A Feasibility Study on Disseminating Spatio-temporal Information via Vehicular Ad-hoc Networks

Bo Xu, Ouri Wolfson, Channah Naiman, Naphtali D. Rishe, and R. Michael Tanner

Abstract— **In this paper we study the feasibility of disseminating reports about resources via vehicular ad-hoc networks. Each disseminated report represents information about a spatial-temporal event, such as the availability of a parking slot at a particular time. The simple flooding algorithm is used for dissemination in a VANET. The feasibility is analyzed by comparing the effectiveness of VANET with that of client-server. The performance measure integrates throughput and response time, the two traditional measures for evaluation of data dissemination algorithms. The comparison is based on realistic simulation of vehicle mobility in a real road network and of the 802.11 protocol. The comparison enables determining the superior architecture (VANET or client-server) for a given environment.**

I. INTRODUCTION

In a vehicular environment, drivers often need to search for local resources. For example, a driver would like the vehicle to continuously display on a map, at any time, the available parking spaces around the current location of the vehicle. Or, the driver may be interested in the traffic conditions one mile ahead. Or, a cab driver would like to be notified when there is a customer waiting nearby. Such information is important for drivers to optimize their travel, to alleviate traffic congestion, or to avoid wasteful driving.

There are essentially two alternatives to enable vehicular local search. The first one is the client/server model. In the client/server model, a sensor senses the availability of the resource, and sends a report to a central server when the resource becomes available. The vehicle accesses the server through a cellular network. The second alternative is vehicular ad-hoc networks. A vehicular ad-hoc network (VANET) is a set of vehicles that communicate via short-range wireless technologies such as IEEE 802.11. With such communication mechanisms, a vehicle receives information from its neighbors, or from remote vehicles by multi-hop transmission relayed by intermediate vehicles.

In this paper we compare VANET with the client-server model in terms of their effectiveness in vehicular local search. At the intuitive level, there are advantages and drawbacks with each of the two approaches. There are several drawbacks of the client-server model. First, it is difficult for the model to scale to a large number of vehicles. One possible solution to increase the scalability is to divide a geographic area into service regions (similar to cells in a cellular infrastructure). There is a server in each service region that handles resources and vehicles within that region. However, this solution introduces the complexity of hand-over, which occurs when vehicle crosses the border between two service regions. Furthermore, the temporary nature of the resources makes update and query response time critical, which again necessitates a large number of servers. Second, the client/server model is vulnerable to the failure of the central server and to adversary mining (see [1]). Finally, in the client-server mode, a user has to pay for the cellular communication and the information service. In the VANET model a user only needs to pay for the initial installation of the communication module. The operation of the communication module is virtually free.

There are drawbacks with the VANET-based local search as well. First, the vehicle traffic may be sparse or the fraction of vehicles that participate in the VANET may be small, in which case the network is subject to disconnections. Second, a vehicle may have other applications (e.g. video/voice transmission) that share the wireless bandwidth with the local search application. The vehicle may also have to reserve bandwidth for communication of emergency information (such as collision warning/avoidance) [15]. Thus the bandwidth allocated for local search may be limited. The limited bandwidth allocation may translate into transmission delay and packet collisions. Due to these issues, a VANET is not always guaranteed to deliver the resource information to all the interested users and in a timely fashion.

The objective of this paper is to compare the quality of data received with VANET and client-server, and to provide a model that enables determining which architecture is superior for a given environment. An important issue is to determine the performance measure for comparison. Traditionally two performance metrics are used, throughput and response time. In this paper we argue that they can be combined. We do so as follows. Since each communicated data item reports the availability of a resource, and in our

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applications the resource is usually available only for a limited period of time, the quality of the data item is measured by its spatio-temporal relevance. The spatio-temporal relevance indicates the probability that the resource will be still available when the vehicle reaches it. As will be discussed in the paper, the performance measure we use integrates the two traditional performance measures for data dissemination, namely throughput and response time.

