Data Forwarding System with Error Detection and Leader Selection Features

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Abstract. The concept of vehicular networks utilizes vehicular nodes and roadside units to exchange data to achieve travel comfort and convenience. However, as the number of vehicles on the road increases exponentially, the data dissemination becomes inefficient and lossy due to communication factors, one of which is the availability of too much sources of information. In this paper, a data forwarding system (DFS) is proposed to address communication failure due to bit error during data transmission and in the presence of data collision. The proposed system enables the receiver to detect errors in the received data using Hamming codes and utilizes a retransmission scheme to correct bit errors. DFS also selects a limited number of vehicles, called leaders, that can communicate with the infrastructure to minimize data collision and flooding. DFS, under various number of vehicles, is tested in additive white gaussian noise (AWGN) and Rayleigh channels. Simulation results show that DFS reduces bit error rate (BER) to approximately 54% in the AWGN and 62% in the Rayleigh channel for the maximum number of retransmissions simulated, respectively. Also, with DFS, data upload to infrastructures is reduced by at most 99.5% depending on the maximum allowable number of clusters and vehicles inside the RSU coverage.

1. Introduction

The exponential rise of the number of vehicles in an urban environment has contributed to the increase in traffic congestions [1]. Most countries address traffic problems by improving existing traffic infrastructure, adopting scientific transportation planning and management, and the application of Intelligent Transportations Systems (ITS) to make roads and vehicles more intelligent [2]. ITS improves transport safety and mobility through the integration of technology allowing communication in vehicles and infrastructure [3,4].

There are two types of wireless communications in a vehicular network: Vehicle-to-Vehicle (V2V) communication and Vehicle-to-Infrastructure (V2I) communication. These two types of communications can be used to improve traffic mobility by addressing traffic congestion. In [5], V2V is used to improve the speed efficiency of each vehicle. The speed efficiency was increased by up to 15% with the use of V2V compared to vehicles without wireless communication. V2I can also be used to address traffic congestion by detecting these areas and informs vehicles to avoid congested areas [6]. In [7], vehicle communication is used to provide clearance for emergency vehicles in congested areas.
Aside from addressing traffic congestion, vehicle communication also addresses road safety. The increase of cooperative vehicles on the road can contribute to road safety. If the road is composed of mostly cooperative vehicles, the percentage of time exposed time-to-collision (TET) and time-integrated time-to-collision (TIT) is reduced by 99%. The safety risk increases significantly if the cooperation between vehicles is lost due to communication failure [8]. In [9,10,11], the different driving scenarios show that cooperative or connected vehicles can help in the improvement in traffic efficiency and road safety.

Different works of literature have shown the different methods of applying vehicle communication to improve road safety and traffic efficiency. The main drawback of the connected vehicles is that in the event of communication failure, the vehicles operate similarly to a regular human or autonomous vehicle. In this event, the improvement enabled by the connected vehicles is gone or unusable.

2. Problem Formulation

The major challenges for vehicle communication are the short or intermittent wireless connection of moving vehicles, the short coverage of Roadside Units (RSUs), and the high speed of vehicles. Some works of literature have tried different methods in resolving different challenges with vehicle communication. In [12], Combination Property (CP) and Binary Zigzag Decoding (BZD) were used to correct errors encountered when data is transmitted. Turbo codes can also be used as an error correction coding scheme to reduce error in transmission [13]. Another method is the use of Systemic Network Coding (SNC) which uses redundant packets to recover lost packets [14]. The papers [15,16,17] address the error in transmission due to the nature of the wireless channel degrading the data transmitted.

Another source of error in transmission is the loss of data due to simultaneous broadcast of data causing data collision. Data collision is when data from different sources collide and both data are lost. To reduce collision, [15] modeled 802.11p unicast and performed optimization to reduce packet collision during transmission.

