Evaluating DTN Routing Schemes for Application in Vehicular Networks

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***Abstract*—Vehicle-to-vehicle networks have gained significant interest in recent times from researchers all around the world. V2V/V2I are emerging as an efficient solution for achieving road safety and securely transmitting data from one vehicle to other. However, in such opportunistic environments such as a sparse vehicular network where disruption, dynamic network topology, fast vehicle movement, and environmental conditions are the major concerns, data forwarding is extremely challenging. Traditional ad-hoc routing protocols like Ad hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) fail to deliver in such laborious conditions. Routing protocols of Delay/Disruption Tolerant Networks(DTN) exploit the Store-Carry-Forward Mechanism (SCF) strategy in these cases. Taking advantage of temporary connections to disseminate information is the focus of DTN. DTN helps to increase information propagation coverage in sparse areas where there are very few devices. In this paper, we first compare the performance of AllJoyn framework and Direct Delivery protocol in a single-hop scenario and then draw the attention towards a multi-hop scenario by comparing other three routing protocols that use DTN as the underlying paradigm. These protocols are Flooding, Epidemic, and PRoPHET. The performances are evaluated by transmitting the files of size 1, 4, and 10 MB from a static sender to a mobile receiver in the multi-hop scenario. We also develop an Android application that contains the implementation of these routing protocols along with file sharing functionality. From the outcomes of this experiment, it can be said that Epidemic routing protocol performs the best in our considered multi-hop scenario in terms of transfer delay, coverage, and throughput whereas, Direct Delivery routing protocol performs better than AllJoyn in single-hop communication.**

***Keywords*—Vehicle-to-Vehicle (V2V) Communication; Vehicular Ad hoc Networks (VANETs); Delay/Disruption Tolerant Networks (DTN); Direct Delivery; Flooding; PRoPHET; Epidemic; AllJoyn**

I. Introduction

Vehicle-to-Vehicle (V2V) network is one of the core technologies enabling Intelligent Transportation Systems (ITS). V2V aims at providing low-latency short-range communication and multi-hop connectivity between vehicles. V2V communication is supported by smart vehicles equipped with multiple interface cards from wireless technologies such as Wi-Fi, cellular V2X, and IEEE 802.11*p*. In-car infotainment, increased safety, information sharing, and being environment-friendly are the key advantages of connected cars. However, automobile industries face some of the greatest challenges in creating a network of connected cars viz., strict latency, wider coverage, dynamic network topology, vehicle network security and disruption. Vehicular Ad-hoc Networks (VANETs) have emerged as a competent solution for achieving seamless connectivity in ITS [1]. VANETs make use of Dedicated Short-Range Communication (DSRC) for transmitting and relaying data over multi-hop mode. The majority of all nodes in VANETs are vehicles that are capable of forming self-organizing networks without prior knowledge of each other. The primary intended application of VANETs is to provide safety to drivers. High mobility, unbounded network size, dynamic network topology, no power constraint due to the on-board power unit, and time criticality are some of the key characteristics of VANETs. Due to highly dynamic network topology and rapid movement of vehicles, communication in VANETs is extremely challenging. When environmental conditions also start to play their role, it becomes even more difficult to make connected cars efficiently communicate and share data over the ad-hoc network. Hence, there is a need for developing efficient V2V technologies and robust routing protocols that can address these challenges.

Routing protocols in VANETs are considered as one of the critical components that need a comprehensive study to improve reliability and efficiency. Many routing techniques and frameworks are proposed in the literature to tackle the limitations of VANETs e.g., Delay/Disruption Tolerant Networks (DTN) [2], AllJoyn [3], etc. However, we have considered a sparse vehicular network where vehicular traffic or density is significantly less because of the limitation of high link breakage in the dense vehicular network [4]. Vehicle density in a country like India is 32 vehicles per 1,000 people, which becomes even less on highways and in rural areas. This is a prime concern because unlike Urban areas a robust communication infrastructure is not available in rural areas. Performance of routing protocols in ad-hoc networks depends on several factors such as environmental conditions, obstructing structures, Signal-to-Noise Ratio (SNR), and the distance between nodes. These impact of these factors is even more adverse when nodes in the network are mobile, as in the case of vehicular networks. Therefore it becomes very crucial to measure the performance of these routing techniques.