In order for the results to be reliable and practical, the comparison is conducted by simulations over the STRAW/SWANS platform. STRAW [2] simulates realistic vehicle traffic mobility on a region of downtown Chicago. SWANS [3] simulates the detailed procedure and factors of 802.11 communication.

Our experiments show that VANET dissemination may result in more or less discovery time than client-server, depending on the environmental parameters such as the density of vehicles that participate in VANET dissemination, the bandwidth allocated to VANET dissemination, the wireless transmission range and transmission reliability in VANET, and the delay of dissemination in client-server mode. For example, if access to the server incurs no delay, then client-server mode generally has better performance, but this advantage diminishes and may become negative as the delay increases. The experiments provide an approach to determining which of the two modes performs better given the environmental parameters. In this sense, we answer quantitatively a question that was considered only in a qualitative sense in [4]. To the best of our knowledge, this is the first time the VANET approach is compared with the client-server model in a quantitative way and by realistic simulations in terms of mobility and communication.

The rest of the paper is organized as follows. Section 2 introduces the model and the VANET and client-server dissemination algorithms. Section 3 describes the evaluation method. Section 4 presents the results and analysis. Section 5 discusses relevant work. Section 6 concludes the paper and discusses future work.

II. THE MODEL

A. Basic Concepts

The system consists of two types of nodes, namely resources and vehicles. Resources are located at static points in two-dimensional geospace (think of parking slots). Resources are spatial in the sense that they are tied to a location, and are temporal in the sense that they are available only for a limited time-duration. The period of time during which a resource is available is called the *availability duration*. Each node *o* is capable of communicating with the nodes within a Euclidean distance of *r*. These nodes are refered to as the *neighbors* of *o,* and *r* is referred to as the *transmission range*.

Each resource *R* produces *reports* to indicate its availability. Denote by a(*R*) a report for *R*. Each report a(*R*) contains at least three attributes, namely *report-id*, *timestamp*, and *location*. Attribute report-id is the identification of the report that is unique among all the reports in the system. The uniqueness can be achieved by, for example, the combination of the MAC address of the resource (which is globally unique) and a sequence number that monotonically increases for each report produced by the resource. The timestamp attributes indicates the time at which *R* becomes available. The location attribute indicates the location of *R*. Other attributes that are used by applications may exist (e.g. the type of resource), but in this paper we only refer to the above three attributes.

Each vehicle *o* has a *reports database*, which stores all the reports *o* has received.

B. VANET Dissemination by Simple Flooding

The flooding algorithm works as follows. When a report a(*R*) is produced, it is broadcasted by *R* to all neighboring vehicles. Each of those vehicles in turn rebroadcasts a(*R*) exactly one time (based on the unique report-id), and this continues until all reachable vehicles have received a(*R*). In order to avoid excessive collisions, each vehicle waits for some uniform random amount of time before rebroadcasting a received report. This (small) jitter allows one neighbor to obtain the channel first, while other neighbors detect that the channel is busy and consequently back-off. A previous study [6] has shown that a small jitter (<=1ms) can significantly reduce collisions in simple flooding. Based on this result we set the jitter to be random between 0 and 1 millisecond.

C. Client-Server (CS) Dissemination

CS is an offline algorithm that has complete knowledge and delivers reports with a fixed delay. Specifically, after a report a(*R*) is produced, it is received by all the vehicles with a delay called the *CS delay*. This corresponds to an installation in which there is a central server, each newly produced a(*R*) is transmitted from *R* to the server, and the server broadcasts a(*R*) to all the vehicles. The CS delay abstracts the processing time in server and the delays of data transmission from resource to server and from server to vehicles. The data broadcast (i.e. "push") by the central server can be substituted by data "pull" by the vehicles using instantaneous or continuous queries, and the results of the paper would not be affected.

III. EVALUATION METHODOLOGY

In §III.A and §III.B we introduce the simulation models for mobility and communication respectively. In §III.C we describe the report generation model. In §III.D we discuss the performance measure.

