Multi-hop Data Dissemination with Replicas in Vehicular Sensor Networks

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Abstract— **This paper proposes a novel multi-hop data dissemination method using data replication technique to collect sensor data in Vehicular Sensor Networks (VSN). Currently, existing network protocols for general sensor networks pose problems when used in VSN applications. Even the majority of research based on VSN network protocols has some problems, as they limit their data harvesting schemes to only single-hop or short distance transmissions, or use high-cost relay stations to support multi-hop cases. As a result, these works cannot completely solve some critical issues in VSN, such as data transmission delay, packet overhead, and network connectivity. We believe such problems can be alleviated by our scheme, which uses replicas in a multi-hop data dissemination scheme. Our simulation study conducted using the QualNet 4.0 simulator shows the effectiveness of the proposed scheme.**

Keywords-Vehicular Sensor Network; Data Replication; Data Dissemination; Vehicular Ad Hoc Networks.

I. INTRODUCTION

Vehicular Ad Hoc Networks (VANET) is a communication technology that creates a network between vehicles [1] or roadside gateways to allow information exchanging between users. VANET is currently considered as one of the popular issues in the network research community, as this technology can provide safety, comfort, and information to drivers on the road. Especially, research on Vehicular Sensor Networks (VSN), a part of the VANET, is gaining much interest as a promising future sensor technology. Vehicular sensor network is a technology where sensors are deployed on the roads or on vehicles to sense various phenomenons on the road, and transmit this information to users that require them. Using this technique, VSN is capable of providing services and applications to drivers. Below lists just few of the many applications this promising technology can introduce:

- *Recognize the current road situation.* The VSN can be used for the driver to recognize the current situation of the nearby roads and take appropriate actions. For example, sensing information of the upcoming roads can be acquired to avoid traffic jams, or make the driver aware that there is a car accident or a hazard nearby [11]. Also, VSN has potentials to be used in warfare to sense enemy vehicles or mines deployed on roads.
- *Pursuing criminals.* Roadside Sensors can store information of criminals or stolen vehicles using image sensors. Police vehicles can receive these images on complicated roads to pursue the criminals. Also, this information can be used to predict the current whereabouts of a stolen vehicle and block the road beforehand.
- *Road Navigation.* The current road navigation systems using GPS technology can provide drivers an optimal path to the destination in terms of distance. However, sensors on the road can provide not only the distance based optimal path but also the current status of these roads, allowing more information for road navigation.
- *Vehicle Parking.* Sensors installed in car parks can provide information to drivers and direct them to a nearby empty parking lot.

One of the biggest issues in realizing VSN is concerned with data harvesting. Data harvesting is a technique where VSN sensors create meta-data that summarizes the characteristics of the data and send it to any requesting vehicles. The vehicles can receive these meta-data to locate the data of interest, and then later receive (harvest) the actual sensed data. However, the unique characteristics of VSN, such as high mobility of nodes, unstable network topology, and high energy supplies for sensors make existing schemes for general sensor networks such as [2] and [3] undesirable for VSN. For example, high velocity of vehicles can create problems in keeping routes and neighbor tables. Since vehicles can move at a speed of up to 30m/s, connections between nodes can break easily, and updates have to be made frequently. Also, vehicles can exist from 1 to nearly 500 on a single kilometer road; therefore coping with the dynamic network topology becomes another non-trivial task. Lastly, unlike general sensor nodes, sensors in VSN can receive nearly infinite energy from vehicle batteries, buildings, and streetlights. Therefore, previous low-rate, low-power sensor network protocols that focus on achieving energy efficiency cannot be the optimal solution, as large size of data such as image or audio files needs to be transmitted using high-speed protocols in VSN. With these differences in mind, there is a need to develop new types of data harvesting protocols that can adapt well to these characteristics.

"This research was supported by the MIC(Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute for Information Technology Advancement)" (IITA-2008-C1090-0801-0015), (IITA-2008-(C1090-0801-0003)), and with Ajou university research fellowship of 20072890, 2007.

