Project Plan

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

sdmay19-04

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List of Acronyms

AV (Autonomous Vehicle)

BS (Base Station)

CPS (Cyber Physical Scheduling)

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 Introductory Material

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 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 Open Air Interface (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 Operating 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 Intended 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 Other 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 Proposed Approach and Statement of Work

2.1 OBJECTIVE OF THE TASK

The goal of this project is to create an add-on to the open source software OAI. The add-on will be a scheduling algorithm called CPS, which will help reduce interference for AV's. After the add-on is done we will test it using a traffic simulation software known as SUMO, which integrates well with OAI. When our program produces the desired results, we will implement it physically using SDR's.

2.2 FUNCTIONAL REQUIREMENTS

Our project has two parts of implementation: software simulation and hardware implementation. Each part has different requirement as follows:

Software:

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.

OAI:

- Ubuntu 16.04 LTS
- Low-latency kernel version 4.8-15

SUMO:

To reflect the real-world road conditions, the following specifications need to be set:

1. Vehicles' location
2. SUMO sample map: Ames
3. Setting the speed limits on the road:
    a) Small city street: 25 mph
    b) On I-35: 70 mph
4. Desired communication range: 1 - 150m

Figure 1: Map of Ames IA, USA[12]

Hardware:

Based on the CPS algorithm running over OAI, we will upload the algorithm to the SDRs and perform real-road testing. Five SDRs, antennas and vehicles are required.

- SDR - USRP SDR B210
- Antenna - VERT 2450
- Vehicles - Personal vehicles

2.4 Previous Work And Literature

Our advisor, Prof. Zhang, has already done research on V2V communication with CPS. In his work, the simulation was ran over SUMO and ns-3. ns-3 is a widely used network simulator. During this simulation, he experimentally analyzed the behavior of CPS by integrating high fidelity ns-3-based wireless network simulation and SUMO-based vehicle dynamics simulation. Based on this research, we are going to make a simulation over a different OAI communication simulator. The advantage of using OAI is that it 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).

2.5 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 five SDRs during the physical testing process to verify the CPS algorithm for correctness.

Figure 2: V2V Communication [10]

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.

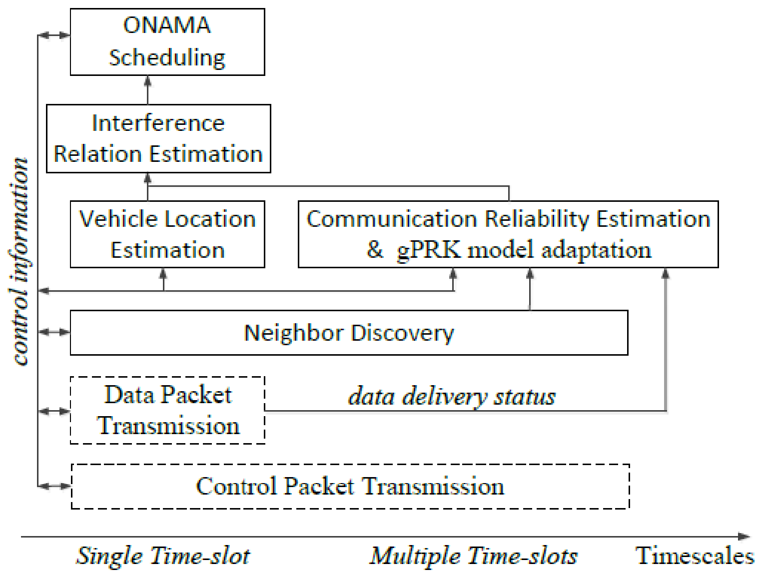

Figure 3: Cyber Physical Scheduling (CPS) Framework [8]

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.

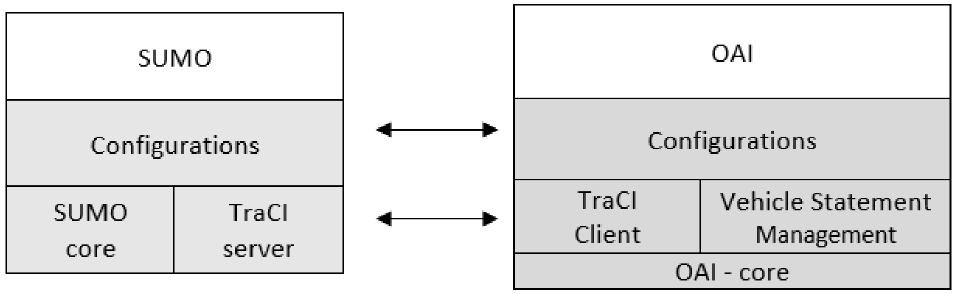

Figure 4: Integration of SUMO with OAI

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.

