Request-adaptive Packet Dissemination for Context-aware Services in Vehicular Networks

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Abstract—**Many applications in vehicular networks are context-aware in that the observations of sensing nodes, potentially vehicles, at a target location should be made available to the requesting node possibly at a different location. In order to provision such applications, two phases of *packet routing* between the requesting node and the target location and *packet dissemination* within the target location need to be implemented. In this paper, we focus on the second phase and propose an efficient reliable packet dissemination mechanism, Request-adaptive Packet Dissemination Mechanism (RPDM), in target location. RPDM allows for different applications to generate request packets based on their exclusive observation needs and delay requirements and adapts the dissemination mechanism in target location to specific needs of the request packet received. Besides, RPDM also takes the intrinsic characteristics of vehicular environments into account to make sure roadmap and connectivity constraints are considered and broadcast storm is prevented. Finally, RPDM is compared with a best-known state-of-the-art data dissemination mechanism, COR, and the results show that RPDM outperforms COR in terms of both resolution time and packet overhead traffic.**

Keywords- context-aware applications; vehicular ad hoc networks; packet dissemination mechanism;

I. INTRODUCTION

A large group of applications in vehicular networks can be categorized as being *context-aware*. In these applications, the vehicular user which is running the application, *requester*, needs to fetch some context observations at a specific location in the network, *target location*, which is not necessarily its current location. Note that the sensing nodes that the observations are read from could potentially be vehicles. Typical examples of context-aware applications are requesting traffic conditions or price, menu and operating hours of gas stations or cafes in the target location. The traditional approach of provisioning such applications is Crowd Sensing (CS) in which observations are periodically made in the target location and individually reported to a server in the Core Network (CN) [1-3]. The requester can then fetch the observations required by directly accessing the server. In the CS approach, all the sensing nodes are registered and known to the CN. Obviously, the CS approach consumes large network resources in terms of memory and bandwidth usage. A more recent approach is the Ad Hoc Networking (AHN) approach [4-7], in which the observations of the sensing nodes in the target location are collected on-the-fly using multi-hop packet dissemination mechanism, and in the end, only the aggregate observation is sent back to the server, as opposed to individual observations of the sensing nodes in the CS approach. Another advantage of using this approach is that the sensing nodes are not required to be a priori registered and known to the CN.

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In the AHN approach, a request and reply mechanism is employed in which a request packet is generated and sent to the target location to fetch the aggregate observation in form of a reply packet. Hence, in the implementation of this approach two distinct phases can be recognized. The first phase is to transport the request packet from the requester to the target location (or the reply packet from the target location to the requester) for which one of the state-of-the-art routing protocols proposed for vehicular networking environments can be adopted [8, 9]. The second phase is the dissemination of the request packet within the target location until a Return Condition (RC) is met that triggers the generation of the reply packet. Indeed, the RC, which is part of the request packet, determines what constitutes successful resolution of the request packet. To implement the second phase, three key design concepts should be dealt with. One is the *migration procedure* that allows for the transfer of tuple (state, service code) between the sensing nodes. The state basically includes all the observations made up to the time of transfer. The migration procedure that is a higher layer design concept has already been studied in the literature [5, 6] and is outside the scope of our paper. The other two design concepts are the structure of RC and the packet dissemination mechanism in the target location to resolve RC. The study of these two key design concepts is the focus of this paper.

In most previous studies, the RC includes a limited number of observations from any part of the target location [4, 7]. An example of the context-aware application with this type of RC is environmental air sampling for pollution sensing. However, this basic type of RC can only cover a limited number of context-aware applications. Clearly, in order to provide a wide range of context-aware applications, new types of RCs with more degrees of freedom should be developed to fully describe all different type of inquiries. In this regard, in Section II we investigate all different possible types of inquiries that can be potentially demanded by context-aware applications and define their corresponding RCs.

