Autonomous Intersection Management System (AIMS)

<u>Project Vision Document</u>

Team: Protocol Pros

- **Ashutosh Mishra**
- **Prakash Acharya**
- **Brendan Edgerley**
- **Julian Villarreal**
- **Sarah Ryan**
- **David Schelanko**
- **Amado Lazo**

Table of Contents

Section 1: High Level Project Overview

1.1 Business Problem

Currently, traffic intersections do not have any autonomous, and time-efficient control system, and the entire intersection operation is almost dependent on traffic signals. Traffic signals are apparently safe, but are inefficient in terms of time, and do not dynamically respond to road conditions and requirements. They operate in a uniform pattern, unless intervened by human beings. An autonomous intersection management system aims to provide a dynamic approach to solve the traffic intersection problem and make it time efficient, while prioritizing road safety. Depending on the paradigm of the intersection, traffic congestion and the road conditions, the autonomous intersection management system is expected to provide appropriate signals to every agent based on their direction of movement and further intentions. Agent, here, depicts all the entities that are involved in the road transportation, such as vehicles, pedestrians, and animals.

1.2 Purpose

The main purpose of this project is to comprehend the possibilities of an intersection, and accordingly analyze, research, develop and execute a networking protocol for autonomous intersection management system. The networking protocol will involve transmission of signals and critical information between entities involved in the system and enable assistance to the agents for deciding their trajectory based on the road conditions.

1.3 Scope

This Project Vision document applies to the development of an efficient protocol for Autonomous Intersection Management System (AIMS), which will be implemented by '**Protocol Pros**' using Omnet++, and derived from other standard protocols like MAC, HMAC, SHA2, TCP/IP, UDP, etc. The AIMS protocol will depict the entire flow of data transmission between the traffic intersection entities. However, few things like early setup of the system, pre-allocation of secret-keys for MAC authentication, deciding the number of rounds in SHA-2, maintaining consistent bandwidth and throughput for communication is beyond the scope of this document.

1.4 Definitions, Acronyms, and Abbreviations

- AIM(S) – Autonomous Intersection Management System
- SIM(S) – Smart Intersection Management System
- MAC – Message Authentication Code
- HMAC – Hash-based Message Authentication Code

- TCP – Transmission Control Protocol
- IP – Internet Protocol
- UDP – User Datagram Protocol
- SHA – Secure Hash Algorithm
- IOT – Internet of Things
- UML – Unified Modeling Language
- Intersection – A point where two lines or streets cross. Typically, there can be three types of intersections: Three-leg or T-intersection (with variations in the angle of approach), Four-leg intersection and multi-leg intersection.
- Agent – As far as this document is concerned, an agent is any entity that is involved in the intersection, like vehicles, pedestrians, street-animals, pets, traffic management system, intersection management system, Smart City management system.
- IOT capacity/capability/ability – The ability of an agent to directly interact, convey or respond to any other agent by means of digital medium.
- V2V – Vehicle to Vehicle interaction
- V2X – Vehicle to agent interaction
- X2X – Agent to agent interaction

1.5 References

- **Sequential Online Chore Division for Autonomous Vehicle Convoy Formation.**
  Harel Yedidsion, Shani Alkoby, and Peter Stone
  pdf
- **Scalable Multiagent Driving Policies For Reducing Traffic Congestion.**
  Jiaxun Cui, William Macke, Harel Yedidsion, Aastha Goyal, Daniel Urieli, and Peter Stone
  In *Proceedings of the International Conference on Autonomous Agents and Multi Agent Systems (AAMAS), 2021*
  pdf
- **A Protocol for Mixed Autonomous and Human-Operated Vehicles at Intersections.**
  Guni Sharon and Peter Stone
  In *Autonomous Agents and Multiagent Systems - AAMAS 2017 Workshops, Best Papers*, 2017
  pdf
- **Traffic Optimization For a Mixture of Self-interested and Compliant Agents.**
  Guni Sharon, Michael Albert, Tarun Rambha, Stephen Boyles and Peter Stone
  In *Proceedings of the 32nd AAAI Conference on Artificial Intelligence (AAAI-18)*, 2017
  pdf
- **Multiagent Traffic Management: A Reservation-Based Intersection Control Mechanism.**
  Kurt Dresner and Peter Stone.
  In *The Third International Joint Conference On Autonomous Agents and Multiagent*

