Networking Team Project

The Course Project Goals

1. Developing an application as a team
2. Gaining network and network protocol design skills
3. Researching trending application domains
4. Developing project documentation skills
5. Experiencing team dynamics

The Application Domain

Smart city applications are gaining attention in recent years. One particular application domain is smart traffic. Autonomous (or Smart) Intersection Systems will be an important part of smart traffic systems. The application of this project is an Autonomous Intersection Management System (AIMS). This application may also be called Smart Intersection Management System. See the details related to this application at the end of document.

The Project Goal

You will research, develop, and implement a networking protocol for autonomous/smart intersection management systems. You will develop a running simulation application and a protocol document detailing the protocol details.

The Project Team

This will be a team project. The team size will be 5. There may be various roles within the team such as the project manager, the technical manager, the researchers, the designers, the developers, the testers. A person may assume multiple roles.

Minimum Required Effort

<u>Each of you at least put 4-5 hours of work every week to be successful at this project.</u> This is in addition to your normal coursework.

Advised Project Development Approach

1. Determine the roles in the team
2. Develop a schedule
3. Research the autonomous intersection domain

4. Research current vehicle to vehicle (VxV) and vehicle to infrastructure (VxI) protocol development efforts
5. Research how to document a networking document
6. Determine the development tools (The programming language, the Integrated Development Environment (IDE), configuration management tools (such as GitHub), etc.
7. Develop requirements
8. Design the networking protocol
9. Design and implement the application
10. Test the application
11. Document the protocol
12. Document the design
13. Deliver deliverables

The Development Tools

You will use OMNET++, a network simulation tool.

The Deliverables

1. The project vision document (Includes your research notes, references)
2. The project plan
3. The software requirements document
4. The software design document
5. The software test document
6. The running simulation application code
7. The protocol specification
8. Other deliverables that may support your project

Note. There will be deliverables on specific dates. I will review these deliverables. You may (and will likely to) deliver new versions of these deliverables after the assigned date. If you seek feedback, I will provide feedback. You will be graded based on the deliverables at the final project delivery date.

How the Project Will be Assessed

1. The depth and breadth of your protocol design (How well you cover the actors and their properties in the protocol, how well you handle various use cases with your protocol design, etc.)
2. How you handle the project as a team (The plan, the roles, the schedule, on-time delivery)

3. The quality of your documents
4. The quality of your application

Note. I was a software program and project manager for a long time. I reviewed and approved many deliverables related to projects costing multi-million dollars. Throughout the years, I naturally developed skills on understanding how much effort is put into developing a particular deliverable.

Autonomous Intersection Management System (AIMS) Introduction

Intersections are a critical part of road systems. Current traffic lights are inefficient in heavy traffic. Traffic congestion costs billions of dollars to nations. According to the 2021 Urban Mobility Report for the USA, from 2000 to 2019, traffic delay rose from 5.1 to 8.7 billion hours, wasted fuel rose from 2.4 to 3.5 billion gallons, excess greenhouse gas emissions rose from 25 to 36 million tons, congestion cost rose from $77 to $190 billions of dollars. Intersections are a significant source of traffic accidents3,4 and delays in cities5,6. According to a U.S. National Highway Traffic Safety Administration report, in 2010, 32,999 people were killed, 3.9 million were injured, and 24 million vehicles were damaged in motor vehicle crashes in the US7. $277 billion is the economic cost of these crashes. More than 40% of reported accidents occur in intersections in Europe and the US3. Operating traditional intersections create significant costs such as labor waste due to delays in traffic, fuel and energy waste, increased carbon emissions, loss of critical time in city emergency response, noise pollution, and psychological stress. Introducing smartness into intersections has significant potential to save time and money while increasing traffic safety.

Smart city vision includes many types of smart city applications such as smart infrastructure and utility management, smart power grid, smart homes, smart schools and campuses, smart workplaces, smart businesses, smart roads, smart traffic management, etc.8 Autonomous intersections are an application within the smart city vision as part of smart roads and smart traffic management. Autonomous intersection management systems (AIMSs) are real-time, safety, and mission-critical systems. While introducing smartness into cities has great savings potential in many aspects, it also comes with various costs and problematic issues. Ensuring safety, cybersecurity, high maintainability, high performance, and high reliability are among critical issues. The AIMS architectures and implementations have to consider these critical issues.