For the basic type of RC in [4] and [7], an on-demand broadcast-based mechanism is employed that first discovers sensing nodes in the target location and then forwards the request packet to the discovered nodes. The downside of using broadcast-based mechanisms is that in vehicular networks in which the size of the target location and the density of nodes

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may become extremely large they are not scalable and the broadcast storm problem may be inevitable [10]. On the other hand, the downside of using on-demand mechanisms in vehicular environments is that the routes discovered to the sensing nodes are very unstable and very likely to fail even before they are used. Provided that context-aware applications have different delay requirements and are allowed to issue different types of RC, the packet dissemination mechanism should also accommodate different delay requirements and be adaptable to the type of RC. In this regard, we propose a novel Request-adaptive Packet Dissemination Mechanism (RPDM) for vehicular networks that is adaptable to different RC types and delay requirements. How RPDM adapts to different types of RCs and how it is extended to meet different delay requirements are explained in Sections III and IV, respectively. In Section V, the performance of RPDM is compared to that of another plausible state-of-the-art data dissemination mechanism in the literature in terms of resolution time and packet overhead traffic. The results show that RPDM is resilient to the broadcast storm problem and it can keep the resolution time below a given delay constraint. Section VI concludes the paper.

II. POTENTIAL USER INQUIRIES

As mentioned earlier, different context-aware applications have different types of inquiries that translate into different types of RC. For the basic type of inquiry explained in Section I, namely *inquiry type 1*, we define the corresponding RC of the format [*'Observations', n*] where *n* is the number of required observations that can be arbitrarily captured at an arbitrary point in the target location. Also, in inquiry type 1 we allow for any two observations to be *d* meters away from one another by adding one more input to the RC as [*'Observations', n, d*]. Such a feature is beneficial when the observations are demanded to be independent.

In another possible type of inquiry, *inquiry type 2*, at least one observation in every street in the whole area of the target location is required. For inquiry type 2, the RC takes the format [*'WholeArea'*]. Alternatively, context-aware applications can request that at least one observation in every street along a specific path in the target location is needed. For this type of inquiry, *inquiry type 3*, the RC is described as [*'Path'*, J_S, ..., J_D] where the sequence of junctions J_S, ... , J_D describes the path and the coordinates of any junction J_i , i.e., (x_i, y_i), are known to all the nodes in the network. Note that for the inquiries type 2 and 3, the corresponding RCs of the formats [*'WholeArea'*] and [*'Path'*, J_S, ..., J_D] can be easily extended to take number *n* as another input if more than one sample on every street in the area or along the path are required. We believe that all of the possible types of inquiries that can be potentially demanded can be put in form of one of the three types of inquiry introduced in this section. For more clarification, two examples of inquires type 2 and 3 are given in a typical scenario demonstrated in Fig. 1. Car *A* is driving from J_5 toward J_{13} and its final destination is J_{28}. Obviously, car *A* has two options: it can take the path via junctions $(J_{13}, J_{22}, J_{27}, J_{28})$ or (J_{13}, J_{14}, J_{28}). Assume that car *A* is advised by its Global Positioning System (GPS) system to take the shortest path, i.e., the first option. However, car *A* knows that the neighborhood around J_{27} as depicted in Fig. 1 (on the right) is very likely to be congested. So, car *A* needs to know the traffic conditions in the neighborhood around J_{27} before making its decision. So, this neighborhood as depicted in Fig. 1 (on the right) would be the target location and car *A* requires the traffic information, e.g., the average density or the average speed of vehicles, in every single street in this area for which an inquiry type 2 is generated. Alternatively, car *A* can request that at least one observation in every street along the path recommended by the GPS system is made by generating an inquiry type 3.

Another necessary field in the request packet is the description of the target location. As in many other vehicular studies, we define the target location as a square-shaped two-dimensional area [(x_1, y_1), (x_2, y_2)] where (x_1, y_1) and (x_2, y_2) are the coordinates of the bottom leftmost edge and top rightmost edge of the square, respectively. Other than specifying the target location and the RC, the requesters can also select the type of sensing nodes, e.g., cameras, air sensors, vehicles, etc., from a pool of available sensing nodes in the request packet.