A. Simulation of mobility

We used STRAW (STreetRAndom Waypoint) [2] for the simulation of mobility. STRAW provides a realistic vehicular traffic model on a road network. In the STRAW model, vehicle movement is constrained to streets defined by real maps and vehicle mobility is limited according to car-following rules and traffic control mechanisms (e.g., stop signs and timed stoplights).

For all of our experiments, the simulated field is a 3.2km×2.2km region of downtown Chicago (see Figure 1). We deployed 4000 vehicles in the region, which creates a moderate traffic load according to the calibration provided by [2] (see Figure 2). The average traffic speed is 9 meters/second (20 miles/hour). Out of the entire vehicle population, n vehicles participate in VANET dissemination, and are referred to as *participating vehicles*. By varying n we varied the density of the VANET network. In order to provide a more intuitive indication of the density, we translate n into the average distance between two VANET neighbors on a same street, and refer to it as the *inter-vehicle distance* (denoted h). n is translated into h as follows. The total length of all the road segments in the simulated road network is around 100 km. Thus $h = 100/n$ (km). For example, if the number of participating vehicles is 200, then the inter-vehicle distance is 500 meters. In the rest of this paper we will use h rather than n to indicate the density of the VANET network.

Figure 1. Simulated field: portion of downtown Chicago. Black boxes represent resources.

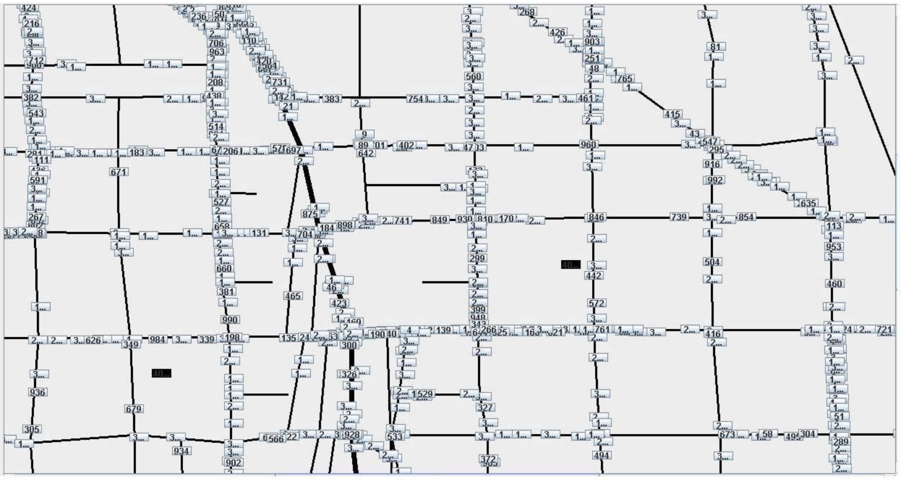

Figure 2. Snapshot of a portion of the simulated field with vehicles loaded. Snapshot is taken at the 188th second. White boxes represent vehicles. Black boxes represent resources.

Initially, each vehicle o is placed at a random location on the road network, and another random location on the road network is selected to be the destination. The vehicle then moves along the shortest path between the origin and the destination. When the destination is reached, another destination is randomly selected. This procedure is repeated until the end of the simulation.

B. Simulation of Communication

The STRAW system uses SWANS (Scalable Wireless Ad hoc Network Simulator) [3] for the simulation of inter-vehicle communication. SWANS implements the IEEE 802.11b Medium Access Control (MAC) protocol. While simulating, SWANS considers detailed communication factors such as the decay of radio signals with increasing distance, signal collisions, and the delay for channel capturing. Using these factors it determines whether each reception succeeds, and how long it takes.