This paper will focus on these characteristics of VSN and propose a novel scheme for disseminating sensed data using multi-hop transmission and data replication. Section 2 organizes the related works of this scheme. Section 3 introduces the proposed scheme, along with the network architecture applied in this paper. Section 4 evaluates the results of the simulation conducted with QualNet. Section 5 will introduce some future works and conclude the paper.

II. RELATED WORK

Due to the distinct issues of VSN, previous data dissemination techniques that may function well for general sensor networks pose problems when applied directly to the VSN. Especially, the well-known algorithm such as "Directed Diffusion"[2] cannot be used because the gradients it creates using multi-hop querying cannot adapt to the high mobility of the vehicle. This is because when the nodes participating in the gradient move from its current location, transmission links between the nodes can become broken. Consequently, the protocol will have to create new gradients frequently to keep up with the mobility of the vehicle, which will produce additional packet overhead. Ad Hoc On-Demand Distance Vector routing (AODV) [3] may function as one of the multi-hop data harvesting techniques in VSN. This scheme can create an optimal path between the vehicle and the sensor node using route request broadcasts and route replies. However, also due to the vehicle mobility, the path will have to be created frequently if the link is broken before all the data are transmitted. Also, the flooding of the route request broadcasts without special time-to-live controlling may flood the whole network of the VSN, which can be small as a road but also as big as a whole city. Therefore, AODV cannot be the ideal protocol. Simple routing protocols suitable for sensor networks such as tree routing also cannot be used, because the network topology of the VSN is simply too large and too dynamic to create an efficient tree topology. Instead, basic geocast forwarding schemes [12], a method that delivers data to a group of destinations identified with x and y coordinates can be used to efficiently find and request for data.

Some recent work has been made in developing network protocols suitable for vehicular sensor networks. In Mobeyes[4][5][6], vehicle-to-vehicle communication is defined, and the mobile sensors will share their data with other nearby vehicles using 'Summary Diffusion'. When the data cannot be sent due to broken links, the vehicles will keep their sensed data until they enter a transmission range of another vehicle, and then opportunistically transmit their summaries of sensed raw data. Any other vehicle that requires this data will request its current neighbors, and the neighbors can transmit any missing packets that the requesting vehicle has not yet received. This method will support data transmission between short distances, because the sensed data will be shared around only to the neighbors of the source. The summary sharing between the neighbors can be extended to multi-hop, but this will greatly increase the total packet overhead. Therefore, we argue this protocol is not the ideal solution in vehicle to roadside communication, and the reasons will be shown in the simulation results in section 4.

The idea of using infostations in [7] describes another type of data harvesting protocol for VSN, in a more hybrid form. Vehicles will send all their sensed data to infostations, where the data will be forwarded to corresponding infostations based on the infostation's management area. Later, any vehicle requesting sensed data can request to these infostations, which is more of an indirect form of vehicle to vehicle communication using relay nodes. However, this technique requires installation of an infostation infrastructure, which can be very costly and complex.

III. THE PROPOSED SCHEME

We present the proposed multi-hop data dissemination scheme for Vehicular Sensor Networks in this section, along with the network architecture that has been applied for this scheme. The network architecture used for this protocol creates communications between vehicles and sensor nodes on the road side for data dissemination. Sensors are uniformly placed on the roadside with fixed distances, and collect data requests from vehicles. We will assume that each sensor knows its current location information, using technologies such as Global Positioning System (GPS)[8] or triangulation technique. Sensors will store the sensed data in its memory until any vehicle requests for the sensed data. The general view of this architecture can be observed in Fig 1. At the initialization of the network, each node will create and maintain a neighbor table. To fill this neighbor table, each sensor node will periodically send beacon messages to let its neighbors recognize its existence. Upon reception of a beacon message, the node will fill up its neighbor table with the beacon sender's ID and the x and y coordinates of the sender. The neighbor table will be updated at intervals to make sure that data are not sent to a dead node. Important thing to note here is that vehicles will also send beacons and update their neighbor tables. A replica table is also maintained by each node to track all the replicas it received. When the node with replicas receives a request from a vehicle, it will search in its replica table and if the corresponding data exists, it will transmit the replica to the vehicle that requested it.