The Concept of Autonomous Intersections

A traffic intersection may include multiple roads and crossings. There are vehicles and pedestrians crossing. There are also other types of moving objects, such as animals entering the intersections. For example, guidance dogs for disabled people are also crossing. Some pets, especially dogs, are trained to use intersections. Some dogs even use intersections without training. In many intersections, a traffic light system may be utilized. Normally, all intelligent entities using the intersection are expected to obey the traffic lights. However, there are cases that traffic lights are ignored both intentionally and unintentionally. Emergency response vehicles, such as ambulances, fire engines, and police vehicles, are allowed to ignore traffic lights. In addition to intentional ignorance of traffic lights, careless drivers or pedestrians run red lights. With the advancements in AI and robotics, autonomous vehicles (AVs) and service robots, such as delivery robots as pedestrians, are expected to use intersections soon. Currently, there are companies offering services using self-driving delivery robots.

Autonomous intersections are also called smart or intelligent intersections.

Within the smart city vision, autonomous intersection management systems (AIMS) will be installed on intersections. In some studies, autonomous intersection management is also called smart intersection management. There are various expectations from AIMS. As part of the smart traffic system, these systems are expected to optimize the use of intersections to increase traffic flow. This will be achieved by sensing and analyzing the crossing needs of crossers and eliminating unnecessary waits. Furthermore, these systems are expected to increase traffic safety, again by sensing and analyzing conditions that may lead to accidents and affect the traffic to eliminate dangerous conditions. Another expectation from these systems is helping emergency response vehicle crossings. This will decrease emergency response time in cities. Reporting the condition of the intersection traffic to the smart traffic system is another expectation from these systems. In addition, these systems are also expected to report their system status to the traffic management system. AIMS will naturally depend on energy. While the energy need may be satisfied by the city power grid, these systems may also be self-powered by solar power during daylight. At night, stored energy may be utilized. There may be other renewable energy solutions for power. Therefore, smart energy management will be a part of AIMS. Depending on the location and the structure of the intersection, there may be performance or preference expectations. All these expectations should be considered in AIMS architecture designs and implementations.

We view an autonomous intersection management system as an ambient intelligent system. Ambient Intelligence (AmI) environments are electronic or digital environments that are sensitive and responsive to the presence of people. An ambient intelligent system is also defined as “AmI is a digital environment that supports people in their daily lives by assisting them in a sensible way”. While these definitions emphasize the presence of humans, we believe the definition of AmI should also extend to agents other than humans. These are agents that are capable of interacting with its environment such as animals, drones, robots, etc. Therefore, we extend the definition of AmI. We define AmI as “digital environments that support agents by assisting them in a sensible way”. Note that this agent does not have to be an intelligent one but an interacting one. For example, an animal in an autonomous intersection is such an agent. Figure 1 presents a conceptual autonomous intersection management system developed by adapting the generic ambient intelligence (also called smart environments) conceptual design. Note that we categorize the interacting agents into two types. The first type is agents without internet of things (IoT) capability. The second type is agents with IoT capability. This capability may be embedded into systems such as autonomous vehicles, robots, drones, etc. For other agents such as humans or pets, this capability may be achieved by a smartphone or another IoT device. IoT capability refers to computation and communication capability. In a smart city, people, pets, robots, drones, and vehicles will be equipped with IoT devices capable of communicating with smart city applications via standardized interfaces. For example, cellular V2X for communication between vehicles and other things, such as other vehicles, pedestrians, traffic lights, etc. Naturally, there will be a transition period, and equipping various agents with these devices will take time. Some will be equipped and some others won’t. Agents with IoT devices will be interacting with the AIMS intelligently, meaning communicating its expectations, intentions, and status with the system. Agents without IoT equipment will only interact with the environment, meaning the agents will use the intersection. Agents with IoT equipment will also use the intersection, such as crossing. The AIMS will monitor the intersection to capture events relevant to its operation. In addition, the AIMS will be connected to the smart traffic management system for various purposes including reporting status, getting updates, traffic management tasks, etc. The system will communicate with other external systems, such as smart weather services, smart power grid, etc.

