Ascertaining Viability of WiFi based Vehicle-to-Vehicle Network for Traffic Information Dissemination

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***Abstract*— Traffic congestion has become a part of daily life for most of us. One possible way of preventing congestion from building up is by disseminating traffic information. Today a number of commercial solutions exist for disseminating traffic information (e.g., Traffic.com, Metrocommute, EtakTraffic). However, these solutions are plagued by prohibitive deployment and maintenance cost that prevents widespread deployment. As an alternative, solutions based on peer-to-peer architecture have been proposed. This results in a vehicular ad hoc network that is never connected because of the large geographical extent of a typical transportation network. In this paper, we examine the characteristics of such a network and whether it can support effective traffic information dissemination.**

I. INTRODUCTION

"Highway congestion is not just a problem of recurring "rush hour" delay in major cities. More than half of all congestion is non-recurring, caused by crashes, disabled vehicles, adverse weather, work zones, special events and other temporary disruptions to the highway transportation system." [8]. One possible way of controlling the extent of congestion is by disseminating traffic information. Today a number of commercial systems exist for collecting and disseminating traffic information (e.g., Traffic.com [9], EtakTraffic [5]). However, these systems tend to cover select highways while leaving out a major fraction of roadways, thereby creating a *"digital divide"*. The main factor that prevents these systems from covering the entire road network of the US is the cost involved. Each of these systems requires an infrastructure to be deployed (e.g., helicopters, cameras, flow sensors). This represents a huge amount of money in one-time deployment cost, and a significant annual cost in maintenance. As an alternative solution, system based on peer-to-peer architecture have been recently proposed [13]. In this solution, vehicles equipped with GPS and a WiFi link collect traffic information as they travel. (throughout this paper, we use the term WiFi to refer to wireless link using any flavor of IEEE 802.11 protocol [10] or one that is part of the DSRC standard [2]) They disseminate some of the collected traffic information by communicating directly with other vehicles via WiFi link. Like any other peer-to-peer system (e.g., Napster [6]), the effectiveness of the solution depends on number of vehicles participating in the system. If the number of vehicles *volunteering* to participate in the system reaches a *critical mass*, the system has the promise to address many of the problems faced by the existing commercial solutions — firstly, a true peer-to-peer solution would require zero-additional infrastructure [13] cutting down maintenance costs; secondly, it would have wide coverage, covering not only urban heavily traversed highways, but also other part of transportation network frequented by participating vehicles; thirdly, it would be extremely reliable because of its highly distributed nature.

A true peer-to-peer solution results in an ad hoc network of highly mobile vehicles. The high mobility and large geographical extent results in characteristics that are significantly different from that of traditional ad hoc networks studied in the literature [14]. Most importantly, the resulting peer-to-peer network will *not* be connected. Instead, it would consists of clusters of vehicles in communication range. These clusters merge and disintegrate dynamically, as vehicles move in and out of range. The degree to which the network is connected is highly dependent on two factors — the range of the wireless link and the fraction of participating vehicles. Lack of connectivity raises questions about whether the vehicular ad hoc network can effectively disseminate traffic information. In order to determine this, it is important to analyze the requirements of the domain — Firstly, what is the "useful" dissemination radius for traffic information so that drivers are aware of congestion in advance and are able to avoid it? We say that knowledge of traffic information on a certain road segment is "useful" at a certain location if it helps drivers in reducing their commute time. Secondly, what

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is the effective communication bandwidth the network must support? In this paper, we attempt to determine these two requirements for a specific section of the transportation network. In this study, we have used Paramics [7], a state-of-the-art micro-traffic simulator.

In [19], [20] authors have also proposed using a peer-to-peer network of cars for spreading traffic information, where each car is equipped with a WiFi link. These papers tacitly assume that WiFi link is appropriate for this purpose. In [12], authors argue that packet load in such a network would exceed the channel capacity, and suggest different aggregation techniques. In this paper, we would like to examine the validity of this argument.

In the next section, we give an overview of the system. In section III, we discuss the potential problems in using peer-to-peer solution for disseminating traffic information. In section IV, we outline our approach to determining the domain requirements using simulations. In section VI, we enumerate the performance metrics. In section VII, we present the simulation results and finally discuss their implications and conclude in section VIII.