***Systems* (AAMAS 04), July 2004.**
[pdf]

- **Human-Usable and Emergency Vehicle–Aware Control Policies for Autonomous Intersection Management.**
  Kurt Dresner and Peter Stone.
  In *The Fourth Workshop on Agents in Traffic and Transportation* (ATT 06), May 2006.
  pdf
- **Marginal Cost Pricing with a Fixed Error Factor in Traffic Networks.**
  Guni Sharon, Stephen D. Boyles, Shani Alkoby, and Peter Stone
  In *the Proceedings of the 18th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2019)*, 2019 pdf

Section 2: Positioning

2.1 Problem Statement

The problem of	intersections not being able to dynamically manage themselves according to the traffic congestion and interact with traffic agents
affects	the efficiency and safety of traffic as a whole
the impact of which is	consumption of a lot of time of the urban congested traffic, and compromise in road transport safety every so often
a successful solution would be	implementing an ambiently intelligent, responsive, and sensible autonomous intersection management system which determines the ambulation of agents, and provides the optimal trajectory to each agent in terms of safety, time and cooperation among all agents, considering emergency vehicles, innocent agents like animals, and unexpected circumstances like irregular behavior of vehicles, unexpected appearance of pedestrians, etc.

2.2 Product Position Statement

This idea, if implemented well, can lead to immense benefits in the making a safe and sustainable traffic management system, subsequently leading to a smart city. It is extremely essential that a smart city has effective, safe, and smart traffic management system, in order to enable smooth ambulation, while accommodating emergency mobility. Autonomous Intersection Management System can add a firm value to this sector and make a significant contribution to any metropolitan looking up to making itself a smart city, by means of smart transportation.

Section 3: Stakeholders and User Description

3.1 Market Demographics

It is intelligible that road transportation is the most widely used transportation mode in the world. There are higher chances of usage of road transportation that any other means because of various reasons. Roadways enable both short and long-distance travel without many intricacies. Even if we consider that owning a personal vehicle is an unaffordable thing for majority in the world, using public vehicles is not a big deal for someone who looks to travel distances around a 100 mile. According to Statisa's Global Consumer Survey, 76 percent of American commuters use their own cars to move between home and work, making it the most popular mode of transportation by far. The remaining 11 percent use public transportation, wherein 60% of these 11 percent people use buses. 10% of overall people use their own bikes. With these statistics, we can presume the magnificence of road networks. Maintaining a considerable number of resources on making 'Road' a safe and effective mode of transport would contribute to a lot of people, insinuating a Smart City, thereby a prosperous one.

3.2 Stakeholder Summary

Name	Description	Responsibilities
Project Manager	This stakeholder works with the customers and translates the needs into requirements.	Specifies domain, requirements – both functional and non-functional, requirement refining as per need. Keeping a check into the whole project and maintain the progress
Technical Manager	This stakeholder analyzes the requirements and does a feasibility check of the same.	Checks if the requirements can be well implemented without any modifications. Design ways to implement requirements.
Researcher	Makes a check of available and conventional methods of implementing the requirement and figures out better ways of designing them.	Crawls through available systems which revolve around the specified requirements and cite improvements in the execution methodologies.
Designer	Based on the papers produced by the researchers, this stakeholder designs a systematic and technical methodology of implementing the requirement	Figure out the optimal way of implementing the suggested methodology of the researcher and produce the design of the same.
Developer	Substantiates the proposed design by implementing the same in the decided technology stack.	Decide the best way to implement and execute the design, in order to support

		scalability and encompassing all possible cases.
Tester	Identify all possible test cases of every module in the system and cite out the test cases, thereby testing the system against each of them.	Figure out the possible test cases in every segment/module of the system and perform manual/automation testing of the developed system against the drawn out test cases.

3.3 User Summary

Name	Description	Responsibilities
Intersection	Primary end-user of the system	Exploit an instance of the AIMS system and maintain the traffic based on business logic of the system. Provide a timely report to the upper level in the hierarchy.
Smart City Systems	Beneficiary of the system	Receive the periodic reports from every instance of the system and analyze if everything is going well. Ensure safety across all the instances and notify instances in case of absurdity.
Interacting agents with IoT capabilities	Primary end-user of the system	Stay within the vicinity of their closest interaction instance and communicate their intentions in the intersection. Receive and follow the instructions provided by the system.
Interacting agents without IoT capabilities	Allied agent of the system	They cannot directly interact with the system. However, our system, inculcated with ambient intelligence, can identify these agents and have an estimate of their intentions in the intersection