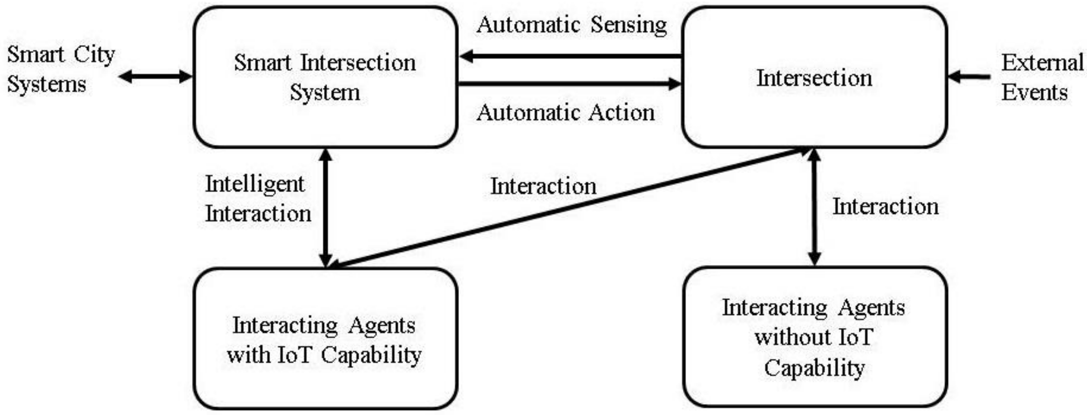

Fig. 1. A conceptual autonomous intersection management system (AIMS)

The intelligent interaction with the AIM system will also be a part of vehicle-to-everything (V2X) communication including vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication. In our generic AIMS view, interacting agents do not only include vehicles but also other things with IoT capability. In this sense, communication will be everything to everything (X2X) as the notion of IoT suggests. Figure 6 shows the agent types in Unified Modeling Language (UML) notation.

Note that we differentiate the vehicles and emergency response vehicles since they are subject to different traffic regulations. Furthermore, we highlight the public transportation vehicles as they may have a higher priority in intersection use. We also list the drones as a separate agent type. Currently, there are telepresence robots. While not in widespread use, these types of drones will be a part of smart city applications. One prospective use may be for disabled, sick, or elderly people. These people may prefer to have a telepresence robot or drone that wanders the streets. The focus of Industry 4.0 is smart manufacturing. The use of robotics mostly consists of industrial robots. There is criticism regarding Industry 4.0 due to its shortcomings in various areas. The discussions on Industry 5.0 have already started. The emerging theme for Industry 5.0 is human-robot collaboration or human-robot co-working. European Commission already published a policy brief on Industry 5.0. The technological trend indicates human-robot co-living and human-robot co-working will be the focus of many studies soon. Therefore, there will be many robots and drones on the streets for various applications such as delivery, personal assistance, etc.

Figures 2 and 3 show examples of complex intersections from various parts of the world. Figure 5 shows object recognition and trajectory calculating markings from intersections.