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.

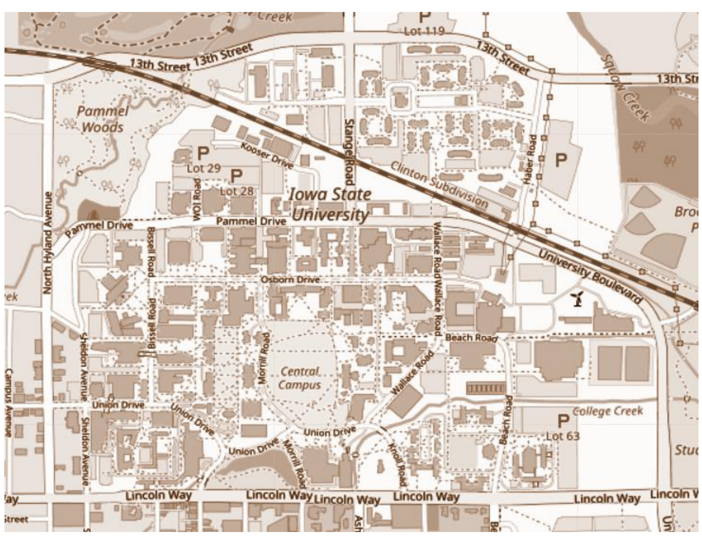

Figure 5: Map of Iowa State Campus [12]

Figure 6: VERT 2450 Antenna[13]

Figure 7:SDR B210 (Board Only)[11]

2.6 Technology Considerations

The main constraint of the algorithm is that we must consider nodes in the system within a geometric approximation of the Physical-Ratio-K, gPRK, and give them an opportunity to transmit within a given time constraint. This time constraint and the gPRK are relative to the system constraints based on the strength of transmissions as well as the importance of fast communication in different scenarios. For our tests, we will be using 150m as our benchmark requirement. Another important consideration to make is the fact that this algorithm is not just applicable to a 2D plane, but to a full 3D space. This is due to the fact that transportation infrastructure tends to operate in a 3D space -- i.e. planes and aerial vehicles, ground vehicles using overpasses, tunnels, parking garages, etc.

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.

2.7 Safety Considerations

Part of the project will require that we drive around the city simulating a moving node. This will require that we use safety precautions while driving, such as seat belts, attentive driving practices (i.e. no texting while driving), and make sure that our cars are up to standards with things such as airbags and brakes.

The inherent design will improve the safety of V2V communication, by minimizing the potential for nodes to interfere with each other while communicating. This increased transmission reliability will prevent miscommunication between vehicles which often can lead to dangerous situations in practice. However, the security of our system is not being considered, as this is outside the scope of this project.