In this paper, we compare the performance of DTN routing protocols and investigate the relevance of the AllJoyn framework to sparse V2V scenarios. We consider a network with low vehicle density and low mobility [5]. In our experiment, we consider the sparse scenario to examine the effect of vehicle mobility on delay incurred in file transfer in the multi-hop scenario. The previous works on this problem did not

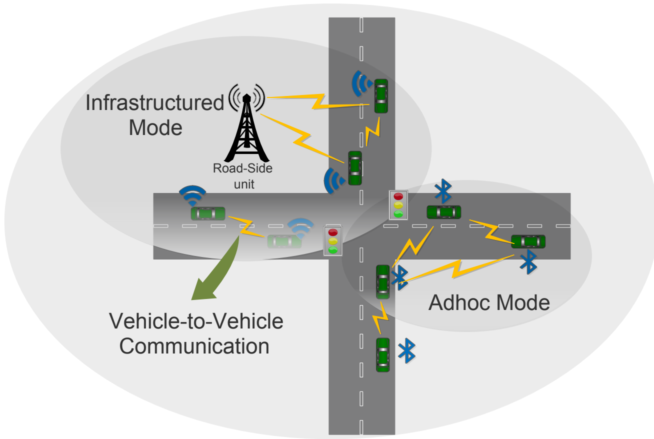

Fig. 1. V2V/V2I Communication

consider the effect of the file transfer by varying the distance between devices and they also did not consider the mobility of the devices. A mobile vehicle can transmit and receive information such as vehicle location and incident reports in the form of files and messages. Hence, it also becomes important to understand the behavior of routing protocols by transmitting the files of variable sizes. There are four protocols that use DTN as the underlying technology viz., Epidemic, PRoPHET, Flooding, and Direct Delivery. We first compare the performance of Direct Delivery with AllJoyn in a single-hop scenario. Thereafter, we evaluate the three multi-hop DTN protocols by transmitting files of size 1MB, 4MB, and 10MB. We show that Epidemic performs better than the other two DTN protocols except for file of size 1MB where the results are comparable with PRoPHET. Our results show that Epidemic outperforms all other protocols.

The rest of the paper is structured as follows: Section II gives an overview of routing protocols, their advantages, and disadvantages. Experimental setup and detailed analysis of results are presented in Section III. Finally, conclusions are drawn in Section IV.

II. Overview of Ad-hoc Network Technologies

A. DTN: Delay/Disruption-Tolerant Networking

Delay/Disruption-Tolerant Networking (DTN) is a networking architecture that is designed to provide communications in the most challenging and unstable environments e.g., post-disaster scenarios [6]. DTN is generally used in the scenarios where traditional routing protocols like Ad hoc On-Demand Distance Vector (AODV) [7] and Dynamic Source Routing (DSR) [8] fail to deliver due to poor connectivity and longer delays. Disruption in the network may occur due to extreme terrestrial environments, scattered nodes, limits of wireless radio range, and interference. In VANETs, connectivity is often impacted by frequent changes in topology, vehicle speed, and unpredictable movement of vehicles. Hence, it becomes essential to use a bundle-protocol such as DTN to achieve reliability and seamless communication between vehicles. DTN enables communication between nodes in the network in an opportunistic manner [9], [10]. To deal with frequent disruptions and high mobility of vehicles, the Store-Carry-Forward (SCF) mechanism in DTNs makes the opportunistic routing feasible in VANETs. In DTNs, finding the most suitable next-hop node to forward messages is quite challenging. There are several routing protocols proposed in the literature that use distinctive techniques to identify the most appropriate node in the network to relay the messages. Traditional routing protocols simply focus on selecting a path out of the many available. DTN uses some intelligence, apart from selecting a path, on being as efficient as possible such as Store, Carry and Forward mechanism to incrementally transmit data across the network in hops. Some of the widely used routing protocols that use DTN as underlying technology are as follows:

1) Direct delivery: This routing scheme is very simple to implement as it maintains a single copy of each message. It is a single-hop protocol and works only if both devices are in the range of WiFi-Direct or a hotspot. Messages are handled on the first-come-first-serve basis. Due to its simplicity, it does not consume more resources such as battery. Problems like flooding, duplicate messages, etc., are unlikely to occur in this protocol. However, this protocol leads to a massive number of message drops leading to less delivery probability. Due to single-hop, this protocol fails to deliver packets beyond a certain range.