All of the nodes use the 802.11b protocol operating at 2Mbps (default configuration of SWANS). They share common radio properties typical of commodity wireless network cards and operate in an environment with a free-space path loss model. The size of each report is assumed to be 100 bytes. This includes report-id, timestamp, location, and other application specific information (e.g. the dollar cost of a parking slot). The actual size of each broadcast is adjusted to a *bandwidth allocation* parameter *b*. For example, a user may allocate only 10% of the available short-range bandwidth to resource discovery (the rest may be used for internet access, videos download, emergency information, etc.). Then the broadcast size is taken to be 10 times of the report size (i.e. 1K bytes). In other words, out of the 1K-byte payload, 900-bytes are used to represent the traffic generated by other network applications.

We tested VANET dissemination with different transmission ranges. Since SWANS does not provide a setting for transmission range, we chose to vary the transmission range by varying the transmission power. In SWANS, the relationship between the transmission power and the transmission range is given as follows:

$$P = 20\log_{10}\left(\frac{4\pi r}{\lambda}\right) + T$$

P is the transmission power (dBm), λ is the free space wave length, and T is the receiving threshold (dBm). λ is defined by c/f where c is the speed of light (3×10^8 m/s) and f is the radio frequency (Hz). In our experiments, $f = 2.4\times10^9$ Hz and $T = -81$dBm. $20\log_{10}(\frac{4\pi r}{\lambda})$ gives the free-space path loss. We computed the transmission power for the given transmission range. For example, if the transmission range is 150 meters, then the transmission power is set to be 2.56 dBm (i.e., 1.8 mWatt).

C. Report Generation

We placed 20 resources in the simulated field. The locations of these resources were obtained as follows using Google Earth[2]. From Google Earth we located 20 businesses in the simulated downtown Chicago area. These businesses include gas stations, banks, shopping malls, hospitals, and they are roughly uniformly distributed in the field. For each business, Google Earth provides its location as longitude/latitude coordinates. At each resource, reports are generated by a Poisson distribution with intensity ϕ. ϕ is a system parameter.

We assume that the availability duration of each resource follows an exponential distribution with mean *u*. *u* is a system parameter. The *relevance* of a report a(*R*) to a vehicle *O* that receives it *t* time units after a(*R*)'s timestamp, and *d* distance units from the location of *R*, is defined to be

$$\mathrm{Rel}(R) = e^{-\frac{1}{u}\cdot\left(t+\frac{d}{v}\right)} \qquad (1)$$

v is the average speed of the vehicle. Notice that *t*+*d*/*v* represents the length of the time period starting when *R* becomes available, and ending when *O* reaches *R* (if the vehicle *O* decides to go to *R*). It can be easily proven that Rel(*R*) is the probability that *R* remains available when *O* reaches *R*, which justifies formula (1). Given the road structure of downtown Chicago, we used the Manhattan distance (i.e. sum of the distances along the two orthogonal axes) for the computation of *d*.

The length of each simulation run is 300 seconds (Preliminary experiments have shown that the performance converges by the 300-th second). All the parameters and their values are summarized in Table 1.

TABLE 1: SYSTEM PARAMETERS AND THEIR VALUES

Parameter		Unit	Value
Total number of vehicles			4000
Inter-vehicle distance	h	meter	167, 200, 250, 333, 500, 1000
Transmission range	r	meter	50, 100, 150, 200, 250, 300
Bandwidth allocation	b		0.0001, 0.001, 0.01, 0.1, 1
CS delay	g	second	0 to 60 with increment of 10
Number of resources			20
Intensity of report generation at each resource	ϕ	reports /minute	3
Mean availability duration	u	second	180
Size of each report		byte	100
Length of each simulation run		second	300

D. Evaluation Metric

Given a time point *t*, we define the *top relevance* of a vehicle *o* at *t* to be the relevance of the most relevant report (i.e. the report with the maximum relevance) among all the reports in *o*'s reports database at *t*. In the applications considered in this paper, only the most relevant report is used for a user's decision making. For example, when searching for a parking space, a user

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[2] http://earth.google.com/.

chooses the one with the highest relevance (i.e. the highest probability of capturing) to pursue. Thus we use the top relevance report as an indication of the data quality of the reports database maintained by a vehicle. During a simulation run, we trace the top relevance report of each vehicle at each second. At the end of the run, we average the top relevance among all the seconds and among all the participating vehicles. The average value is called the *average top relevance* and is used as the performance measure.