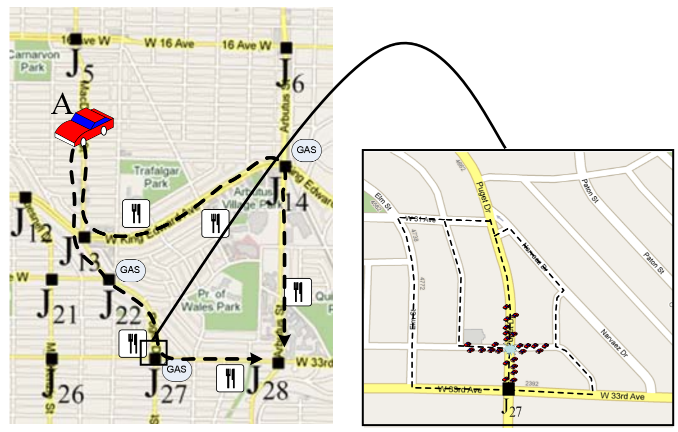

Fig. 1. Motivating scenario

III. REQUEST-ADAPTIVE PACKET DISSEMINATION MECHANISM

As in most other studies on vehicular networking [11-15] we assume that all vehicles are equipped with GPS receivers which can provide position, velocity and time information. Also, all vehicles can obtain roadmap information via the digital maps installed on them. Other than the road topology, digital maps also include the ranges of speed and the average vehicle densities in every street or highway in the map. Such digital maps have already been commercialized [16]. Vehicles are equipped with digital radios for wireless communications and they periodically send beacon messages to report their positions, velocities and the types of sensors available on them to surrounding vehicles and based on these beacons they maintain an accurate list of one-hop neighbors in their look-up tables. The digital radios could operate according to any appropriate wireless standard, such as WiFi, WiMAX or DSRC. The mechanism that we propose in this paper is general in nature and independent of specific radio technologies. In this section we explain how RPDM works to resolve different types if inquiry that translate into different RCs.

In case of inquiry type 1, the request packet is sent to a node in the vicinity of the bottom leftmost edge of the target location. The node receiving the request packet is then responsible for running a round of processing. The processing is needed to determine whether the request packet should be unicast or broadcast within the target location to make sure *n* sensing nodes can be found to resolve the corresponding RC, i.e., [*'Observations', n*]. The purpose of this processing is to avoid packet broadcasting, which can potentially result in broadcast storm, as long as the RC can be resolved by using packet unicasting. Based on the average density of sensing nodes in every street in the roadmap at any time, provided by the digital map of the node, the node can estimate the expected number of sensing nodes in any given street, path or the whole target location.

If n is greater than the expected number of sensing node in the whole target area, the RC in the request packet is changed to [*'WholeArea'*], for which the packet dissemination mechanism is explained later in this section. Otherwise, within the target location the path with the maximum expected number of sensing nodes is calculated and this maximum expected number, denoted by m_1, is compared with the required number of observations n. When $m_1 \geq n$, forwarding along the calculated path is expected to provide enough number of observations to resolve the RC. Hence, the node starts forwarding the request packet along the calculated path. As explained in the previous section, paths are described by a sequence of junctions where the coordinates of any junction J_i, i.e., (x_i, y_i), are known to all the nodes in the network. Packet forwarding between any two consecutive junctions is according to a geographic greedy forwarding mechanism. In the geographic greedy forwarding, every forwarding node looks for all the neighbors with the required type of sensors in its look-up table and forwards the request packet to the one closest to the next junction in the path. If no node with the required type of sensors is found, the packet is simply forwarded to the neighbor closest to the next junction. Note that if a disconnection occurs, i.e., no next-hop node with wireless capability is detected within the transmission range for forwarding the packet, the current node starts carrying the packet until a new node comes into its range.

When $m_1 < n$, forwarding along the calculated path does not suffice and observations along more paths are required to resolve the RC. For this purpose, when $m_1 < n$, the next path with the maximum expected number of sensing nodes in the target location, when the streets in the previous calculated path are excluded, is calculated. Then, the sum of the expected number of sensing nodes in the paths calculated so far, i.e., $m_1 + m_2$, is compared with the required number of observations n. Again, if $m_1 + m_2 < n$, another path should be calculated and the sum of the expected number of sensing nodes in all the paths calculated up to that point should be compared with n. This procedure continues until i non-overlapping paths are found such that $m_1 + m_2 + \ldots + m_i > n$. The forwarding node should send multiple copies of the request packet along all of the calculated paths. Note that for the case where n is greater than the total expected number of sensing nodes in the whole area we have already changed the RC to [*'WholeArea'*]. The packet dissemination mechanism for this type of RC is explained in the next paragraph.