2) Flooding: In this routing protocol, the packet is forwarded to all nodes in the network except the node from which the packet has arrived. This protocol does not require any information like channel condition, load, cost of paths, topology, etc. As all the available paths between sender and receiver are taken into consideration, the shortest path is always guaranteed. The major disadvantage of this protocol is a huge number of duplicate packets which can cause congestion in the network.

3) Epidemic: Epidemic protocol is an improvement over flooding-based routing protocol in which nodes continuously replicate and transmit messages to the nodes which are newly discovered and do not already possess a copy of the message. Epidemic routing protocol guarantees message delivery at destination by providing a sufficient number of random exchange of messages. To maintain a list of messages, each node has a database called the *summary vector*. First, the summary vectors are exchanged and then only those messages are transmitted which are not already shared. When a node is aware of the existence of neighboring nodes, it replicates and forwards all of its stored messages to each one of them directly. Hence, in Epidemic Routing, a message is forwarded from node to node all over a network, like the spread of a viral epidemic [11], [12].

4) PRoPHET: This protocol is based on the idea that if a node has contacted with a node frequently, the probability of contacting the same node is higher. It is a greedy routing protocol which intentionally does not make an effort to eliminate duplicates in order to increase delivery predictability. Delivery predictability between two nodes is calculated based on contact history between them, where higher delivery predictability implies a higher probability of future contacts between them. In PRoPHET protocol, a message is sent to a contact node only when the delivery predictability to a destination node of the contact node is more than that of the transmitting node. Due to this, PRoPHET protocol achieves good delivery predictability satisfying the constraint of less overhead, using the above constraint on delivery predictability. Keeping duplicate packets in order to increase the delivery probability can affect the transfer time and throughput of this protocol. Key advantages and disadvantages of DTN routing protocols are stated in TABLE I.

B. AllJoyn Framework

AllJoyn [13] is an open source framework designed by Allseen Alliance for automatic discovery and communication between mobile devices. It is a proximity-based peer-to-peer communication framework for devices in a distributed system which does not need an infrastructure for communication across devices. AllJoyn performs service advertisement, discovery, bus attachment, and session management in order to transfer messages and files to mobile devices. An advertising device initiates an AllJoyn network by creating a channel, which is a data sharing session and also called as a bus in AllJoyn terminology. When a service is started on the advertising device, other devices receive the service advertisement and they can latch on to a bus to share data or make use of service provided by the advertising device.AllJoyn framework has the following key components :

Fig. 2. Features of AllJoyn Framework

1) AllJoyn Router: The AllJoyn Router provides main functionalities of AllJoyn Framework, including peer discovery, connection establishment, routing of messages. Each AllJoyn router is associated with the Global Unique Identifier (GUID). A new GUID is generated when the AllJoyn Router starts up. One AllJoyn router can be associated with a single application or multiple applications. The router can communicate with other routers and applications.

2) AllJoyn Bus: An AllJoyn router provides a lightweight software bus functionality. The AllJoyn bus is a medium for communication between applications as one or more applications can connect to the bus in order to exchange messages. AllJoyn bus establishes communication over technologies like Wi-Fi while hiding all communication link details from the applications.

3) AllJoyn App: AllJoyn provides different applications, including AllJoyn chat and AllJoyn file transfer on various platforms such as Android, iOS, etc., to make use of services offered by AllJoyn [14]. An application can communicate with other applications but cannot communicate with a router.

TABLE I
SUMMARY OF ROUTING PROTOCOLS

Routing Protocol	***Advantages***	***Disadvantages***
Direct Delivery	• Consumes minimal resources. • Overhead is less as it sends only one message at a time.	• Works only for single hop. • Lower probability of delivery.
Flooding	• Packet delivery is guaranteed. • Easy to implement and converges fast. • Robust: Packets are delivered via some route even in the case of a link failure.	• Bandwidth wastage is more. • Due to duplicate messages network load increases. • Redundant packets may loop in the network forever.
Epidemic	• Explores all available paths to forward messages. • Number of redundant packets is reduced compared to flooding.	• Still suffers from bandwidth wastage. • Utilizes more resources.
PRoPHET	• A higher delivery ratio, less communication overhead as compared to Epidemic.	• Resource consumption is high as this protocol duplicates a message if delivery predictabilities are same for multiple receivers.

