Localized Data Dissemination in Vehicular Sensing Networks

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1. INTRODUCTION

A vehicular sensing network (VSN) is a type of wireless sensor network (WSN) that empowers legacy resource-constrained WSNs by exploiting the rich resources (e.g., the battery life, storage capability, and mobility) of vehicles. In the recent years, a substantial amount of research effort has been invested in this area, and several real-world deployments have been carried out to demonstrate the feasibility and potential of VSNs. The potential applications of VSNs are wide ranging. For instance, it would be advantageous to employ vehicular sensing systems for reporting road surface conditions [5], monitoring environmental pollution [6], and providing urban surveillance [8].

VSNs differ from conventional wireless networks and sensing systems in a number ways. First, full-coverage cannot be guaranteed for infrastructure-based networks (e.g., WiMAX, GPRS, and 3G) in VSNs, since the latter may have to subsist in uninhabited areas and challenging environments (e.g., in mountains and desserts). Second, MANET-based solutions cannot be applied to VSNs directly, since network contacts (i.e., communication opportunities) are intermittent and unpredictable due to the diversity of vehicle mobility; and MANET-based solutions have difficulty maintaining end-to-end paths in a network. Third, delay tolerant network (DTN)-based solutions are not suitable either, as the sensed data in VSNs may vary/oscillate frequently, and DTN-based solutions are short on yield time and reliable data transmission. Moreover, in VSNs, the sensed data is mostly local in nature, i.e., vehicular networks are primarily interested in information from an event source that is nearby. For example, we may be interested in information about traffic jams on the route we are taking to a destination, or air pollution readings in the area where we work or live. Ideally, localized data dissemination should *1) only "affect" vehicles in the area where the information is relevant*, and *2) ensure that all vehicles connected to the network in the area are aware of the information.*

In this paper, we propose a novel solution, called *To-and-Fro* (TAF), for localized data dissemination in vehicular sensing networks. The TAF scheme is an opportunistic network-based approach that does not require a fully covered infrastructure-based network, and it is not necessary to maintain an end-to-end path between the source and the destination. Specifically, the TAF scheme follows a very simple rule: *it only forwards messages to passing vehicles if they are traveling in the opposite direction.* Using a comprehensive set of simulations, we evaluate the TAF scheme in terms of the spatial distribution, message population, dissemination ratio, and load distribution. The results show that the scheme is simple, practical, and very effective in preserving data sensed in the regions close to the event source, thereby fulfilling the goal of localized data dissemination. Moreover, it is easy to deploy, as long as the GPS information (i.e., the geographic position and the movement direction) can be accessed by each vehicle in the network.

2. THE PROPOSED APPROACH

In this section, we present the proposed localized message dissemination approach, called *To-and-Fro* (TAF). It exploits the mobility of VSNs, which are basically *to-and-fro*-based. The objective of the TAF scheme is twofold: 1) to disseminate messages about local events in nearby areas only; and 2) to ensure that all vehicles in the nearby areas are aware of the local messages. In this study, for simplicity, we assume that each local event (e.g., a car accident) is witnessed by all passing vehicles, and is associated with a constant deadline T_d (i.e., the event will be valid for T_d and then expire).

More specifically, suppose $\overrightarrow{m_A}$ is the normalized movement vector of vehicle A, and $\pi(A,B)$ is the angle between the movement vectors of two vehicles A and B. Then, $\pi(A,B)$ can be calculated by the arccos function of the inner product of $\overrightarrow{m_A}$ and $\overrightarrow{m_B}$, as shown in Eq. 1.

$$\pi(A,B) = \arccos(\overrightarrow{m_A} \cdot \overrightarrow{m_B}) \tag{1}$$

When the TAF scheme is used in mobile vehicular sensing, there are two scenarios where a vehicle A may encounter another vehicle B on the road:

1. When $\pi(A,B) \geq \theta$ (i.e., A and B are moving in opposite directions), A will forward to B a number of messages that B may be interested in.
2. When $\pi(A,B) < \theta$ (i.e., A and B are moving in the same direction), A has no contact with B.

In these scenarios, θ is a constant threshold that determines 1) whether A and B are moving in opposite directions[1]; and 2) whether the messages that B finds interesting are new to B and have not expired yet.

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[1] For simplicity, we set θ to 90^o, and defer a detailed discussion and evaluation of this issue to a future work.