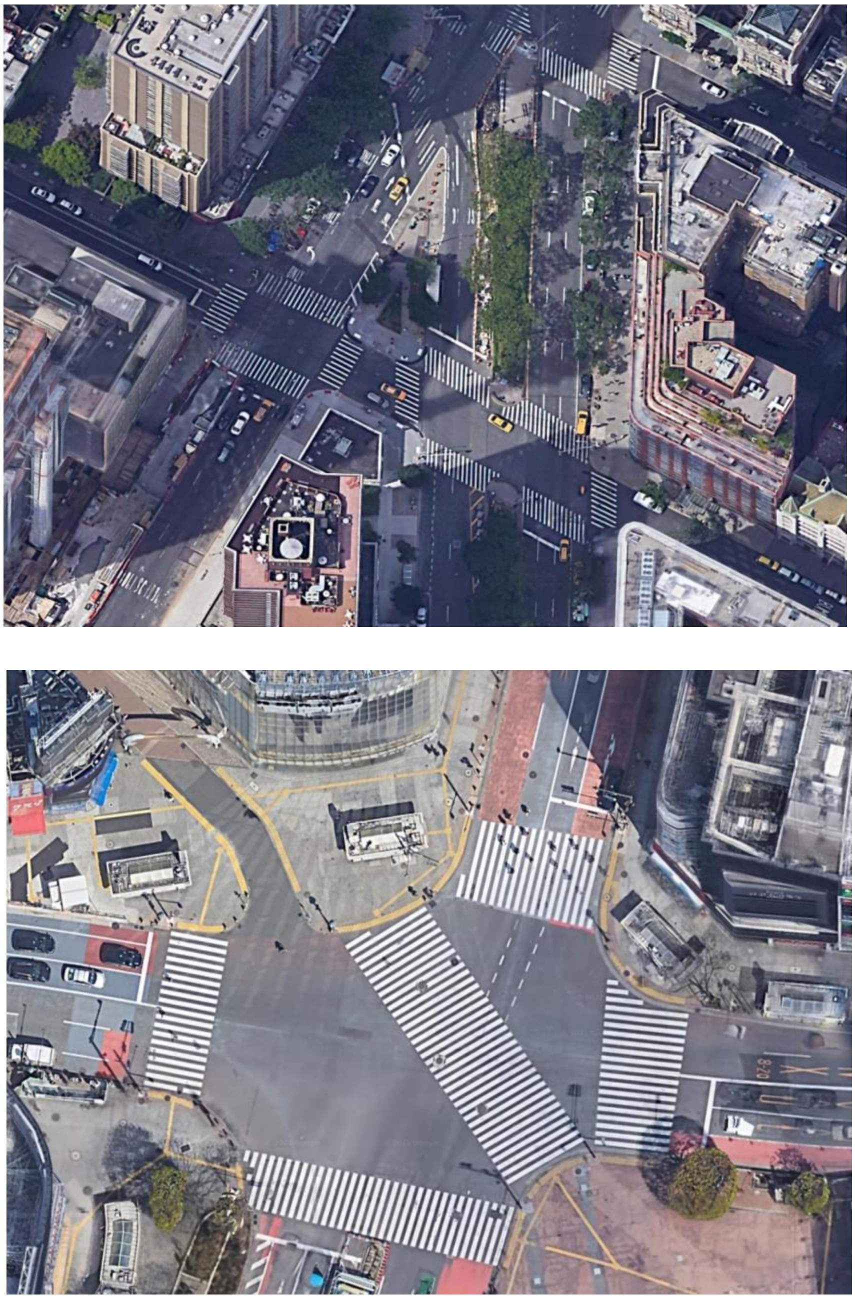

Fig. 2. Complex Intersection Examples (New York, Tokyo) (Source: Google Maps)