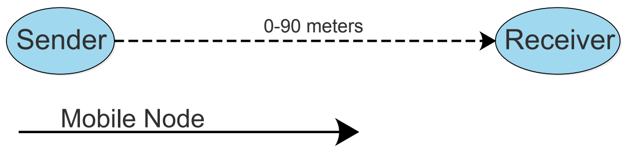

Fig. 3. Topology for AllJoyn and Direct Delivery

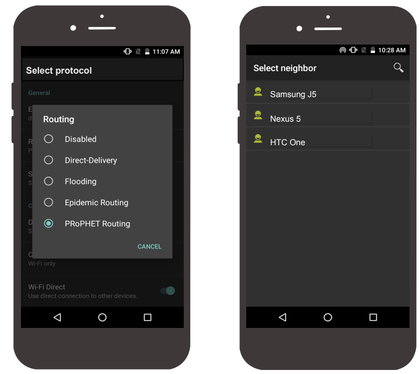

Fig. 4. Android app to transfer files

III. Experimental Setup and Performance Results

A. Single-Hop Scenario

In this experiment, the performance of Direct Delivery routing protocol is compared to the AllJoyn Framework by setting up the topology shown in Fig. 3. Both, Direct Delivery and AllJoyn framework transmit packets to immediate neighbors over a single-hop. We consider only two nodes in the topology where one node is the sender while the other is the receiver, where the receiver is an investigator who is carrying the mobile. The receiver is moved away from the sender with an average speed of 1.4 meters per second which is also the average human walking speed, with multiple obstacles in between. We are considering the mobility of a single device (the receiver) in our experiment, to emulate sparse and low-mobility V2V scenario.

Figs. 5, 6, and 7 show the comparison of AllJoyn with Direct Delivery in terms of delay incurred in transferring the files of size 1MB, 4MB, and 10MB respectively. It can be seen that both of them fail to transmit beyond 70 meters as they support only single-hop communication.

Another conclusion that can be drawn from the above results is that AllJoyn performs better than Direct Delivery up to 50 meters and than its performance starts to deteriorate with the increase in distance. This is because AllJoyn uses traditional routing protocols which fail to deliver when the network topology is dynamically changing. Also, the delay induced by both the protocols is rather high for challenging scenarios like Vehicular Ad hoc Network. Hence, there is a

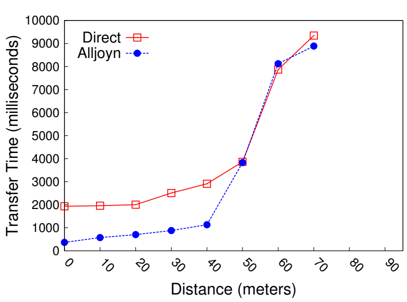

Fig. 5. Transfer Time vs Inter-node distance (1 MB file transfer)

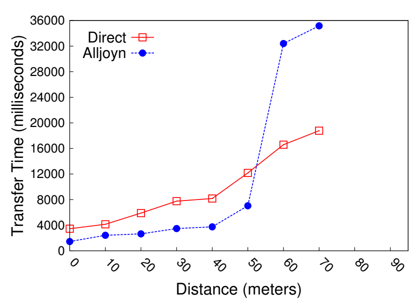

Fig. 6. Transfer Time vs Inter-node distance (4 MB file transfer)

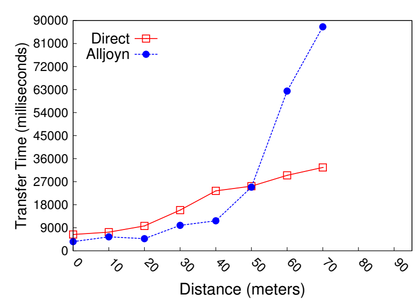

Fig. 7. Transfer Time vs Inter-node distance (10 MB file transfer)

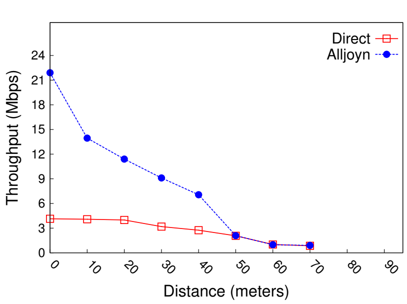

Fig. 8. Throughput vs Inter-node distance (1 MB file transfer)