Table 1: The properties of the network scenario

	Scenario
Duration (seconds)	2,500
Size (meters)	900 × 900
# of vehicles	1,680
# of vehicle flows	8
inter-arrival time T_a (seconds)	10
Avg speed (km/hr)	25.6898
Max speed (km/hr)	79.4455
Number of contacts	139,558
Avg # Contacts/pair	0.098952

3. EVALUATION

To evaluate the performance of the proposed TAF scheme, we implemented it and performed simulations in DTNSim2 [1]. We assume there is only one source, which produces one new event every 60 seconds, and each event is valid for 300 seconds (i.e., $T_d = 300$). Moreover, all vehicles passing the source witness the events that have been initiated and have not expired yet. We consider that two vehicles are moving in opposite directions if the angle of their movement vectors is greater than 90^o (i.e., $\theta = 90^o$); otherwise, they are moving in the same direction.

Our network scenario is based on a map of the Afton Oaks area in Houston, Texas, from TIGER [2] database. We assume the event source is located at the center of the network topology , and there are 8 vehicle flows in the scenario . Moreover, we set the inter-arrival time of the vehicles per flow as a constant T_a, and assume that each vehicle leaves the area after it reaches the map boundary. The vehicle mobility models are generated by MOVE [7]. A network contact (i.e., a communication opportunity between two vehicles) occurs if two vehicles are within each other's wireless transmission range, which is set to 100m in this study. Table 1 details the properties of the scenario. number of network contacts made by each vehicle.

For simplicity, we assume that each vehicle has an infinite buffer size, and the wireless data transmission between vehicles is error free with a fixed bandwidth of 5Mbps. All the presented results are based on the average performance of 200 simulation runs for each network configuration.

3.1 Evaluation I: Spatial Distribution

In the first set of simulations, we evaluate the spatial distribution (i.e., the *dissemination distance*) of the proposed TAF scheme over each message's lifetime in the two network scenarios. The *dissemination distance* is the average distance between the event source and the vehicles that are aware of it (i.e., vehicles that carry a message about the event). This is a good evaluation metric for indicating whether the TAF scheme can efficiently disseminate messages in local areas.

From the simulation results, shown in Figure 1, we observe that there are two phases in the curve of the average dissemination distance: a *linearly increasing phase*, and a *convergence phase*. For instance, the average distance increases linearly in the first 30 seconds, and then converges to 210 meters. Specifically, in the *linearly increasing phase*, because the event has only just occurred, only a small number of vehicles are aware of it, and most of them witness the event independently (i.e., rather than learning about it from other vehicles). Since these 'early witnesses' are moving away from the source, the average dissemination distance increases linearly over time. Meanwhile, in the *convergence phase*, a comparable number of vehicles, which are moving towards the source, learn about the event from the 'early witnesses' as they pass each other. As a result, the average dissemination distance stops increasing and starts to converge to some point.

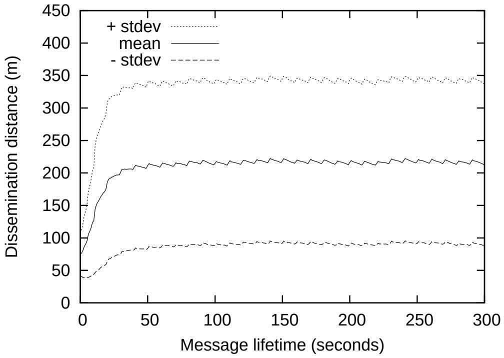

Figure 1: The average distance of message dissemination (with a standard deviation of ±1) over time.

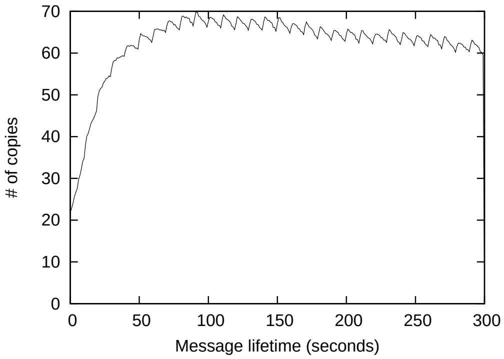

Figure 2: The average number of message copies per event in the network

3.2 Evaluation II: Message Population

Next, we evaluate the distribution of the *message population* under the TAF scheme. The *message population* is the average number of messages about each event existing in the network (i.e., the average number of vehicles that are aware of a particular event). Generally, the larger the message population, the more resilient the dissemination scheme will be against malicious network attacks [3, 4].

