A Wireless Network with Adaptive Modulation and Network Coding in Intelligent Transportation Systems

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Abstract—Transportation has evolved to a topic which is highly regarded in multi aspects. Partly, the contribution to its increasing complexity and everlasting significance has some correlation to the continuous rising demands of public transportation. Transportation systems are now urged to break through the boundaries using communication technology. The integration of communication and computing in the realm of transportation is coined Intelligent Transportation Systems (ITS). The reliability of transportation systems have yet to mature as there are still problems that require support or restructuring. The current new fleets of public transport lacks of proper communication assistance which could potentially identify traffic conditions instantly. The dynamic environments of transportation regions will always pose challenges to wireless communications. Accordingly, there is a need for reliable, uninterrupted and high speed communication systems for the application in ITS. The objective of this paper is to demonstrate a wireless communication protocol suitable for vehicular scenarios. The wireless communication scheme exhibits ad-hoc behaviour and coupled with adaptive capabilities. Together, with multiple communication units, they are able to deliver reliable point-to-point wireless communication within a network. With good planning, the communication system can help with the improvements of the efficiency and safety public transportation systems.

Keywords—adaptive modulation; intelligent transportation systems (ITS); vehicle-to-infrastructure networks; network coding

I. INTRODUCTION

Intelligent transportation systems are coined from the merging of both transportation and computing technologies. The demands for safer, faster, and more efficient transportation systems are even more significant now that the rise in population and the amount of vehicles will contribute increased complexity and challenges. The essence of ITS is to achieve ubiquitous computing in the realm of commuting. These technologies that are about to be embedded into our cars and public transport are bound to be helpful and integrated to the way we use transport. They serve to assist drivers in decision making and intelligent danger avoidance. Many commercial applications can also be allowed while using a certain transportation mode which can be highly informative and personal to one’s needs. The wide range of the technology to be implemented can be summed up as a diverse network of intercommunicating computing devices designed to sense and take necessary action. Such advantages can provide up-to-date data to traffic intersections for traffic control [1].

To ensure quality of service for passengers, the architecture for ITS must have a reliable communication system supporting its structure. Without a fast and error-free communication architecture, the objectives of ITS will be short from achieving its goals. Furthermore, the inevitable mobility nature of vehicular scenarios poses a difficulty in realizing a wireless communication link. An anti collision system for cars at risk prone spots must have good and up-to-the-minute information relayed to parties inside that region. An adaptive traffic light control system using wireless sensor networks are presented in [2]. The proposal is classified into three layers: the wireless sensor network, the localized traffic flow model policy and the higher tier controller agents of traffic lights. These three layers work hand-in-hand to reduce traffic waiting time and also maximize traffic flow. A quick navigational system has to have updated and adequate information to perform vehicle routing. Besides that, an organized network with a suitable protocol is paramount to mitigate communication network traffic.

ITS is divided into two modes: Vehicle to infrastructure (V2I) and Vehicle to vehicle (V2V) communication [3]. V2V is further divided into direct and in-direct. Indirect functionality means the V2V communications is conducted via multi-hop where networks among vehicles can form via ad-hoc whenever needed. In this sense, a cooperative network can be formed at any time and any topology. Currently, there is wide potential to develop routing techniques that appeal to vehicular network scenarios which cooperate to form a platoon control [4]. At current moment, there are dedicated vehicular communication standards such as the Dedicated Short Range Communication (DSRC) with Wireless Access in Vehicular Environment (WAVE) which is an extension from the IEEE 802.11p and IEEE 1609.x and Communication Air-interface for Long- and Medium-Range Communication (CALM) to provide a set of air interface protocols using ITS communication with several media. CALM is basically a standardization method for distinguishing the applications with suitable communications protocol but it still lacks a medium access method to avoid collisions. Furthermore, security for vehicular wireless...
communications must also be considerate. For infrastructureless technologies, there is the existing WLAN, InfraRed, Millimeter Wave, ZigBee and Bluetooth. Wireless sensor networks are widely used to detect road conditions and also pollutants in targeted areas. There is a survey with substantial study regarding wireless sensor network for ITS found in [5]. The heterogeneity of all these wireless technologies must collaborate to achieve their joint measures.

In this paper we describe an architecture that is a design of a public ITS architecture maintained by the government. It should be designed to put minimum impact on the existing environment. Deployment also must be cost effective. This architecture caters to mainly government public bus transportation services. From the management side, the policy makers can also revise existing policies to make a population that is encouraged to depend more on public transport. This motion reduces the carbon footprint in the long run.