In V2I communication, the RSUs have a limited area of coverage, and vehicles are constantly moving which causes the vehicles to exit the area of coverage. To make sure that vehicles are constantly in communication with the RSU, additional RSU should be placed on the roads. RSU placement needs to be optimized since the additional cost is required to completely provide coverage in the entire city. There are different methods in addressing the RSU coverage. A consolidated weighted mean approach considers different parameters gathered through taxi GPS traces [16]. Another method is to use a genetic algorithm in determining the optimal placement of RSU for maximum performance [17].

In this paper, a data forwarding system (DFS) is proposed to address data loss in V2I communication. The proposed system is composed of two modules: an error detection module and a vehicle leader selection module. The error detection module implements channel encoding to the data to be transmitted. This module allows the transmitter to encode the message with parity bits to allow the receiver to detect any error in the transmitted message. The vehicle leader selection module, on the other hand, limits vehicles which can communicate with the RSU to address communication issues related to data collision. The error detection module will be tested under two different channels and across different signal-to-noise ratio (SNR) to determine its performance.

The paper is divided into sections. Section 3 discusses the methodology used and the proposed solution. Section 4 presents simulation results and the discussion. The last section provides the conclusion of the paper and possible future directives.

3. Methodology

3.1. Vehicle Leader Selection

Data collision is caused when multiple transmitters attempt to utilize the channel at the same time. The transmitters send a signal through the communication channel at the same time causing the signal to
collide with each other. When data collision occurs, the data is lost or corrupted, the transmitter would have to wait a specific amount of time before being able to transmit again. In [18], the probability of collision is described in (1), where \( P_{tr} \) is the probability of transmission and \( P_s \) is the probability that a transmission is successful for a single transmitter. The total number of contending users is \( n \) and \( \tau \) is the probability that a station transmits in any time slot.

\[
P_{\text{Collision}} = P_{tr} (1 - P_s) \quad (1)
\]

\[
P_{tr} = 1 - (1 - \tau)^n \quad (2)
\]

\[
P_s = \frac{nt(1- \tau)^{n-1}}{P_{tr}} \quad (3)
\]

Based on (2) and (3), \( P_{tr} \) increases, and the \( P_s \) decreases as the number of users increases. This relation will increase the probability of collision as more vehicles try to communicate with the RSU. To minimize data collision, a leader is selected from a vehicle cluster that will communicate with the RSU. This minimizes the number of vehicles that can directly communicate at a given time.

\[
\begin{align*}
\text{Figure 1. Intersection environment (Left) and Generated Vehicles (Right)}
\end{align*}
\]

Figure 1 shows the intersection environment used and how the vehicles are generated for the simulation. A simple cross intersection is used since this is one of the common locations where an RSU can be placed. The intersection consists of 4 entry points and 4 exit points. The vehicles shown in each lane is the assumed vehicles inside the RSU radius, \( R_r \). The vehicle selection is done by grouping the vehicles into clusters, depending on its transmission range, \( R_v \), where \( R_v < R_r \). The centroid of each cluster will be computed and then the vehicle closest to the centroid will be selected as the leader which will communicate with the RSU. K-means clustering is used in grouping the vehicles. The vehicles in the range of the RSU will be evaluated with a different number of clusters using Calinski-Harabasz [19]. This will identify the optimal cluster based on the number of vehicles.

3.2. Error Detection

The coding technique used for error detection is a (7,4) Hamming code. The ‘7’ indicates the codeword length while the ‘4’ indicates the message length. An additional error detection used is the Longitudinal Redundancy Check (LRC) which is added to the end of the data to be transmitted. The module transforms the outgoing data stream into a matrix. Each row of the matrix is considered as a frame,
which contains 4 bits. The data stream is converted into a matrix by framing every 4 bits starting from the most significant bit of the data stream. These frames are then added to a matrix as a row as shown in Figure 2. This is done until the data stream is completely transformed. The encoded data to be transmitted is shown in Figure 3. It also shows the LRC parity bits added to the last row of the message bits. LRC determines the number of 1’s in the column and places a ‘1’ or ‘0’ bit to make the number of 1’s even or odd. The implementation of LRC for the module uses an even parity. After performing the longitudinal redundancy check, the 4 bits are encoded with additional parity bits using Hamming codes.