The steps below will describe more in detail how data is disseminated and replicated in the proposed scheme for successful transmission from the source sensor node to the requesting vehicle. The scheme will be divided into three parts: the Data Requesting Phase, Data Replication Phase, and the Data Sharing Phase.

1) Data Requesting Phase

A vehicle that requires data will send a request control packet to a target location via general geocasting method. This control packet contains information of the vehicle's ID, vehicle's information, and the type of sensor data it is requesting. The vehicle can send this message to the sensor node that is currently closest to the vehicle, by searching the vehicle's neighbor table and calculating the distances between

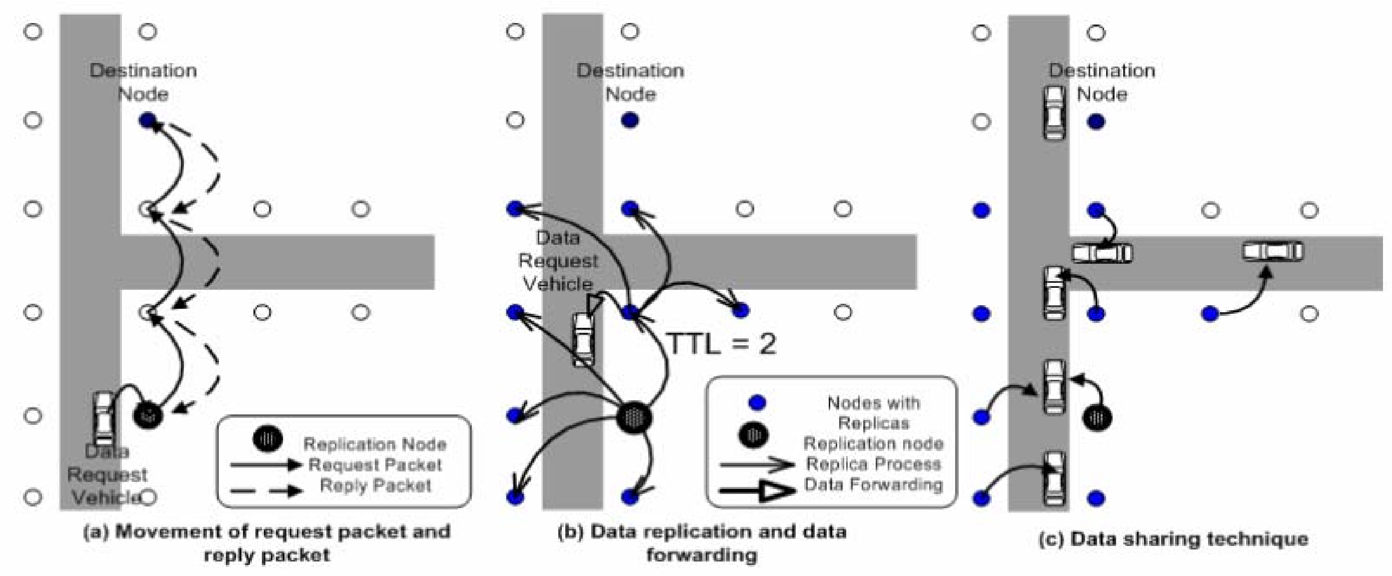


Fig 1. Multi-hop Data Dissemination with Replicas in Vehicular Sensor Networks

the neighbors. The sensor node that receives this request packet will declare itself as the 'Replication Node'. The replication node includes its ID in the packet as the new destination, include its x and y coordinates, and then forwards the packet. At the time of transmission, the replication node will initiate a timer which will be used later for controlling the data replication. The packet will be forwarded until any sensor node that is included in the destined location receives it. When the node holding the requested data receives the request packet, it will compare the replication node's x and y coordinates with the x and y coordinates of all of its neighbors. When the closest node to destination in its neighbor table has been found, the data will be sent to that closest node. The data messages will be forwarded in the same manner described above, and eventually reach the 'Replication Node', but not the vehicle that requested the data yet. The process of the data requesting phase can be observed in Fig 1 (a).

