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Cooperative volunteer protocol to detect non-line of sight nodes in vehicular ad hoc networks

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A B S T R A C T

A vehicular Ad hoc Network (VANET) is a special type of Mobile Ad hoc Network (MANET) application that impacts wireless communications and Intelligent Transport Systems (ITSs). VANETs are employed to develop safety applications for vehicles to create a safer and less cluttered environment on the road. The many remaining challenges relating to VANETs have encouraged researchers to conduct further investigation in this field to meet these challenges. For example, issues pertaining to routing protocols, such as the delivery of warning messages to vehicles facing Non-Line of Sight (NLOS) situations without causing a broadcasting storm and channel contention are regarded as a serious dilemma, especially in congested environments. This prompted the design of an efficient mechanism for a routing protocol capable of broadcasting warning messages from emergency vehicles to vehicles under NLOS conditions to reduce the overhead and increase the packet delivery ratio with reduced time delay and channel utilisation. This work used the cooperative approach to develop the routing protocol named the Co-operative Volunteer Protocol (CVP), which uses volunteer vehicles to disseminate the warning message from the source to the target vehicle experiencing an NLOS situation. A novel architecture has been developed by utilising the concept of a Context-Aware System (CAS), which clarifies the OBU components and their interaction with each other to collect data and make decisions based on the sensed circumstances. The simulation results showed that the proposed protocol outperformed the GRANT protocol with regard to several metrics such as packet delivery ratio, neighbourhood awareness, channel utilisation, overhead, and latency. The results also showed that the proposed CVP could successfully detect NLOS situations and solve them effectively and efficiently for both the intersection scenario in urban areas and the highway scenario.

1. Introduction

Drivers' response to an emergency siren is normally one of delayed reaction, which is mainly attributed to their lack of understanding and information about what to do and where to turn to (left or right). Thus, the reaction time they require to make a decision is longer than usual. Subsequently, this situation leads them to make wrong moves and decisions, thereby possibly resulting in fatal accidents on the road or some delay in the arrival of the emergency vehicle. As the emergency vehicle has limited time to reach its destination, the chances of collision with other vehicles are normally higher in the wake of an emergency. The term *emergency vehicle* in this paper means any vehicle authorised to use a siren such as police vehicles, fire engines, or ambulances, which are required by law to follow the traffic rules and regulations [1]. However, the latter is used to distinguish other vehicles on the road that do not have any authority to sound an emergency siren while moving on the road.

According to a report issued by the German Federal Highway Research Institute, the risk of an emergency vehicle being involved in serious accidents is eight times higher, and four times higher for fatal accidents [2]. Similarly, the risk of being involved in property damage is 17 times higher. This data clearly shows that any mistake made by the driver of an emergency vehicle on the road can have disastrous consequences [3]. It has been reported that erroneous driving by emergency vehicle drivers can lead to 60% of accidents, out of which 30% are caused by faults made by other drivers driving vehicles on the road. Around 40% of such accidents take place at road intersections [4].

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Furthermore, wrong decisions made by drivers of other vehicles can precipitate delays in the arrival of emergency vehicles at their destination points, in which could in turn have serious implications for the patients being rushed to hospitals in the case of ambulances or lead to criminals being pursued by police vehicles escaping. Of late, Intelligent Transportation Systems (ITSs) have been applied to augment surface transportation systems. Several ITS projects have been initiated in the USA, Japan, and Europe. These systems employ Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications to relay emergency messages to target vehicles within short times to enable the drivers to make quick decisions and avoid collisions with either emergency vehicles or other vehicles. The underlying network utilised by these communications (V2V) is termed a vehicular ad-hoc network (VANET), which is responsible for delivering the information in a timely and cost-efficient way [22,21,20].

However, there is no comprehensive communication protocol that can reduce the latency in the dissemination of messages by VANETs. The major challenge in this dissemination of messages is related to how to shorten the time period between the time of emergency event and the time of delivery of warning messages to other vehicles to avoid collisions. Maintaining coverage of all vehicles within the target range in terms of dissemination of messages is another issue. The high density of vehicles on the road at intersections means that the dissemination of messages is normally challenging. Other vehicles, buildings, and foliage can be major obstacles in the way of the dissemination of warning messages from an emergency vehicle to the target vehicles. This stresses the need for continuous research to detect the number of obstacles in the dissemination of messages, which could ultimately be expected to result in the reduction of collisions because of the timely receipt of messages and quick decision-making processes of the drivers.