![Figure 2. Data stream into rows of 4 bits](image)

![Figure 3. Data with parity bits](image)

Hamming codes and LRC can be used to detect single-bit errors. An error is detected if the message bits do not correspond to the parity bits. The Hamming codes can correct single-bit errors. After decoding the data sent by the transmitter, the LRC parity bits can check again if there is a bit error after decoding the message. The Hamming code and LRC are not enough to correct multi-bit error or burst stream error [20]. Error correction can be done using a retransmission scheme. The error detection module will request the same data from the leaders of a specific lane. The request for retransmission will continue until there is no available leader to retransmit the message. For vehicle communication, the movement of a vehicle may be too fast to retransmit the message multiple times. To allow retransmission, the same message is forwarded to vehicles in the same lane as the leaders. As the number of vehicles on the lane increases the more chance for retransmission. Each retransmission will be used to compute the correct value, before decoding the message.

4. Analysis and Discussion

The performance of the error detection module is tested by bursting a stream of encoded bits through a channel then comparing the transmitted data to the received data. The parameter selected in determining the performance of the proposed solution is the Bit Error Rate (BER). The BER is the rate an error occurs over a transmission channel. The higher the BER the higher the chance of error.

There are two channels used to test the module: the Additive White Gaussian Noise (AWGN) channel and the Rayleigh Channel. The AWGN channel is common to every communication channel but does not consider fading [21]. The Rayleigh channel is used to consider the fading effect of the channel on the transmitted data. The BER performance of the module is tested from -35 dB to 35 dB. Figure 4 shows the BER in an AWGN channel. The figure shows the effect of the retransmission scheme on the BER. With more transmissions, the RSU can decode the data with less chance of error. As more vehicles are present, the BER is reduced. This is possible because at the vehicular level, the message is made to be error-free already because of the vehicle collaborations. In turn, to achieve a desired BER, a small
amount of SNR will just be needed when compared to situations where there are few vehicles on the road. Practically speaking, this leader selection will also reduce the load at the RSU.

Figure 4. BER for AWGN channel for various number of vehicles on the road segment of an intersection.

The BER performance for the Rayleigh channel is shown in Figure 5. The encoded data stream is modulated using Binary Phase Shift Keying (BPSK) before going through the Rayleigh channel. Similarly, as the number of retransmissions to the RSU increases, the BER decreases. Single vehicle transmissions will have to rely on its own to make sure that its message is correctly received at the RSU, thus, requiring more energy to accomplish it.

Figure 5. BER for Rayleigh channel

The performance of the vehicle selection module is tested by generating random vehicles per road segment, ranging from 50 to 1000. The maximum number of clusters is limited to 20 for the simulation. Figure 6 shows that as the number of vehicles per road segment increases, the maximum number of clusters increases as well. When the maximum number of vehicles is reached, the number of clusters formed is 20. The vehicle helped reduced the number of vehicles transmitting to the RSU from 4000 vehicles to 20 clusters, indicating a reduction in contending users of 99.5%.
5. Conclusion

In this study, a data forwarding system that can address data loss in V2I communication has been proposed and verified. The data forwarding system comprises of two modules namely, the error detection module and the vehicle leader selection module. As more vehicles are grouped into clusters before communicating to the RSU, message errors are reduced and achieved at the vehicular level. Vehicular messages are then transmitted by the cluster vehicle leader only, effectively, reducing the number of competing channel users. Simulation results have shown that the BER performance under wireless channel is improved as more vehicles are on a road segment. However, a higher number of retransmissions is required to further minimize the BER but is accomplished at the vehicular level of each cluster, effectively reducing collision at the RSU.

In the future, the study on V2V communication and data exchange will be studied and analyzed further. Here, it is assumed that in a cluster, all vehicles will automatically transmit and be correctly received by their cluster leader, thus, neglecting data collision at the vehicular level.

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