2) Data Replication Phase

When the replication node receives the data from the sensor node originally holding the requested data, it will calculate the time *t(seconds)* using the timer. The value *t* will be the time it took for the data to reach the replication node after the first request for the data. After the calculation, the replication node will flood the data packets to its neighbors, creating replicas of the data to its neighbors. Since transmission via flooding covers the whole network, we want to control the flooding by calculating the time-to-live (TTL) value. With the velocity of the vehicle that requested the data *v(m/s),* the distance between each sensor node *d(meters),* and the time required for the data to arrive to the Replication node *t(s)*, we can calculate how far the vehicle has moved while receiving the data with the equation below:

$$\frac{v*t}{d} \qquad (1)$$

As shown above, the equation (1) is divided with the parameter *d,* meaning that the distance the vehicle has traveled is calculated in number of hops, not meters. The value calculated from the equation cannot be used by itself to calculate the time-to-live value, since the size of the data and data transmission rate has to be also considered. If the size of the data is *p(bytes)* and the transmission rate of the sensor is *r(bytes/s),* we can calculate the distance the vehicle has traveled while the data is transmitted to the vehicle with (2).

$$\frac{v*\left(\frac{p}{r}\right)}{d} \qquad (2)$$

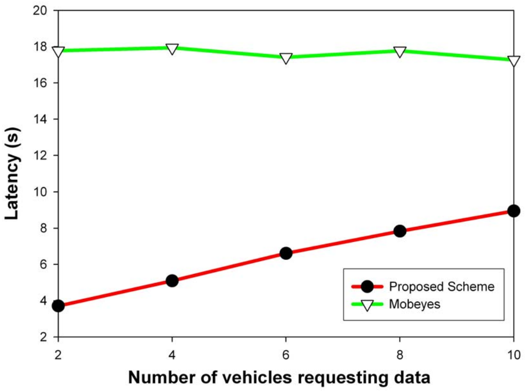
The two equations (1) and (2) will be added together and rounded up to calculate the appropriate time-to-live value. The equation (3) shows the calculation of the TTL value that will be used to control the flooding of the data replication.

$$TTL = \left\lceil \frac{v*t}{d} + \frac{v*\left(\frac{p}{r}\right)}{d} \right\rceil \qquad (3)$$

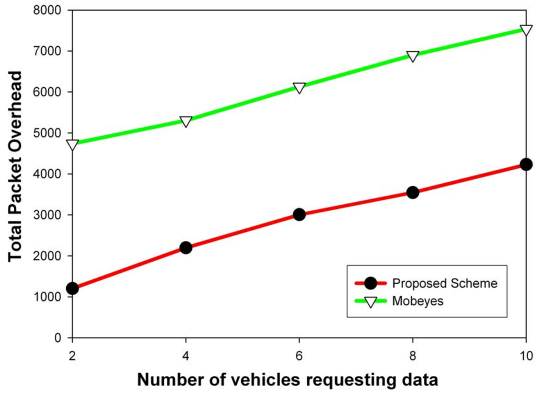
The formula (3) above shows that more replications will be made as the velocity of the vehicle becomes faster, and also as the transmission rate of the sensors becomes slower. It can be seen in Fig 1 (b) that the vehicle can receive data packets from any of the sensor nodes with the replica, even if the vehicle is out of the transmission range of the replication node.