The next sections of the paper are organized as follow. Section II introduces the ITS system architecture named Intelligent Bus Management System (IBMS). Section III showcases a network coding architecture approach to improve traffic flow in the network. Section IV provides an insight into adaptive modulation and coding schemes in IBMS and in section V the onboard computing and communication unit is described. Section VI presents system evaluation of IBMS. Finally section VII concludes the paper.

II. SYSTEM ARCHITECTURE

In this paper, the architecture henceforth will be referred to as IBMS. The block diagram is shown in Fig. 1. The system’s architecture is a combination of several existing technology and organized according to priority of service. The main features that make up of the system can be described as follows:

- Information relaying via network coding – Network coding can allow the network to have speedier throughput and with more transmissions made in routing transport information using less time.
- Data mining and management – Huge amounts of data collected will be automatically sorted and processed in the data centre to allow better integration of superior mobility into the infrastructure.
- Wireless link optimization – Adaptive Modulation and Coding (AMC) copes with the diversities in the dynamic wireless environment so that information loss can be mitigated.
- Collective priority queuing – Low latency communications gives the architecture an edge to provide fair and rapid communications for the passengers.
- Identity with functionality – Using RFID based identity cards, demand for transportation can be quantified rapidly.
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III. IBMS NETWORK ARCHITECTURE

In this section, network architecture of IBMS is discussed in detail. The networks from point to point are connected by wireless sensor network. Wired network may offer higher transmission rate but due to advantages wireless network offer such as easy deployment and easy maintain, in this architecture wireless communication will be used. The disadvantage of wireless network in transmission rate will be overcome by network coding approach which is the method to increase network throughput.

A. IBMS Networks Structure

The Network architecture for IBMS is shown in Fig. 3. Every bus stop has a wireless sensor device to transmit data to server. Every wireless sensor device is connected with an Radio Frequency Identification (RFID) reader and a tablet.

Any user that wishes to register in bus stop will use their radio frequency card and tag on the RFID reader, RFID reader will transmit the request to server, every respond from server will shown in touch screen tablet. User may request where they wish to go after identification step. After the user requests where they want to go, server will assign a slot for the passenger based on the position of the bus and current availability. Besides, the system also queues by the quantity of passengers on the bus. The estimated arrival timing of the bus will also be shown on the tablet screen. At the same time, every bus has a tablet to show the conductor which bus stop they want to drop passengers. Every passenger is required to authenticate before they take the bus because every user is assigned to a corresponding bus when they register in server.

B. Network Coding Hop to Hop Transmission

Wireless sensors are easy to deploy and they can have multifunction capabilities, due to this reason wireless sensors are chosen to be a device that transfer packets to server. But wireless networks face low throughput on the networks. In order to overcome this, network coding has been used to increase the throughput of wireless sensors networks.

Network coding is a method that will intelligently combine several packets from incoming flow into single packet size length and send this packet to next hop. This method has been proven to be an efficient method that increase wireless network throughput. Fig. 2 show the difference of conventional method on wireless network and network coding in bidirectional communicate scenario.

In scenario shown in Fig. 4, node 1 will send packet $a$ to node 3 and node 3 will send packet $b$ to node 1. In this scenario, both nodes are out of wireless coverage range, so they invite an intermediate node in the middle to relay their packets.

For conventional store and forward method, node 1 will send packet $a$ to node 2, and node 2 will relay this packet to node 3. At this time, node 3 also send packet $b$ to node 2 and node 2 forward the packet to node 1, in total store and forward require 4 transmission time slot.

For network coding method, node 1 will send packet $a$ to node 2, and node 3 will send packet $b$ to node 2, instead of transmitting packet $a$ and packet $b$ separately to node 1 and...
node 3, the intermediate node will XOR the packet into a single coded packet with same size length, and broadcast to node 1 and node 3. Node 1 will extract packet b from the packet it receive by XOR with the packet it sent earlier, and node 3 will do the same procedure to get packet a. In total, network coding only use 3 transmission time slots to deliver packet a to node 3 and packet b to node 1. Fewer time slot leads to higher throughput and reduced times of transmission.

In IBMS, network coding protocol is used to hop packets from source to server and vice versa, network coding will increase the performance when a lot of request occurs. The traffic of the network are heavy when peak hour, network coding will reduce the burden by increasing the throughput of the networks.