Traditionally, the effectiveness of a data dissemination algorithm is measured in terms of its throughput (how many reports are received) and the response time (i.e. the time it takes on average to receive a report). The resources addressed in this paper, which have limited availability durations, enable us to combine the two measures into a higher level one, namely the average top relevance. It is clear that the average top relevance is straight-forwardly related to the response time: the lower response time, the higher top relevance. To see why the average top relevance integrates the throughput as well, observe the following. Even if the response time of a single received report is small, if the vehicle does not receive more reports subsequently, the relevance of this report is likely to keep decaying (because the age of the report keeps increasing). Thus, the average top relevance is likely to be dragged down. In other words, in order for the average top relevance to be high, both throughput and response time have to perform well.

IV. RESULTS AND ANALYSIS

Impact of inter-vehicle distance. Figure 3 shows the average top relevance as a function of the inter-vehicle distance. The performance of VANET increases as the inter-vehicle distance decreases (i.e. as the vehicle density increases). Intuitively, the smaller the inter-vehicle distance, the better the vehicular network is connected, and therefore each report reaches more vehicles. As a participating vehicle receives new reports more frequently, its top relevance during each time unit gets higher. Observe that the performance of VANET approaches CS when the inter-vehicle distance is 200 meters and the transmission range is 150 meters.

Impact of transmission range. Figure 4 shows the average top relevance as a function of the transmission range in VANET dissemination. The performance of VANET increases as the transmission range increases, and the reason is obvious. Observe that the performance of VANET approaches that of CS when the transmission range is 250 meters and the inter-vehicle distance is 500 meters.

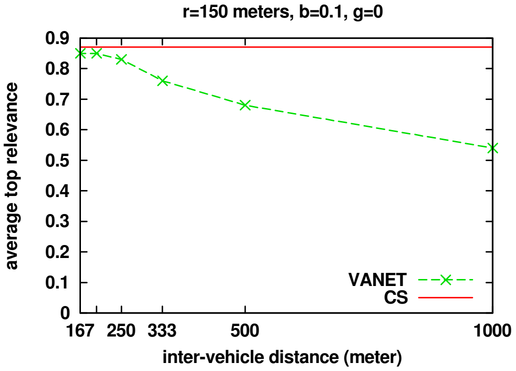

Figure 3: Average top relevance as a function of inter-vehicle distance

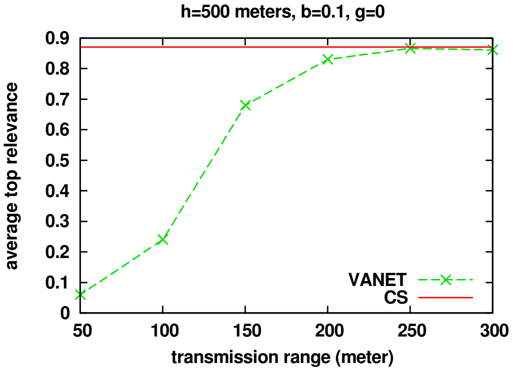

Figure 4: Average top relevance as a function of transmission range

Impact of bandwidth allocation. Figure 5 shows the average top relevance as a function of the bandwidth allocation in VANET dissemination. The performance of VANET decreases as the bandwidth allocation decreases. Intuitively, when the bandwidth allocation decreases, two effects are generated. First, the transmission time of a report message increases, and thus a node has to wait for a longer period time in order to capture the wireless channel for its own transmission. Thus the delay increases. Second, there are more collisions caused by hidden terminals. Thus the throughput decreases. These two effects (higher delay and lower throughput) jointly bring the average top relevance down.