II. System Overview

In our envisioned peer-to-peer system, we believe that only a small fraction of the vehicles would participate. Each of these participating vehicles would be equipped with a device that we call *TrafficRep.* This device is responsible for collecting and disseminating traffic information. The TrafficRep device connects to the in-vehicle navigation system, supplying it with current traffic conditions. From a user's (driver) perspective, TrafficRep device appears as a black box. A user only interacts with the in-vehicle navigation system posing queries like, *"What is the fastest route from Busch Campus to Newark Airport?"* The in-vehicle navigation system, in turn, queries the TrafficRep device to obtain current traffic information on various road segments, computes the fastest route, and displays it to the user. It is important to note that TrafficRep device can be any handheld computing device like iPaq attached to a GPS device and a wireless link.

A TrafficRep device is attached to three components: a GPS device, a static digital map database of the road network, and a WiFi link. We assume that the static digital map database is organized by road segments, where a road segment is a stretch of a road between two successive exit points (junction, exits, etc). For each road segment, the database stores two attributes: GPS coordinates of its endpoints and the free-flow travel time. TrafficRep uses the location and time information from the GPS unit and the static information about location of end-points of road-segments to calculate the travel time of vehicle for different road segments. Every time the vehicle travels on a road segment and reaches the end of it, TrafficRep records the corresponding travel time information as a travel log report (TLR). This includes identifier of the road segment, the travel time, and the time-stamp of the report. As TLRs get older, they are discarded by the TrafficRep device to create space for new ones.

TrafficRep device disseminates sensed traffic information (TLR) to other vehicles. They act independently of other vehicles based on locally available information in order to decide *what* and *when* to disseminate. Each TrafficRep device maintains an estimate of the travel time on all the links. In the absence of any additional information, this estimate is set to the free-flow travel time on the link (obtained from static database of the transportation network). On receiving disseminated traffic reports, the vehicles update their travel time estimates. In this paper, we assume that TrafficRep device cannot query other TrafficRep devices. As a result, the TrafficRep device assumes that the traffic information available locally is the accurate information.

III. Disseminating information using vehicular ad hoc network

Different flavors of 802.11 have a typical range of 100 meters (outdoors) (D-Link DWL-500 has a communication range between 100 to 300 meters [4]). With simple external antenna, the range can be increased to up to 1Km [1], [18]. In DSRC standard, a wireless link is expected to have a maximum "line-of-sight" range of 1Km [2]. Since non line-of-sight communication will be more common in vehicular ad hoc network, it is not clear what this range would translate to in reality. Even a 1Km communication range may be small compared to the geographical extent of a typical transportation network. Given this and the fact that only a small fraction of all vehicles would participate in the system, the vehicular ad hoc network will have characteristics very different from traditional ad hoc network that have been studied in the literature [14]. In particular, a vehicular ad hoc network is unlikely to be connected. Instead it would consist of clusters of communicating vehicles, where vehicles in each cluster are connected. These clusters merge and disintegrate as a result of high mobility of vehicles. For vehicular ad hoc network to operate without support of any additional infrastructure and serve as an effective traffic sensing and dissemination mechanism, it must be able to meet the requirements of the application with respect to:

1) The radius in which the traffic information needs to be disseminated
2) The wireless bandwidth required to support the traffic reports generated during traffic congestion. We expect this load to be non-negligible as vehicles take independent decision on whether or not to disseminate the traffic information.

Drivers would like to know the information about traffic congestion on their intended route as early as possible. However, given a specific transportation network, a specific road segment within it that is congested, there is always a dissemination radius (centered on the congested road segment) beyond which disseminating traffic information is not “useful”. We consider traffic report about a road segment “useful” at a certain point if its knowledge at that point can reduce the travel time of vehicles. In order to determine the minimum requirements for the vehicular ad hoc network we focus only on “useful” dissemination radius.