2.8 Task Approach

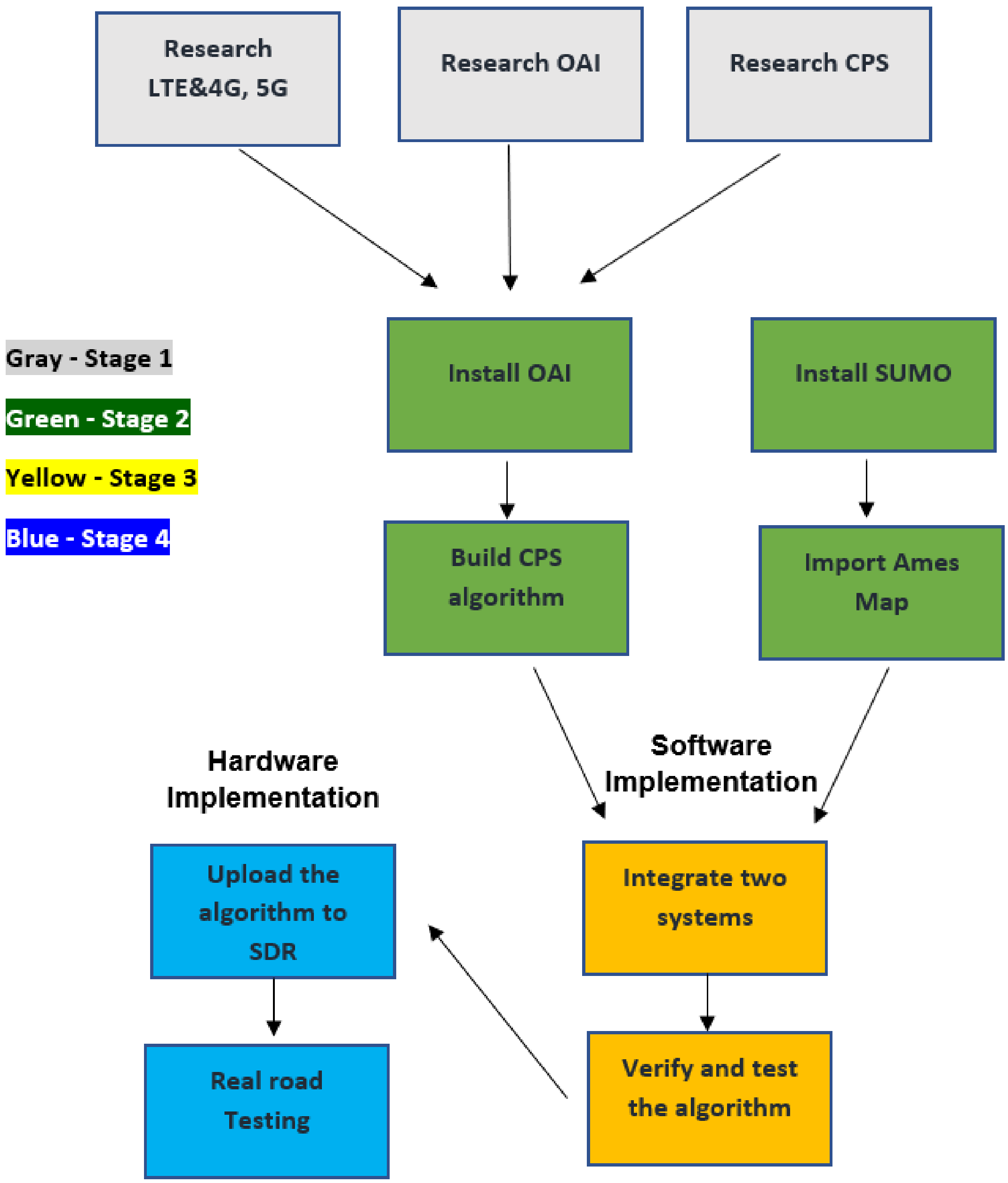

Figure 8: Task Approach Overview

The first part of the project will mainly be focused on research. The research will be broken into two different categories in order to maximize efficiency. One category will be CPS and the other will be OAI. CPS will involve more research and will focus on developing a CPS algorithm. OAI will have less of a focus on research and will mainly be getting the software up and running. After we acknowledge CPS and relevant materials, we will install the OAI and SUMO. We will build the CPS algorithm over OAI simulation and import the Ames map using SUMO. When both simulations are done, we will integrate these two systems and test it.

Once our CPS algorithm runs successfully we will upload the algorithm to the SDRs. We will mount the each SDR to a vehicle and drive around Iowa State's campus to verify the simulation results and check the functionality of the algorithm we've built.

2.9 Possible Risks And Risk Management

There are several risks that the project will face over the course of its life. One of the biggest risks will be that we are using an open source software as the base of our project. This would mean that we are at the mercy of updates to the software. With that in mind we decided to use a single version of the software and not update, so we can work in a controlled environment and focus only on our algorithm. Another risk is that we are going to do our final testing on physical hardware that hadn't been a part of the process before that. So we have allocated extra time to the integration of our software and the hardware.

Computing power was another risk that needed to be dealt with. OAI takes quite a bit of computing power and so does SUMO. In order to test our project we will need to simulate around 75 UEs. We just don't have the computing power to do that with our laptops. To deal with this risk we asked Electronic Technology Group (ETG) to set up a server for us. This server has more computing power than our laptops and should be enough to deal with the simulation. This brings up another risk of the project which is the fact that OAI has to run in a very specific environment. It needs to be on Ubuntu 16.04 with low-latency kernel 4.8 installed. To fix the issue of having to redo figuring out all the steps to get it running we created a step by step list to follow on how to get OAI up and running.

2.10 Project Proposed Milestones and Evaluation Criteria

Most of the materials for this project are completely new for our team, our first milestone is to research current 4G network systems and concepts of 5G. At the same time, we also needed to research CPS which is the key factor of our algorithm. We needed to research OAI, as well how to install and run it. We validated it by communicating with our adviser.

The second milestone is building and running the CPS algorithm over OAI. OAI is running over Linux OS, and requires a specific environment to operate. We installed Ubuntu 16.04, with low-latency kernel v4.8. We need to build the CPS algorithm over OAI, running around 75 UEs. To provide OAI's UE with the mobility dynamics of a vehicle, we are going to use SUMO. To verify it, we will need to check the reliability (more than 90%) of the algorithm over simulation.