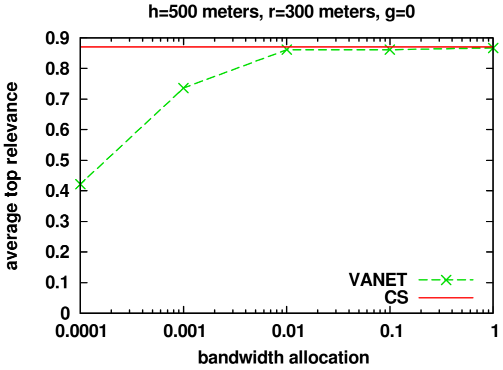

Figure 5. Average top relevance as a function of bandwidth allocation

Impact of CS delay. Figure 6 shows the average top relevance as a function of the CS delay. The performance of CS decreases as the CS delay increases. For a given VANET configuration in terms of inter-vehicle distance, transmission range, and bandwidth allocation, there is a CS delay beyond which VANET performs as well as or better than CS. Let us call this delay the *crossing delay*. For example, when the inter-vehicle distance is 500 meters, the transmission range is 150 meters, and the bandwidth allocation is 0.1, the crossing delay is about 50 seconds. When the transmission range is 300 meters, the crossing delay reduces to 2 seconds. The significance of our result is that it provides an approach to determining the crossing delay given a parameter configuration.

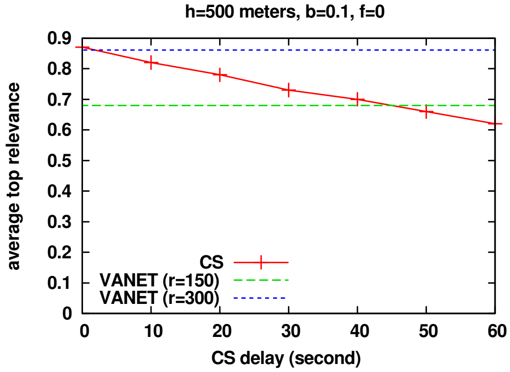

Figure 6. Average top relevance as a function of CS delay

Impact of channel quality. We conducted simulations to study how robust VANET is as the 802.11 channel quality deteriorates. For this purpose we artificially introduced environmental noise to the SWANS system and tested VANET under a wide range of bit error probabilities (from 10^{-9} to 10^{-2}). Specifically, for each packet X successfully received by SWANS (i.e., the receiver is within the transmission range of the sender and there is no signal collision), we generated bit errors to X using the bit error probability q. Thus, letting the size of X be L bits, the probability that X has no bit errors is $(1-q)^L$. X is delivered to VANET only if it has no bit errors. $(1-q)^L$ is referred to as the *packet success probability*. The simulation results are shown in Figure 7.

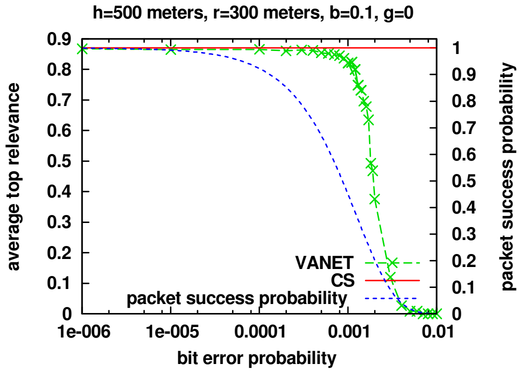

Figure 7. Average top relevance as a function of bit error probability

From Figure 7 it can be seen that

1. The performance curve of VANET drops dramatically when the bit error probability is higher than 0.001, but is pretty much flat when the bit error probability is lower than 0.001.
2. The curve of packet success probability drops dramatically starting from the bit error probability of 0.0001.