In a vehicular ad hoc network, vehicles act independently in order to disseminate traffic information. Collectively vehicles can potentially flood the wireless channel. The amount of traffic generated is a function of the number of traffic congestion events occurring at a particular instant. We consider a simple distributed algorithm used by vehicles to decide when to generate TLR, and try to estimate the bandwidth requirement of the vehicular ad hoc network. Note that another factor affecting the traffic generated is the specific forwarding algorithm used by vehicles in propagating traffic information in a certain dissemination radius. This complicates the goal of finding the minimum bandwidth required. As a result, we attempt to answer a simpler question: Is WiFi bandwidth a limiting factor in this application?

Note that the answers to these two questions are very much a function of the specific characteristics of the transportation network. Given the difficulty of answering these questions in a general manner for the entire US transportation network, we consider a very specific instance of it – a calibrated traffic simulation model of the Southern New Jersey transportation network [17], and try to answer to the above questions for this network.

IV. Evaluation methodology

A. Determining dissemination radius

In order to determine “useful” dissemination radius, we divide the geographic region spanned Southern New Jersey transportation network into cells. We assume that each TLR is disseminated in a certain dissemination radius, which is constant for the system. The dissemination radius is measured in terms of the number of grid-cells spanned (TTL). Dissemination radius is a parameter in our simulations. We use an *ideal* scheme for disseminating traffic information that instantly delivers a message in the target geographic scope, without the need for any forwarding. This is an important assumption as it allows us to focus on determining how large the “useful” dissemination radius should be, without worrying about the specific forwarding scheme used by vehicles for propagating information.

B. Wireless Bandwidth

Vehicles act independently when deciding whether a specific sensed traffic information needs to be disseminated. Given potentially large number of vehicles participating in the system, it is possible for these vehicles to flood the wireless channel by traffic reports. We consider two simple dissemination schemes in this study (section V).

V. TrafficRep Actions

In order to disseminate information about traffic conditions, a vehicle needs to take two decisions: *when* to send the TLR and *what* to include in the TLR. These two decisions are inter-related and they determine the bandwidth requirement of the system.

A. What and When to disseminate

1. *Naive Scheme:* In this scheme, vehicles transmit TLRs at a pre-defined maximum rate of dissemination. Every time a vehicle has to transmit a TLR, it examines its travel times on recently traveled road segments. Among these, it selects the one for which the difference between the expected travel time and the travel time actually experienced by this vehicle is the maximum. Expected travel time on a road segment is the estimate the vehicle had prior to actually traveling on the road segment.
2. *Smart Scheme:* In this scheme, vehicles send a TLR only when they have something “interesting” to report. As in Naive scheme, vehicles have a pre-defined maximum rate of dissemination. At this rate, vehicles select the TLR for which the difference between the expected travel time and the actual travel time is the maximum. However, unlike in Naive scheme, a vehicle actually transmits this TLR only when this difference exceeds a certain threshold.

B. Processing traffic updates

Each vehicle maintains an estimate of the travel time on all the road segments. In the beginning this is set to the free-flow travel time of the road segment. On receiving a TLR, the vehicle updates its estimate of the travel time using the equation: $e(\hat{l}) = \alpha e(\hat{l}) + (1-\alpha)e(l)$, where α represents the decay factor and $e(l)$ refers to the travel time reported in TLR for link l.

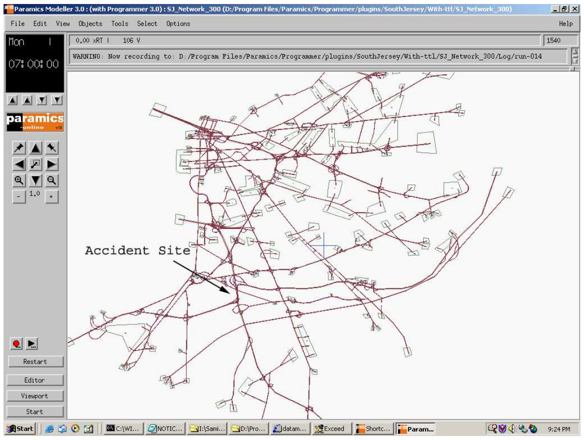
VI. Performance Metrics

We use the following metrics to capture the effect of disseminating traffic information:

1. *Improvement in travel time:* This metric represents the percentage reduction in travel time of vehicles as a result of receiving and acting on traffic information.
2. *Wireless bandwidth consumed:* This metric represents the average number of traffic reports transmitted per cell.