Figure 2 shows the simulation results. Similar to the spatial distribution, the curves increase almost linearly initially, and then converge to some point with slight fluctuations. Here, the *linearly increasing phase* is caused by the fact that the number of witnesses (either firsthand or secondhand) increases as the lifetime of the event increases. However, after some period, as the number of vehicles leaving the network increases (due to the size limitation of the network scenarios), the curve stops increasing and enters the *convergence phase*.

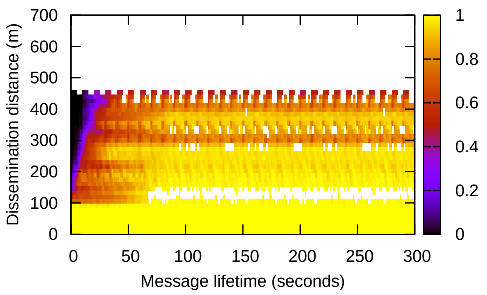

Figure 3: The percentage of affected vehicles within a specific distance of the event source.

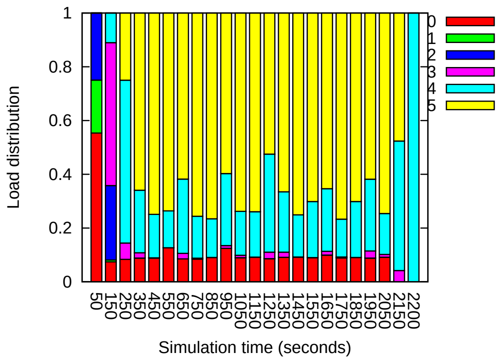

Figure 4: The load distribution of the vehicles in the network.

3.3 Evaluation III: Dissemination Ratio

Here, we evaluate the dissemination ratio of the proposed TAF scheme, i.e., the proportion of nodes that are aware of a particular event and are within a certain distance of it. Intuitively, the dissemination ratio should decrease as the distance from the event increases. Moreover, the ideal localized data dissemination solution should achieve a high dissemination ratio, especially in the area close to the event. Figure 3 shows the simulation results.

The results in Figure 3 demonstrate that, during the lifetime of a message, the dissemination ratio decreases as the distance from the event increases; and, for any distance, the dissemination ratio increases as the message lifetime increases (i.e., an increasing proportion of nearby nodes become aware of the event over time). The results confirm our intuition that the dissemination ratio increases over time and decreases as the distance increases.

3.4 Evaluation IV: Load Distribution

In the last set of simulations, we evaluate the load distribution of the TAF scheme, i.e., the distribution of the number of messages carried per vehicle in the network. Intuitively, the higher the load distribution (i.e., the more duplicates of the message that exist in the network), the more resilient the data dissemination scheme should be. However, on the downside, if the data dissemination scheme has a higher load distribution, it consumes more storage space on each vehicle. Thus, it is more likely to encounter the buffer overflow problem, especially when the vehicular network is very dense and/or the number of simultaneous events is very large.

Figure 4 shows the simulation results of the proposed scheme. Note that, since the event source generates a new event every 60 seconds in our simulations and each event is only valid for 300 seconds, the maximum number of simultaneously valid messages is 300/60=5. The results show that, the buffer consumption is about 3.9 messages; approximately 50% of the vehicles carry 5 messages, 25% carry 4 messages, 10% carry 3 messages, 4% carry 2 messages, and 11% carry 1 message or no message.

The results indicate two facts. First, the load distribution of the proposed TAF scheme is moderate because its “buffer consumption” is about 3.9/5 = 78% of the concurrent valid messages (i.e., the vehicles are not forced to listen to messages that are not nearby). Second, the load distribution tends to become more uniform if the vehicles stay longer in the area close to the event source (i.e., the network topology is more like a “closed loop”).

4. CONCLUSION

In this paper, we study localized data dissemination in vehicular sensing networks, and propose a simple yet effective approach, called *To-and-Fro* (TAF), for such data dissemination. The TAF scheme is tailored for opportunistic vehicular networks in which intermittent connectivity is common and network partitioning may occur. The results show that TAF is effective for localized data dissemination, i.e., it stores live information in the area close to the event. Work on reducing the communication overhead and tuning the system parameters is ongoing. We hope to report the results in the near future.

5. REFERENCES

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