In other words, the performance of VANET deteriorates slower than the packet success probability. This indicates tolerance to packet losses. For example, when the packet success probability is 0.5 (corresponding to bit error probability 0.001), the performance of VANET is almost the same as that when packet success probability is 1. In other words, even with 50% loss of packets, VANET manages to keep its full performance. VANET's tolerance to communication errors is due to two reasons. First, simply flooding provides redundancy in the sense that a vehicle may receive the same report from multiple neighbors. Second, as justified previously, our performance metric considers only the most relevant report stored at a vehicle. Thus the performance is not compromised if a vehicle misses a report that is not most relevant. In other words, not every report has to be disseminated to every vehicle. This distinguishes our system (which takes the application into consideration) from traditional simple flooding systems.

Finally, let us discuss the results from the perspective of error correction. Bit errors may be localized and corrected by an error-correction scheme [17]. Figure 7 suggests that, in the studied environment, the benefit of error correction is not uniform with regard to the channel quality. When the channel quality is good (bit error probability < 0.001), error correction has almost no benefit. Error correction is mostly beneficial in a bad-quality channel (bit error probability > 0.001). Particularly, if an error-correction scheme is able to reduce the bit error probability from 0.01 to 0.001, then it will improve the performance of VANET from zero to almost the full performance.

V. RELEVANT WORK

Numerous schemes have been proposed for broadcasting in mobile ad hoc networks (see e.g., [6, 7, 8, 9]). The goal of these schemes is to alleviate excessive contention and collisions caused by simple flooding. They achieve this goal by minimizing redundant rebroadcasts and differentiating timing of rebroadcasts. Broadcasting and data dissemination in VANET's have been studied recently (see e.g., [10, 11, 12, 13]). Many of the works in this area exploit the unique characteristics of VANET's such as predictable, high mobility and constrained, largely one-dimensional movement due to static roadway geometry. They usually require positioning capability and the knowledge of the road geometry at each participating vehicle. Our work does not compete with the above works. The improvement proposed by these works over simple flooding can be used in our work to promote the performance of VANET dissemination. In this sense, our work introduces a new performance measure, and establishes the higher bound of the performance according to it.

In technical report [14], Goel et al. propose an architecture for dissemination of traffic information in mobile ad hoc environments and evaluate the benefit of traffic information in terms of the reduction of travel time. Their approach is geared to traffic information. For example, vehicles generate traffic reports only when the expected travel time on the road segment differs significantly from the travel time actually experienced by the vehicle, whereas we consider general spatio-temporal resources. Like us, they also compare ad hoc with the centralized solution. But they compare in terms of the reduced travel time whereas we consider the capturing probability for general spatio-temporal resources. Finally, we simulate detailed operation of the wireless protocol and thus are able to capture the communication factors such as delay and collisions.

Wolfson et al. [16] studied the discovery of spatio-temporal resources in vehicular networks and they also compared VANET with client-server. However, the simulation tool in that study does not consider car-following rules, traffic control, and detailed communication factors, whereas we do so in this paper. Thus the method of this paper enables realistic simulations on a particular city area to identify whether the VANET or client-server architecture should be deployed for applications such as ride-sharing and parking space discovery.

VI. CONCLUSION AND FUTURE WORK

In this paper we compared VANET and CS modes in terms of their performance on discovery of spatio-temporal resources. We found that CS with no delay always performs better than VANET. However, the performance of VANET improves with the increase of vehicle density, transmission range and bandwidth allocation. Even with the naive flooding scheme, with very reasonable vehicle density and transmission range (e.g. 200 meters between two neighboring vehicles and 150 meter transmission range), VANET reaches the client-server model in performance. In this sense, our study demonstrates the feasibility of the VANET approach in disseminating spatio-temporal information. We also found that as the delay of the CS architecture increases, VANET may perform better than CS. Our experiments provide a model to determining which of the two architectures performs better for a given environmental configuration.

For the future work, we will investigate methods for integrating VANET's with the cellular network. In this case, the VANET reaches those areas that are not reachable by the cellular network, and it enhances the search power of the cellular network in reachable areas.

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