3.4 Current User Needs

Need	Priority	Concerns	Proposed Solution
Accurate Instruction	High	An absolutely accurate set of instruction for agents for their further move in the intersection, because it may stake high values if provided inaccurately.	Implementation of instruction provision based on a TCP (**connection-based transmission**) between the system and the user so that instructions are received, and the system is notified about the reception.
Unaltered instructions	High	Even though the instructions sent by the system may be accurate, there is a vulnerability that a third party can alter the	Use a Hash-based Message Authentication Code (**HMAC**) protocol for interaction between agents and our system, to ensure that

		instructions by taking over the network.	the instructions are unaltered, and integrity is maintained.
Secured transmission of intersection status	Moderate	The Smart City system and AIMS should have secured communication so that ill-status is not leaked that may turn out to be pugnacious.	Usage of Secure Hash Algorithm (**SHA-2**) to transmit instructions between AIMS and Smart City systems would ensure safety in this communication
Efficient conveyance of instant status of intersection to system	Low	Every intersection, at every quantum of time, is expected to convey its status to the AIMS in order to get instructions and transmit to every agent there.	Exploitation of User Datagram Protocol (**UDP**) for maintaining a connection-less communication from the agent to the AIMS, to maintain efficiency.

3.5 User Environment

- ➔ The AIMS application protocol will be used by Smart City Management Systems, regardless of:
  - Which country they operate in.
  - Which time of the day it is, or which date of the month or which month of the year.
  - What brands of vehicles are used (having an android/iOS car system is required)
  - Which part of the city it is.
- ➔ The AIMS protocol should be feasible for intersections where:
  - Majority of the vehicles travelling through the intersection have IoT capabilities.
  - There is adequate quality of connection setup and the necessary bandwidth to communicate with the maximum possible agents in that intersection.
  - There is assurance that the connection will not be lost anytime in between, and the quality will remain stagnant.
- ➔ The AIM system should work for vehicles that:
  - contain the application and have the necessary connections with adequate bandwidth pre-setup.
  - Have the required secret-keys and hash-function behaviors are inculcated in their systems beforehand.

3.6 Alternative Solutions

- ➔ High-cost flyovers to refrain from having intersections.
- ➔ Traffic signals that are based on a single algorithm, and stagnant in terms of performance
- ➔ Using irresponsive traffic congestion control mechanisms.
- ➔ Other competing AIMS teams

Section 4: Outcome Overview

4.1 Application Perspective

Below is a bird's eye perspective of our application. The overview of how our application is going to function, and what protocols are supposed to be used to communicate amongst agents concerned.