For the RC of the format [*'WholeArea'*] as in inquiry type 2, the request packet is sent to a node in the vicinity of the bottom leftmost edge of the target location. Every node receiving the request packet is then responsible for disseminating the packet toward the top rightmost edge of the target location. For this purpose, the nodes located in the middle of a street forward the packet toward the edge of the street closer to the top rightmost edge of the target location and the nodes located at a junction forward a copy of the packet toward every adjacent junction that is closer to the top rightmost edge of the target location than the current junction. This is illustrated in the typical scenario depicted in Fig. 2. In this scenario, J_{24} and J_6 are the bottom leftmost and top rightmost edges of the target location specified by the dashed square. The packet dissemination directions on every street in the target location to the edge closer to J_6 are shown by the solid arrows.

Even though this causes the presence of multiple copies of the packet in the target location, as we will observe in Section V, it is still much more economical in terms of network capacity utilization than broadcast-based mechanisms. Eventually, upon generating the reply packet, the observations included in all the packets arriving at the top rightmost edge from different paths should be merged. If several observations, each made by a different node, are available for the same street, their mean is calculated and included in the reply packet. Similarly, for the RC of the format [*'Path'*, J_S, ..., J_D] as in inquiry type 3, the request packet is sent to a node in the vicinity of J_S. The node is then responsible for forwarding the request packet along the path using the geographic greedy forwarding mechanism described above. In the next section we discuss how RPDM can be extended to support the request packets with specific delay constraints.

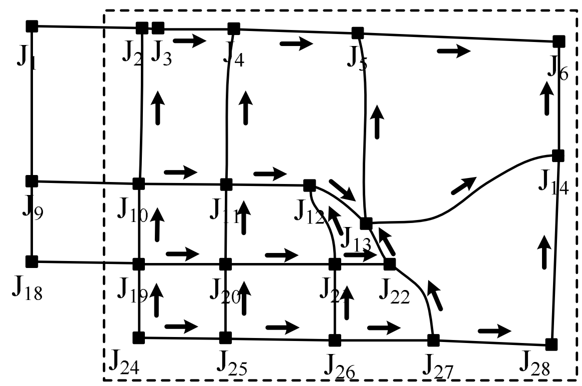

Fig. 2. A typical packet dissemination scenario with RC [*'WholeArea'*]

IV. DELAY-AWARE RPAM

Many context-aware applications have specific QoS requirements, particularly in terms of delay. A good example is depicted in Fig. 1 (on the left) where car *A* needs to receive the reply packet and make decision about which path to take before arriving at J_{13}. Even though RPDM mechanism proposed in the previous section adapts well to the RC in the request packet, for context-aware applications with specific delay requirements, the mechanism should also consider the delay constraints requested by the application. For this purpose, the delay constraint of the application is recorded in a separate field in the request packet. Assuming that the processing delay and the packet forwarding delays between the requester and target location have already been estimated and deducted from the overall tolerable delay, the delay recorded in this field only refers to the maximum tolerable packet dissemination delay within the target location. In the following we explain how RPDM is extended to meet the delay requirements. The idea is that first the packet dissemination delay of the path (area) along (within) which the request packet has been decided to be disseminated, according to the discussion in Section III, is estimated. Next, if the estimated delay exceeds the delay constraint, the path (area) is broken into smaller sections, with allowable dissemination delay in each section, and a separate request packet is sent to each section.