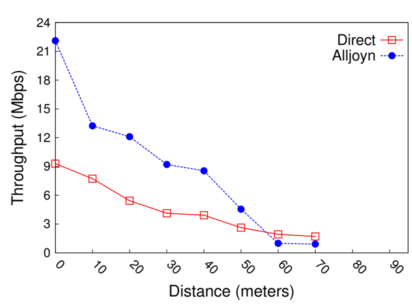

Fig. 9. Throughput vs Inter-node distance (4 MB file transfer)B

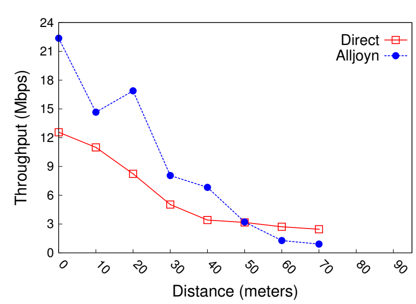

Fig. 10. Throughput vs Inter-node distance (10 MB file transfer)

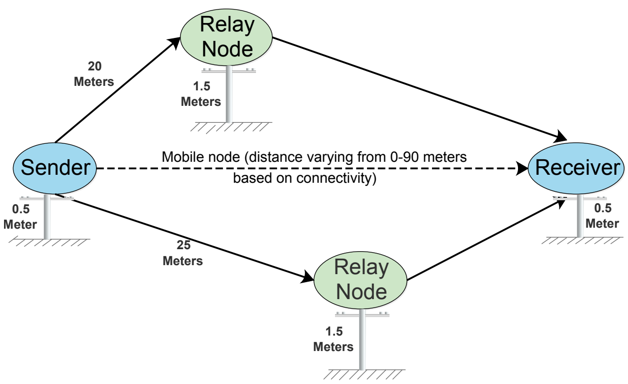

Fig. 11. Topology for Flooding, Epidemic and PRoPHET

Fig. 12. Satellite View of Experimental Site

need to study the performance of other intelligent routing protocols like Epidemic, PRoPHET, Flooding, etc., that offer lower transmission delays and make use of relay nodes to transmit data to a greater extent.

B. Multi-Hop Scenario

Considering the limitations of single-hop communication, we compare the performance of multi-hop DTN routing protocols. To compare the performances of Flooding, Epidemic, and PRoPHET, we consider the topology shown in Fig. 11. In the experiment, smartphones are referred to as nodes. The satellite view of the experimental site is shown in Fig. 12. We consider the multi-hop scenario where two nodes serving as relay-nodes are fixed at a distance of 20 meters and 25 meters, respectively, from the sending node. The receiving node is again moved away from sending node with the same speed as in case of the single-hop scenario, i.e., at 1.4 meters per second, with multiple obstacles in between. To ensure better connectivity, sending and receiving nodes are kept at the height of 0.5 meters from ground whereas both the relay nodes are fixed at the height of 1.5 meters tied to a pole.

To transfer the files between nodes, we design an android application that has all the DTN routing protocols built-in. For each experiment, one of the routing protocols is selected from

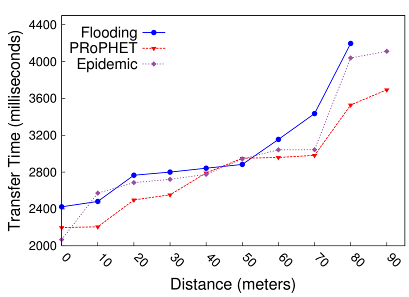

Fig. 13. Transfer Time vs Inter-node distance (1 MB file transfer)

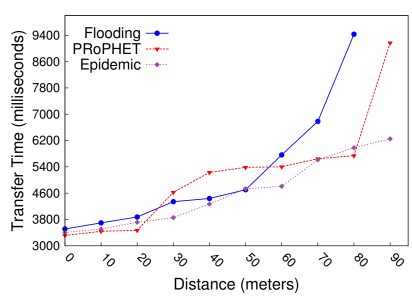

Fig. 14. Transfer Time vs Inter-node distance (4 MB file transfer)

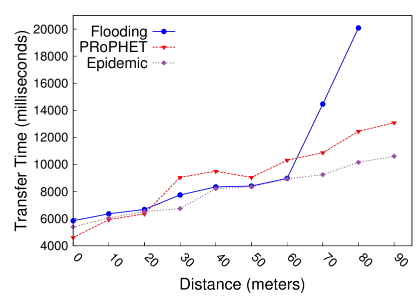

Fig. 15. Transfer Time vs Inter-node distance (10 MB file transfer)

