to handle the processing demand. However, the increasing demand of processing power due to the increasing packages being added to our OAI simulation platform has led us to request a virtual machine from the ETG office. As we move closer to our goal we find that we may need to request hardware support from the ETG office to meet certain specifications that are demanded from the OAI for transition from a simulation environment to hardware environment implementation. The ETG office has expressed the ability to support such a request as they have an allowed amount of funds dedicated to supporting senior design projects.

4 Closing Material

4.1 CONCLUSION

Our project aims to better communications between AVs by reducing interference. This will be done by having vehicles in the vicinity of each other create a schedule for communications. This also will be done using a CPS algorithm that will determine the timing and strength of each vehicle's transmissions. The CPS algorithm will be implemented as an add-on to OAI, which will run the base communications for the vehicle.

We will test the implementation of our algorithm in two different ways. First we will test it using a simulation software called OAI and SUMO, which will simulate vehicles running our algorithm. The second test will be a physical test using SDRs to enable the communication. We will attach them to our cars and drive around to simulate mobile UEs. When all the testing is done, we should have a fully functional and efficient CPS algorithm.

5 References

[1] E. Dahlman, S. Parkvall, and J. Sköld, *4G, LTE-Advanced Pro and the Road to 5G*, Amsterdam: Elsevier, 2016.

[2] Open Air Interface, "Open Air Interface", *Open Air Interface*, 2018. [Online]. Available: http://www.openairinterface.org/. [Accessed Oct. 24, 2018].

[3] Sumo. SUMO - Simulation of Urban Mobility, *German Aerospace Center, Institute of Transportation Systems*, 2018. [Online] Available at: http://sumo.dlr.de/index.html [Accessed Oct. 24, 2018].

[5] A. Woo, "Evaluation of Efficient Link Reliability Estimators for Low-Power Wireless Networks", 2018. [online] Available at: http://digitalassets.lib.berkeley.edu/techreports/ucb/text/CSD-03-1270.pdf [Accessed 24 Oct. 2018].

[6] Ubuntu, "Ubuntu" *Canonical*, 2018. [Online]. Available: https://www.ubuntu.com/. [Accessed Nov. 12, 2018]

[7] H. Zhang, "Scheduling with Predictable Link Reliability for Wireless Networked Control", 2018 [Online] Available at: https://www.ece.iastate.edu/~hongwei/group/publications/PRKS-TWC.pdf [Accessed 24 Oct. 2018].

[8] H. Zhang, "Cyber-Physical Scheduling for Predictable Reliability of Inter-Vehicle Communications", 2018. [Online] Available at: http://www.ece.iastate.edu/~hongwei/group/publications/CPS-IOTDI18.pdf [Accessed 24 Oct. 2018]

[9] H. Zhang, "Link Estimation and Routing in Sensor Network Backbones: Beacon-based or Data-driven?", 2018. [Online] Available at: http://www.cs.wayne.edu/%7Ehzhang/group/publications/LOF-TMC.pdf [Accessed 24 Oct. 2018].

[10] L. Carrillo, "vehicle-to-vehicle communications", 2016. [Online]. Available at:

https://www.a1autotransport.com/how-v2v-technology-will-make-driving-more-safe/.

[Accessed Nov. 12, 2018].

[11] "URSP B210(board only)", 2018. [Online]. Available at:

https://www.ettus.com/product/details/UB210-KIT. [Accessed 12, Nov. 2018].

[12] OpenStreetMap, “OpenStreetMap”, *OpenStreetMap*, 2018. [Online] Available: https://openstreetmap.org [Accessed 12 Nov. 2018].

[13] “Vert2450 Antenna”, 2018. [Online]. Available: https://www.ettus.com/product/details/VERT2450. [Accessed 2 Dec. 2018].