3) Data Sharing Phase

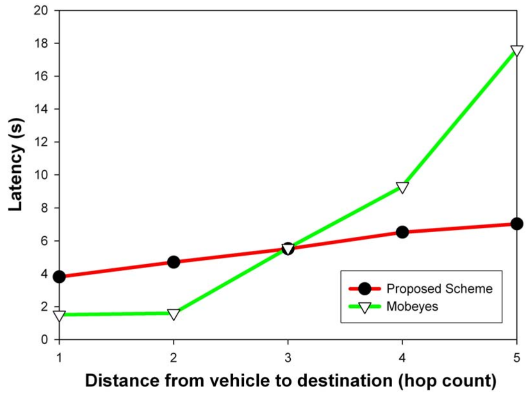
In some areas, data traffic may increase dramatically due to many vehicles requesting for data at the same time. In this case, there is a high probability that more than one vehicle is requesting for an identical data at the same location. To support these cases, we propose a data sharing scheme using the replicas created in the previous phase. It can be seen from



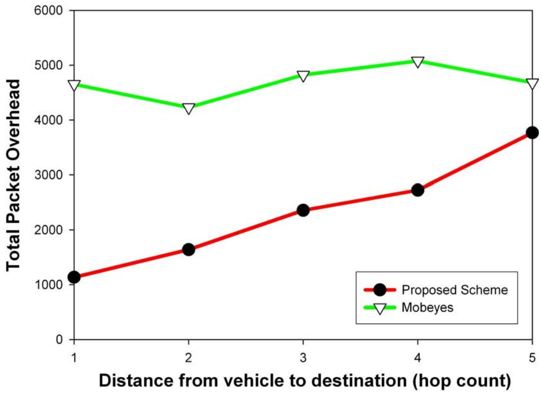
(a) Transmission Latency vs Number of Vehicles



(b) Packet Overhead vs Number of Vehicles



(c) Transmission Latency vs Hop count



(d) Packet Overhead vs Hop count

Fig 2. Performance Analysis of the Proposed Scheme in a comparison with Mobeyes [4]

Fig 1 (c) that after the replicas are made by a request from the first vehicle, other vehicles will attempt to send a request message to its target location. The first static sensor node that receives this message will search its replica table to find any matches for the requested message. If there is a match, the sensor node will send its replica to the vehicle. If no match was found, the regular data requesting phase will be initialized. This method is effective because vehicles can receive required data in a single-hop transmission, instead of initiating another costly replication procedure.

IV. PERFORMANCE EVALUATION

QualNet 4.0 simulator was used to analyze the proposed scheme. The simulation environment was laid out on a 1500 * 1500 meter flat area with 150 sensors deployed uniformly near the roads for sensing and data transmitting. The distance between each node is set to 100 meters. The diagram of the road was created with using the Manhattan mobility model [9][10], with the sensor nodes dispatched on either side of the road to collect any data request or replicas. Each node has information of its x and y coordinates, and this information is periodically broadcasted to neighbors every 10 seconds. The period has been set to a relatively low number, to correctly update and locate the mobile vehicles, which can move in and out of the sensing range of a sensor in less than 10 seconds. However, a longer beaconing interval can be selected if vehicles do not participate in the neighbor table update process. The number of vehicles requesting data has been configured from 1 to 10. Each vehicle has a velocity differing from 0 m/s to 15 m/s. The 2.4 GHz for IEEE 802.11b is used as the radio model, with the transmission power limited to 120 meters. The CBR traffic is used to send 500kB of data at a speed of 250kb/s. We reduced the power of the protocol to reduce the size of the neighbor tables, as well as to avoid collision between packet transmissions. The simulation is compared with the single-hop data sharing scheme of Mobeyes[4], which is a network protocol that is designed for vehicular sensor networks. In the Mobeyes scheme, each node will sense data periodically every second and broadcast the data to all its neighbors. Using these parameters, the transmission delay and the packet overhead of each protocol were compared. The simulation results are shown below in Fig 2.