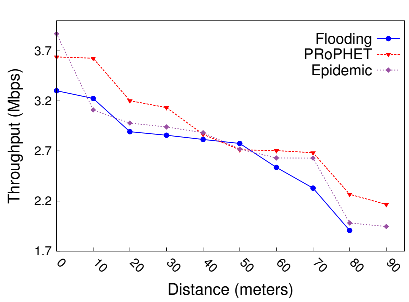

Fig. 16. Throughput vs Inter-node distance (1 MB file transfer)

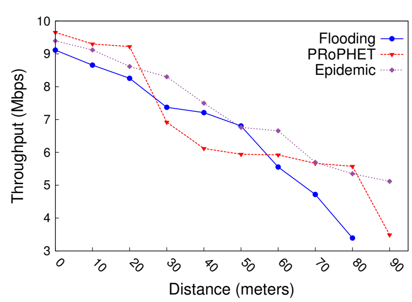

Fig. 17. Throughput vs Inter-node distance (4 MB file transfer)

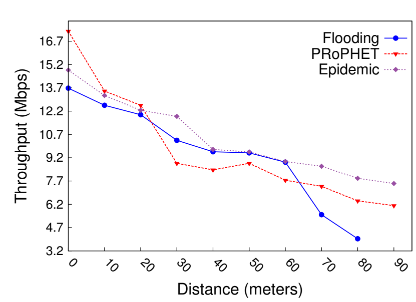

Fig. 18. Throughput vs Inter-node distance (10 MB file transfer)

the drop-down menu as shown in Fig. 4. Receiver and both the relay nodes are connected to the sending node using a hotspot or wifi-direct to establish the ad-hoc topology as shown in Fig. 11. Once the entire network is set up, the receiving node is moved away, and files of variable sizes are sent from the sender after every 10 meters. Network Time Protocol [15] is used to synchronize the clock of both sender and the receiver. The delay and throughput values are recorded for all the protocols.

Figs. 13, 14, and 15 present a comparative study of delay incurred in receiving the files of sizes 1, 4, and 10 MB respectively for all the three multi-hop protocols that use DTN as the underlying technology. In case of Flooding, even though it uses multi-hop, it can be seen that it breaks down at 80 meters due to multiple copies received at receiver leading to congestion. Performance wise both Epidemic and PRoPHET perform better than Flooding. However, Epidemic outperforms PRoPHET as the file-size is increased to 4 MB and 10 MB. For the 1MB file, PRoPHET performs better than Epidemic and ensures high delivery ratio. The possible reason is that for small file-sizes the packet loss may be less due to duplication of packets. The performance of all the routing protocols is comparable initially (up to 40 meters) as the communication is essentially single-hop. But, as the distance is further increased, the performance depends on the choice of relay nodes and path selection. Leveraging multi-hop transmissions, both Epidemic and PRoPHET are able to transfer data up to 90 meters. Fig. 16, 17, and 18 draw the throughput comparison between DTN protocols. Epidemic surpasses all the other protocols and offers maximum throughput.

IV. Conclusions and Future Work

This work presented the performance analysis of routing protocols that use DTN and the AllJoyn framework for V2V applications. In this paper, we investigated the performance of single-hop and multi-hop routing protocols that can be used in VANETs for efficiently transmitting data from vehicle to vehicle. First, we discussed the general idea of DTN and its four routing protocols namely Direct Delivery, Flooding, Epidemic, and PRoPHET, and then we the introduced the AllJoyn framework and its key concepts. Paper does not go into specific details of these routing protocols and only presents a high-level view. The key findings are that AllJoyn initially performs well but suddenly begins to deteriorate after 40 meters when compared to Direct Delivery. Further, it does not support multi-hop communication which is characteristic of V2V scenarios, so it is not suitable for V2V communication. Besides, AllJoyn is not primarily designed for VANETs. Results demonstrate that Epidemic outperforms all other multi-hop DTN protocols. It removes duplicate packets and restricts network congestion, unlike Flooding. Performance of PRoPHET is comparable to Epidemic in some scenarios, but overall it performs worse than the latter because it keeps duplicate packets to improve delivery predictability, which indirectly increases the load on the network leading to higher transfer-time.

As an extension to this work, we plan to develop a smartphone-based application making use of cloud and ad-hoc technologies for real-time collision detection and incident reporting. As a result of this study, we will use the Epidemic protocol to share location data to neighbors in real-time, leveraging both, internet connectivity and mobile ad hoc communication.

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