The last milestone is to implement and verify the algorithm with real-road testing. We will drive around Ames with our own vehicles and verify the simulation. To verify it, the implementation results should be similar to the simulation results.

2.11 Expected Results and Validation

The main purpose of our algorithm is to reduce the communication interference between UEs to maintain the high reliability of communications. We expect our implemented CPS algorithm to achieve the stated 90% communication reliability in the scenario of V2V communications.

2.12 Test Plan

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 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

Assignment	9/3 - 10/12	10/13 - 10/26	10/27 - 12/14	1/7 - 1/31	2/1 - 2/15	2/16 - 3/30	4/1 - 5/1
Read 4G LTE Advance Pro and The Road to 5G							
Research Unified Cellular Scheduling							
Research Cyber Physical Scheduling							
Research PRK paper							
Instialling OAI							
Verify the OAI program on Linux OS							
Installing SUMO							
Verify SUMO program on Linux OS							
Build Network System on OAI							
Build Sample map of Ames on SUMO							
Integrate OAI with SUMO							
Verify the simulation							
Test the simulation to meet the requirements							
Hardware Implementation							
Trobuleshooting the simulation							
Validate and finalize the simulation							

Table 1: Timeline of proposed work schedules

Due to our particular situation for our project, we spend most of our time researching the 5G network and the relevant materials that we require.

The first half of the Fall 2018 semester will be assigned for the research of LTE and conceptual 5G and relevant materials. The second half of the Fall 2018 semester, we are going to install OAI and SUMO on Linux based systems. These two programs have very specific requirements to run. To set up a Linux based system, we used an 'Ubuntu' virtual machine. The first half of the Spring 2019 semester, we will build and test the OAI network system and build the map of Ames over SUMO and validate the systems. The second half of the Spring 2019 semester, we will integrate SUMO into OAI and test the simulation to meet the requirements. Once the algorithm is successfully running, we will upload the algorithm on SDRs and will implement the real-road testing.

3.2 Feasibility Assessment

Realistically we have the necessary information to fully implement the CPS algorithm over the open source prototyping platform creating a 5G prototype network. The steps that are outlined in this project plan demonstrate a step by step approach to achieve this goal. Our time line is set with realistic milestones that are within our capability of completing. We have planned and focused deadlines for our progress. Hardware resources that are required to complete this project are our laptops to fully implement simulations through Ubuntu in conjunction with SUMO for real time data analysis of V2V network communication. Information resources that are available for our project are published works regarding 5G principles, UCS, CPS, PRKS, and future visions of the network. This includes but is not limited to paper listed in the references. At this time we see no requirements for funds. We have scheduled weekly meetings to allot time to ensure our milestones are being met and any issues are being discussed and resolved.

3.3 Personnel Effort Requirements

Task	Description	Estimated Time(hours)
Research 4G LTE and Concepts of 5G	Acknowledge the conventional communication system and the future 5G concept.	100
Read PRKS and CPS papers	CPS is the key algorithm that we are going to implement, and CPS is based on PRK.	50
Installing OAI and SUMO	These two programs are key programs to run the simulation. We will run these program over virtual machine 'Ubuntu'.	80
Build the network system over OAI	Building CPS algorithm over OAI.	120
Build sample map over SUMO	Import the Ames map on SUMO.	60
Integrate OAI with SUMO	For vehicle dynamic, we will integrate SUMO with OAI.	150
Test and Verify the Simulation	Finalize the simulation and test to meet the requirements.	60
Hardware Implementation	We will upload the CPS algorithm on SDRs and drive around Ames to verify the simulation.	60

Table 2: Task-by-task basis timeline

3.4 Other Resource Requirements

We need 5 vehicles for hardware implementation. We will use our personal vehicles for the implementation.

3.5 Financial Requirements

Item	Description	Budget ($)
OAI	Network simulator: Open Source SW.	0
SUMO	Simulation program for urban mobility: Open Source SW.	0
LINUX OS	OS: We will use virtual machine 'ubuntu': Open Source SW.	0
PC	We are going to use our own laptops as well as a provided server to run simulation.	0
VERT 2450 Antenna	It will be provided by Dr. Hongwei.	0
SDR B210	It will be provided by Dr. Hongwei.	0
Fuel (Vehicle)	For fuel for real-world mobile UE testing	500

Table 3: Budget

The server that our simulations will be ran on will be provided by Iowa State University. Since our project is simulating the algorithm and the required SWs are all open-source, and the hardware will be provided by our adviser Dr. Hongwei, the total budget is only subject to the fuel.

4 Closure Materials

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.

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