In Fig 2 (a) and (b), the x-axis of all the graphs was configured to the number of vehicles requesting for data, which varies from 2 to 10. Fig 2 (a) shows the comparison of the time it takes from sending the first control request packet to receiving the last data packet. It can be seen that the proposed scheme has advantages over the Mobeyes protocol. This is because while the proposed scheme can reach any destination without moving using multi-hop data request, the vehicles using Mobeyes scheme must move inside the transmission range of the destination area. Therefore, vehicles using Mobeyes use time to reach the destination before initiating any transmission, inducing big amounts of latency. However, since all data transmission is made in single hop, the probability that the transmitted packets will collide with other data traffic is low. Therefore, the latency does not increase or decrease even if the number of vehicles changes. On the other hand, the proposed scheme can save time by initiating a multi-hop transmission. However, increase in the number of vehicles causes more data flows in the network, causing collisions between data traffic. Therefore we can observe a slight increase of latency in the proposed scheme as the number of vehicles increase. Eventually we can assume that when the number of vehicles requesting for data increase to about 40, the performance of the two schemes will become equal. However, it is unlikely that 40 or more cars will request for data at the same time in a 1500m * 1500m area. Therefore, we can assume that the proposed scheme outperforms the Mobeyes scheme, but future studies on this claim are required to prove the superiority of the proposed scheme.

Fig 2 (b) evaluates the overall packet overhead in the network of the two measured protocols. We can also see in Fig 2 (b) that the proposed scheme outperforms the Mobeyes by a large margin. Since Mobeyes harvests data in single-hop transmissions, it should have better performance than the proposed scheme in terms of data transmission, because the proposed scheme sends out and retrieves packets in a multi-hop fashion. However, Mobeyes protocol creates and shares their data with its neighbors, so all nodes have to broadcast their sensed information to their neighbors every time a sensing event occurs. Since the simulated network topology consists of 150 nodes, this result in a great overhead. On the other hand, the proposed scheme creates replicas of only the requested data. Furthermore, the data sharing technique in the proposed scheme reduces further data overhead, as no replicas are initiated and created in this case.

Fig 2 (c) and (d) compares the latency and the total packet overhead with the hop count from the vehicle to the destination sensor node. We can observe in Fig 2 (c) that when the vehicle requests to a sensor node that is in a single hop or two hop distances, the Mobeyes scheme outperforms our proposed scheme because the vehicle requesting for data can receive information immediately without any vehicle traveling delay. However, when the hop count from vehicle to the destination node increases to more than 3, Mobeyes shows poor performance as the vehicles have to travel certain distances before initiating data transmission. The proposed scheme shows a relatively stable performance, but there is a slight increase in latency as the hop count increases.

Fig 2 (d) shows the comparison of total packet overhead in relations with the hop count. The Mobeyes protocol maintains identical performance regardless of the changes in hop count. Like Fig 2 (b), the data sharing between neighbors causes extreme packet overhead and degrades the overall performance of the protocol. The proposed scheme, on the other hand, shows better performance than its counterpart. However, the increase of the hop count in the data traffic increases the chance of packet collision between them. Therefore, the performance tends to decrease as the hop count dramatically increases, and eventually will have worse performance than the Mobeyes protocol.

In overall, we can conclude that the proposed scheme outperforms the Mobeyes protocol in terms of transmission latency and packet overhead. However, more studies and evaluations will be required to reduce the packet overhead of the proposed scheme, as its performance degrades highly with increases in number of vehicles and data traffic hop count.

V. CONCLUSION

A novel multi-hop data dissemination scheme using replication technique is proposed for vehicular sensor networks. Simulation studies using QualNet 4.0 shows that the proposed scheme has advantages over its counterpart. However, more comprehensive simulation study needs to be conducted to prove the superiority of the protocol. Different comparisons with other VANET or VSN protocols are needed as well, to make further enhance the performance of the proposed scheme. Also, vehicle-to-vehicle communication method can be researched and used in hybrid with the vehicle-to-roadside communication already defined in this paper. Finally, implementation using real sensor motes is required to evaluate the protocol in a real world application.

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