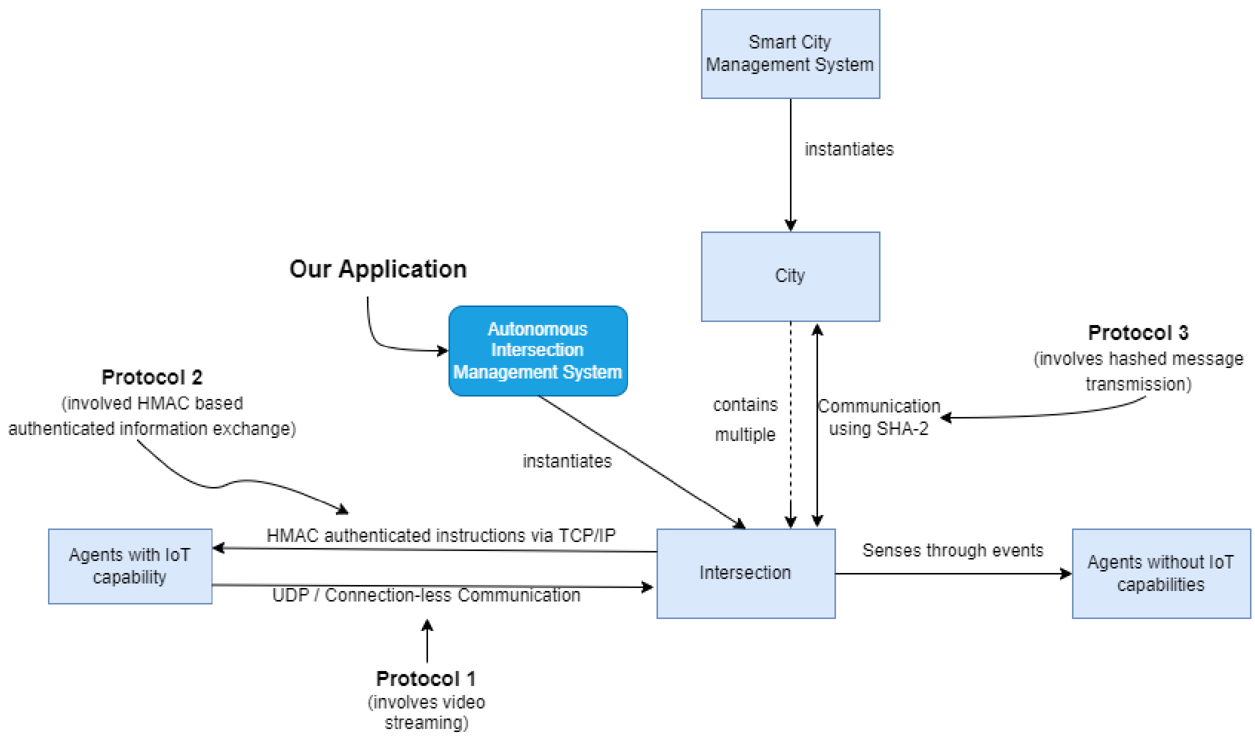

Fig: Overview of AIMS

4.2 Summary of Application Capabilities

Benefits	Supporting Features
Safe communication between agent and application	There is minimal vulnerability in the communication between the application and agents involved, thereby ensuring data-safety and road-safety simultaneously.
Priority based allowance to agents	Emergency vehicles are always given the highest priority in the intersection. The priority of vehicles is preset in the application, and it responds to requests accordingly.
Saves a lot of traffic time	Due to the proper implementation of autonomous intersection management application, a lot of traffic time is saved, as compared to conventional traffic-signal based systems.
Efficient intersection status reports provided to Smart City Systems	AIMS enables the provision of a timely report to the higher levels of the metropolitan such as Smart City Management Systems, subsequently helping the cities to get the status of roads.

4.3 Assumptions and Dependencies

- ➔ It is assumed that majority of the agents in the intersection are IoT capable and are compatible with our application.
- ➔ It is assumed that the vehicles have adequate connection to transmit and receive data from our product.
- ➔ It is assumed that the AIMS has adequate bandwidth and throughput to process and transmit all relevant data to the corresponding entity.
- ➔ It is assumed that the IoT capable agent will strictly follow the instructions provided by our application.

Section 5: Outcome Features

5.1 System Features

1. Instantiate application for a particular intersection.
2. Integrate the instance to a ‘City’(Smart City System).
3. Setup perceptive nodes for that instance.
4. Setup status stream from AIMS to ‘City’.
5. Pause application.
6. Exit application.
7. Change vehicle priority.

5.2 Communication Features

1. SHA-2 based hashed information exchange.
2. Provide instructions to agents through TCP using HMAC authentication
3. Embedded ambient Intelligence through image processing
4. OCR (Optical Character Recognition) for identifying every individual vehicle
5. Image Recognition (Agents without IoT)

5.3 Emergency Features

1. Place emergency vehicle condition.
2. Change vehicle priority in system, based on intersection instance.
3. Send emergency condition alert to higher authorities (Smart City System)

5.4 Constraints

- Usability
    - Clear and perceptive view of agents through camera
    - Pre-trained OCR model embedded to identify vehicle and its position.
    - Strictly integrate each vehicle with the system based on their lane position, further intentions, and accordingly move forward with the processing.
    - Proper SHA-2 implemented and independently integrated with hash functions.
    - Pre-shared secret keys for HMAC based TCP communications among agents

- Performance
    - Accuracy of hash functions in SHA-2
    - Instantaneous judgement of agents by the pre-trained OCR model.
    - Minimal time between vehicle recognition and system response.
    - Minimal data loss in UDP based communication from the agent and systems.

Section 6: Other Product Requirements

6.1 Applicable Standards

The AIMS must comply with the existing standard in terms of responsiveness, performance, usability, and accuracy. It should provide the pertinent instructions even in the most critical emergency situation arising from the intersection.

6.2 System Requirements

System must run on a Windows/Linux based system, and the agents must have an android/iOS based smart-car setup on their vehicles.

6.3 Performance Requirements

System is expected to process the situation in the intersection in the minimal time possible, and provide the optimal decision, considering priority of the vehicles in the optimal time. Accuracy is expected while recognizing vehicles, their positions, their intentions, and identifying agents without IoT capabilities along with an apparent estimate of their intentions and process their instructions. Possible collisions should be instantly prevented by giving pertinent instructions.

6.4 Environmental Requirements

System must recognize vehicles and agents on the intersection through video streaming. Thus, it is expected that the visibility is vivid enough for the system to perceive and identify the motion and behavior of agents.
Likewise, it is expected to have a good internet connection throughout the execution time of the system.