To estimate the dissemination delay along a path or within an area, the first step is to estimate the delay along any given street, denoted by d_i (s) for street i, which is the time it takes a packet to be forwarded from one end of the street to the other end. Clearly, d_i depends on the average vehicle density, ρ_i (car/km) and the average vehicle velocity, v_i (m/s) in street i that can be obtained from the digital map. Note that vehicle density is different from the density of the sensing nodes unless the sensing nodes are the vehicles themselves. Even though the nodes without the appropriate type of sensors cannot contribute to the resolution of the request packets, they can participate in the process of packet dissemination within the target location. If we assume that the arrival of vehicles on the highway is Poisson, which is a common assumption in relevant studies [17, 18], the inter-distances between vehicles in street i have an exponential distribution with mean $1/\rho_i$. Therefore, assuming that the length of the street is L_i, d_i can be written as

$$d_i = (1 - e^{-\rho_i R})(L_i / R) d_h + e^{-\rho_i R}(L_i / v_h) \tag{1}$$

where $(1 - e^{-\rho_i R})$ is the probability that the inter-distances between vehicles are smaller than transmission range R and the packet is forwarded via wireless communications. Similarly, $e^{-\rho_i R}$ is the probability that the inter-distances between vehicles are greater than R, which characterizes the occurrence of a disconnection, and the vehicle has to carry the packet itself. If the packet is being forwarded via multi-hop communications, then (L_i/R) is the number of hops needed to cover the street, which constitutes the forwarding delay when multiplied by the average transmission delay per hop, d_h (s). Note that the rationale behind approximating the number of hops by the division of the street length L_i by R is the mechanism of the geographic greedy forwarding in which every node forwards the packet to the node closest to the next junction in the path that is the ending edge of the street, i.e., the farthest node in its look-up table. On the other hand, (L_i/v_i) is the delay the packet experiences when it is carried along the street.

As explained earlier, when the packet should be disseminated along a path or within the whole area, if the dissemination delay exceeds the tolerable delay, the path or the area should be broken into smaller sections. To implement this idea on a given path, we add up the dissemination delays of the consecutive streets along the path starting from the starting street of the path until the sum is no longer smaller than the tolerable delay. This implies that the previous section in the path should be finalized and a new section should be initialized. Instead of sending one request packet for the whole path, separate request packets should be generated and sent to every section of the path to resolve the RC. If any street is predicted to be disconnected, i.e., d_i approximated according to (1) is expected to be greater than the delay constraint, the street is skipped which means a new section of the path starts from the next street.

Similarly, to implement the idea on a given area as opposed to a given path, we start forming the first section of the area from the bottom leftmost edge in the area. The procedure is to increase the size of the section by including a junction on the right and a junction on the top with the purpose of extending the section toward the top rightmost edge of the area to cover the whole area. After every increasing step, the maximum expected forwarding delay to cross the section in its current form is calculated and compared with the delay constraint. At any point the maximum expected delay is about to exceed the delay constraint, the previous section is finalized and a new section is initialized. Instead of sending one request packet for the whole area, separate request packets should be generated and sent to every section or a limited number of sections, depending on the RC, to resolve the RC. More specifically, in case of inquiry type 3, separate request packets should be generated and sent to all of the section, whereas in case of inquiry type 2, the number of separate request packets corresponds to the required number of observations.

V. PERFORMANCE EVALUATION

We evaluate the performance of RPDM via simulation. The purpose of this section is first to evaluate the performance of RPDM with respect to the performance of other best-known alternatives that are suggested for the AHN approach and second to demonstrate how delay-aware RPDM operates to keep the resolution time below the delay constraints requested by different applications. A gird street layout is used for the road topology in the simulation. For simulating the mobility of vehicles we used the Simulation of Urban Mobility (SUMO) [19], a well-known and validated microscopic street traffic simulation package. To simulate wireless communications, we used network simulator 2 (NS-2) [20]. The vehicular trips generated in SUMO are saved in a log file that can be converted to a mobility trace-file usable in NS-2 with the help of mobility model generator for vehicular networks (MOVE) [21]. The parameters that we used in our simulation scenarios are listed in Table 1.