Moving vehicles can constitute obstacles with different compositions, densities, speeds, and shapes, and this can give rise to additional non-line-of-sight (NLOS) situations, which can affect the communication of location information and updates among neighbouring vehicles. This could prevent the exchange of information between vehicles about the speed, location, direction, etc., and hence fatal accidents could happen on the road. Although a multi-hopping technique could be used to disseminate the message beyond the transmission range, unfortunately hidden nodes, interference, and packet-collisions can terminate the dissemination process during multi-hopping mediated broadcasting. Furthermore, the higher utility of wireless resources mediated by unnecessary re-transmissions is another problem associated with the employment of multi-hopping techniques for message broadcasting. These challenges associated with multi-hop broadcasting have diverted the focus to using a Co-operative Volunteer Protocol (CVP) to achieve reliable, effective, and efficient multi-hop message broadcasting. Most of the solutions proposed in this context rely on direct Line of Sight (LOS), which uses a Roadside Unit (RSU) or cellular networks to overcome the NLOS issue for disseminating the messages to vehicles close to each other. This shows that existing solutions are infrastructure based and require infrastructure for the dissemination of information among neighbouring vehicles. However, the major challenge lies in realising infrastructure-less communication of messages to vehicles in close proximity.

Therefore, this work involved the development of an effective CVP based on a VANET for warning message dissemination among emergency vehicles. Firstly, this is intended to reduce the number of NLOS situations by assuring the broadcast of emergency messages to each and every node within the coverage zone by utilising volunteer nodes to relay messages to those nodes lying outside the coverage zone. Secondly, this is expected to help reduce the dissemination latency, thus delivering the warning messages to the target nodes efficiently and in a timely manner, all of which play a fundamental role in designing safety applications for emergency vehicles. Thirdly, the storm problem in message dissemination will be addressed using CVP. Finally, the proposed CVP aims to enhance the features of existing protocols, such as robustness, reliability, and coverage. The simulation tool EstiNet was used to evaluate the effectiveness of the proposed routing protocol in comparison with other protocols being used in the area of transmission of warning messages from emergency vehicles and other vehicles. EstiNet was selected as a simulation tool because of its special features, relatively easy manipulation of features, and its ability to simulate the various parameters and conditions at the intersection of roads.

The remainder of this paper is organised as follows. Section 2 introduces existing work that has been carried out in the field of non-line of sight and the definition of NLOS and when these situations can arise. An overview of the proposed context-aware architecture is given in section 3. The proposed Co-operative Volunteer Protocol for detecting NLOS is explained in section 4. Section 5 proposes the system simulation and validation, and the conclusion is given in Section 6.

2. Related work

Vehicle communications are vulnerable to signal interference as the vehicles travel in different environmental conditions. Physical objects and construction sites on the sides of the road (i.e., buildings, trees, and area topography) can interfere with radio signals and prevent proper communication. Moving objects such as trucks can also interfere with communication between vehicles and could block a driver's visual and communication line of sight, creating a non-line-of-sight (NLOS) state, which can lead drivers to make poor judgments when changing lanes or merging onto a highway. NLOS can be either intentional or unintentional. Intentional: malicious attacks, fake position. Unintentional: physical obstacles (trees, buildings) or moving obstacles (trucks, e.g., in an industrial area). The proposed work considers unintentional NLOS based on either physical or moving obstacles [5–7].

Many researchers [5–9] covered the challenges that might cause or affect the NLOS issue from different perspectives in communication domains, the main challenges include signal strength, communication range, signal blockage, authentication, and signal interference. Similarly, in location verification and detection domains, the main issues include verification of position of the nodes, reliability of message senders, availability, and issues concerning with the quality and integrity of service. Other Several researchers have proposed location verification techniques for hidden nodes in wireless networks. These approaches are generally categorised into two classes, depending on the underlying principle of propagation models: distance information methods for location verification (infrastructure-based verification methods) and distance-free approaches (infrastructureless-based verification methods). A distance-based method such as the ECHO protocol for location verification that is proposed by [10] is based on the challenge response.

The location verification methods developed by [11,12] verify the location of the hidden node by calculating the distance of three detecting nodes from the hidden node or target node. Similarly, [13] proposed a scheme that uses some reference points around the hidden node to verify the claim of the target node (node under NLOS). The second category of location verification – the distance-free approach – is based on the principle of utilising the distance information; and location claims are verified through location-measuring techniques, such as the angle of the radio signal communicated between the detecting and the target nodes [14]. However, in comparison with the distance-based technique, distance-free schemes do not require the exact estimation of the location of the hidden node, which is why they do not face

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