IV. IBMS COMMUNICATION TRANSMISSION SCHEME

Wireless communication for vehicles are complex because of the interference in the wireless environment which includes shadowing, reflection and path loss. They are common time varying challenges that forces researchers to find better transmission schemes without sacrificing speed. Common rapid changes in the transportation environment can cause a variety of unwanted channel gains and interference. In vehicular scenarios, these problems can substantially affect the channel link. For instance, urban environment has buildings with reflective surfaces which will cause the transmitting wave to travel two or more separate paths. Signal waves arrive at the receiver at a different time causing destruction interference of the intended wave hence results in errors at the receiver end.

In the wireless channel situation coupled with mobility will be even harder to achieve errorless links. Communication between sorts of vehicles that travel different of speeds can cause unpredictable channel characteristics, and this effect is called fast multipath fading. That is the reason why channel modelling is critical for performance evaluation of a communication scheme. Various analytical and experimental results in V2V communications are shown in [11], the significant part to be noted of is the importance of channel modelling for future applications. Advantages of channel modelling include ease of reproducibility in controlled settings and also comparisons between transmissions schemes can be produced with less effort.

In this paper, Adaptive modulation and coding (AMC) is introduced as a remedy to fading effects. AMC is found to perform fading compensation in [12]. Overall, this adaptive technique increases spectral efficiency and reduces error rate by adjusting the transmission according to instantaneous channel condition. As shown in Fig. 5, Adaptive modulation is paired with a channel state estimator at the receiver’s end which estimates Channel State Information (CSI) by...
statistical techniques or by training symbols provided periodically by the transmitter. CSI can be channel value (signal to noise ratio) or signal mean over time duration. Using CSI feedback information, the transmitter has a clear idea of what are the channel conditions. AMC can then adapt the transmit parameters such as transmit power, modulation scheme or code rate. In effect, AMC allows the communication link to maximize spectral efficiency whenever possible and reduce error rate when condition is undesirable. Whereas fixed transmission systems which assume the worst case channel conditions, the spectrum is wasted when the communications link does not take advantage of favourable conditions. In IBMS, technique of AMC with channel estimation is implemented.

V. IBMS ONBOARD EQUIPMENT

In the IBMS enabled bus, computing, communication and sensing equipment and user interfaces are bundled into a single working intelligent unit designed to assist the driver and also contribute to the system. To design an onboard system with communication capability requires understanding [13].

The approach is to use commercial off-the-shelf computing and communication hardware that is open source so that it is easy to customize. E.g. the tablet User Interface (UI) is running on Android OS. The sensing devices are already installed onboard the typical bus, velocity, direction and airbag status. Additional sensor for IBMS integration is Global Positioning System (GPS) unit. Bus capacity is measured by the number of ‘check-ins’ when the passengers board the bus. Referring to Fig. 6, wireless communication modules include a 2-5 GHz antenna and a GPS receiver. Radio and GPS receivers will interface with the antennas via Single Board Computer (SBC) processing board with accurate timestamp for data aggregation purposes. Another important feature for accurate time stamping is networking protocol and application purposes. For time critical tasks such as replaying position and velocity, the sensors are hard-interfaced to the mobile router so that additional processing is not required.

VI. SYSTEM PERFORMANCE EVALUATION

This section evaluates the specifics of the communication link transmission method and also the networking protocol. This architecture uses a combination of network coding with adaptive modulation and coding.

A. Hop to Hop evaluation

In this section, the packet transmission rate from source to destination will be evaluated. The setups of the simulation are shown in Fig. 7. Consider node 1 will send 50 packets to node 4, and node 4 will send 50 packets to node 1. End to end delay of store and forward method and network coding method will be compare.

Simulation result shown in Fig. 8 that end to end delay of the store and forward is more than network coding, but network coding has 4 packets lost in the middle of transaction. This happen because when coded packets transmitted when other wireless channel is not available. In average, store and forward method need a lot of time to deliver packet to destination, so the time used for retransmission for packet lost on network coding is not significant if compare with store and forward method.

B. Adaptive Modulation and Coding Evaluation

AMC performs better in fast fading situations compared to a fixed BPSK scheme. The channel model used in the simulation is settings from V2I, where a mobile receiver accepts signal from a roadside infrastructure. From Fig. 9, the performance of fixed modulation maintains around 0.3 error rate, which reflects on a poor wireless link. However, using adaptive modulation and coding exhibits a better gain in error rate over an improving Signal-to-noise ratio (SNR). This proves that AMC is capable of overcoming channel degrading effects. The simulated channel is a flat fading channel.

Figure 6. Onboard IBMS system equipment: Computer interfaced with a control panel (UI) and communication equipment (ISM band antenna & ZigBee).

Figure 7. Simulation scenario.
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