TABLE1. SIMULATIONPARAMETERS

Simulation area	1500 m * 1500 m
Average length of streets	500 m
Number of vehicles	40 ~ 160
Average velocity	11 ~ 20 m/s
Transmission range	250 m
Radio model	Two ray ground
Packet size	1KB
Beacon size	512 bit
Data rate	2 Mbps
MAC layer	IEEE 802.11 DCF
Beaconing frequency	2 beacons/s
Percentage of sensing cars	%10

One of the commonly used packet dissemination mechanisms in AHN-based solutions is Content-based On-demand Routing (COR) [4, 7]. In COR once the request packet arrives at the target location, a broadcast-based approach is used to discover the sensing nodes within the target location before the request packet is forwarded to them. In the first simulation scenario, we compare RPDM with COR. In this scenario, we assume that a request packet with an RC of the format [*'Observations', n*] is received at a node in the proximity of the bottom leftmost junction of the target location. The request packet is resolved one time using RPDM and another time using COR. The performance metrics that we consider in our evaluations are the average resolution time and the average number of transmissions in the target location in the time period between the arrival of the request packet in the target location and the resolution of the request packet. The average resolution time and the average number of transmissions for different number of vehicles for number of required observations *n=1* and *n=3* with 95% confidence intervals are depicted in Figs. 3 and 4, respectively. It is observed that when the number of vehicles, and consequently the chance of collision in the area, increases, RPDM remains resilient to the broadcast storm problem which guarantees the scalability of the mechanism when the number of vehicles grows. Note that the large delays in low densities stem from the fact that in such densities streets are more likely to be disconnected and packets must be partly carried by vehicles.

In the second scenario, we aim to study the operation of delay-aware RPDM. Particularly, we run the simulation for different delay constraints on the resolution times required by different context-aware applications. Again, we assume that an RC of the format [*'Observations', n*] is of concern. For the given delay constraints as inputs we obtain the average number of separate request packets that should be generated and sent by the requester for number of required observations *n=1*. Each of these request packets is addressed to one of the sections in the target location. Table 2 shows the average number of request packets, with 95% confidence intervals, generated by the requester for different delay constraints when the number of vehicles in the target location is 40 and 80. Note that the reason we give simulation results only for the cases with 40 and 80 vehicles is that in our simulation scenarios as observed in Fig. 3, the delays observed for such cases are larger than delay constraints enforced by most context-aware applications as given in Table 2. Hence, we expect that the improvements made by the delay-aware RPDM are considerably more noticeable in such cases.

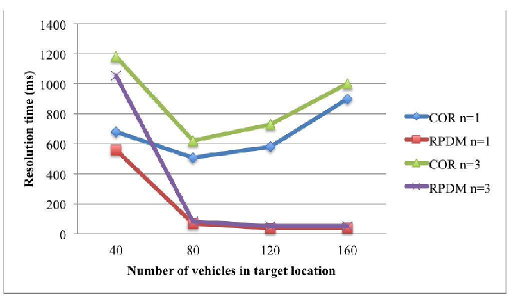

Fig. 3. Resolution time of RPDM and COR for *n=1* and *n=3*

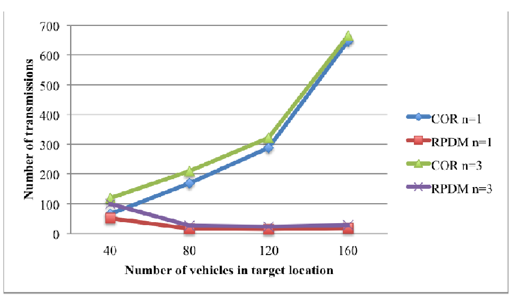

Fig. 4. Number of transmissions in RPDM and COR for *n=1* and *n=3*

TABLE2. AVERAGE NUMBER OF REQUEST PACKETS GENERATED BY REQUESTER

Number of vehicles	Delay constraints	Number of request packets (Number of sections)
40	200 ms	4.2
	100 ms	7.8
80	50 ms	1.8

VI. Conclusion

In this paper we proposed a novel request-adaptive packet dissemination mechanism, RPDM, for addressing vehicular context-aware applications based on the AHN approach. RPDM is adaptable to the specific needs of the request packets in terms of both the conditions that specify successful resolution of the request packets and delay requirements. In order to meet different delay requirements, a delay-aware extension of RPDM was proposed. The performances of both RPDM and delay-aware RPDM were evaluated via simulation and the results demonstrated remarkable improvements over an existing plausible packet dissemination mechanism in the field.

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