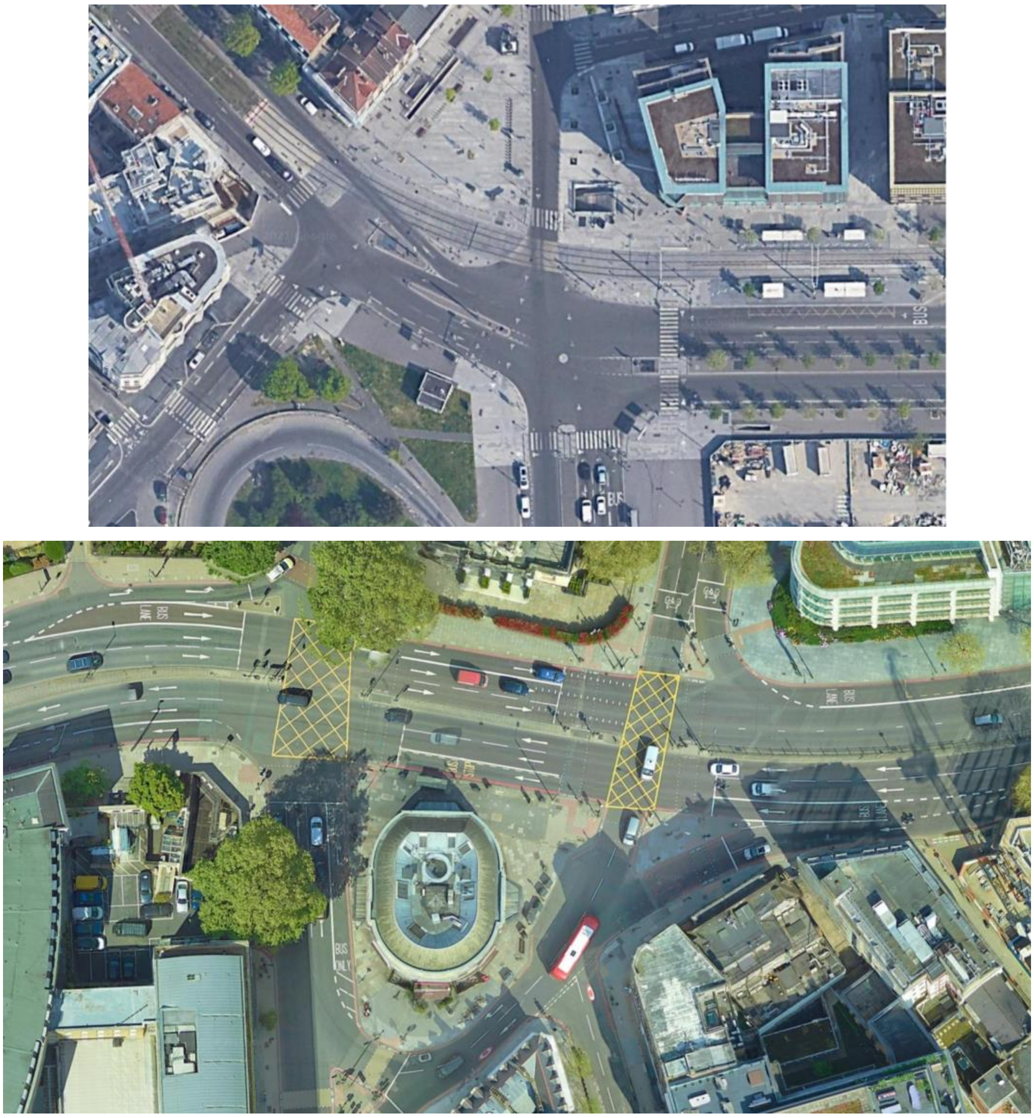

Fig. 3. Complex Intersection Examples (Paris, London) (Source: Google Maps)

Fig. 5. Object Recognition and Trajectory Calculating in Intersections

(Modified from the Source: "Downtown intersection" and “Urban Intersection” by Complete Streets is licensed with CC BY-NC 2.0.).

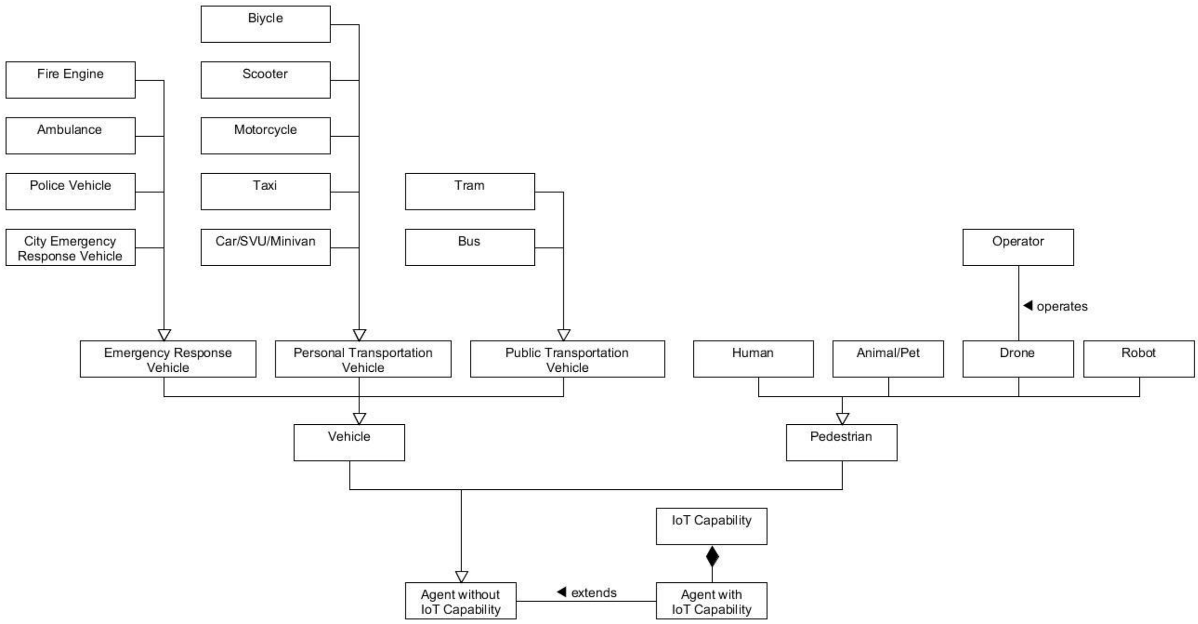

Fig. 6. Interacting agents in autonomous intersection management (AIM) domain