VII. MICROSCOPIC SIMULATION MODEL OF SOUTH JERSEY NETWORK

We have chosen to simulate the peak afternoon traffic in Southern New Jersey area. Figure 1 shows the snapshot of the simulated transportation network. The transportation network model [17] used includes



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WARNING: Now recording to: D:/Program Files/Paramics/Programmer/plugins/SouthJersey/With-ttl/SJ_Network_300/Log/run-014
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Fig. 1. Snapshot of Paramics representation of Southern New Jersey transportation network

most of the highways in Southern New Jersey. The transportation network model consists of approximately 4000 road segments drawn to closely match reality. The parameters controlling the flow in our simulations were based on the data provided by the Delaware Valley Regional Planning Commission (DVRPC [3]) and calibrated in [17] to make sure that the traffic characteristics closely match the ones seen in reality.

In this work, we have used *Paramics* [7], a micro-traffic simulator. It simulates movement and behavior of each individual vehicle and allows programmable control of route chosen by each vehicle. We have augmented Paramics to simulate communication between vehicles.

A. Simulation Methodology

Since the goal of this simulation is not to test dynamic traffic assignment techniques as discussed in [16], [11], [15], we employ a simple route choice mechanism described below. However, it is clear that the reliability of the simulation results can be improved using more sophisticated routing mechanisms as described in [16], [11], [15].

In order to simplify our analysis we consider only the vehicles traveling between a specific origin-destination zone pair. We classify the vehicles traveling between the target OD pair into two categories based on the routes they follow: *default* and *fastest*. The *default* vehicles always follow a pre-computed path. This path is computed based on the free-flow travel times in the network. The *fastest* vehicles recompute their route to the destination based on the travel-log reports received. They alter their routes if necessary. Only a fraction of the vehicles traveling between the target OD pair are categorized as *fastest*. This is to decouple the navigation problem that would arise from having all the vehicles choose the fastest route to the destination. In order to concentrate solely on the problem of effective dissemination of traffic information, we inject *fastest* vehicles at regular intervals into the network. These serve as probes in the network, continuously testing the accuracy of disseminated traffic information. The interval is chosen so as to keep the number of *fastest* vehicles small enough that they do not affect the travel time experienced by *default* vehicles, but large enough to continuously test the effectiveness of dissemination mechanism.

In order to evaluate the effectiveness of the dissemination mechanism, we simulate an incident on the default route in our simulations. This incident results in closure of lanes. The incident occurs 40 mins after the start of simulation, and lasts for 25 minutes. Note that the dissemination radius is a function of the duration of incident and the number of lanes affected by it. Clearly if an incident lasts longer and affects more lanes, the traffic information would have to be disseminated farther. Incident duration of 25 mins is close to the average incident duration.

In simulations, we have set the market penetration (fraction of vehicles participating in the system) to 10%. Market penetration has direct bearing on the wireless bandwidth used. The higher the market penetration, the higher the wireless bandwidth used. We deliberately chose a very high fraction so that our results for wireless bandwidth represent an upper bound.

We used following two parameters in simulations:

1) *Dissemination radius:* In our simulations, we divide the physical region in rectangular cells of size 2 Km x 2Km. As explained earlier, we express dissemination radius in terms of TTL, which controls the number of cell-hops a TLR travels. The TTL values used in the simulation are: 1, 2, 3, and 5 (note that dissemination scope of TTL=5, centered at the chosen accident site, covers the entire simulated road network).

2) *Dissemination scheme:* We evaluate the effect of Naive scheme and Smart scheme for dissemination on both the wireless bandwidth consumed and the travel time of vehicles. For both the dissemination schemes, we have chosen the maximum dissemination rate of once per minute. Note that once per minute is a very high dissemination rate given the rate at which traffic information typically changes. Again we chose a high number so that our bandwidth estimate represents an upper bound.

B. Simulation Results

Effect of TTL

We examine the effect of TTL on the performance of Naive dissemination scheme. Figure 2 summarizes the result. The bar graph plots for different values of TTL, the percentage reduction in the travel time of *fastest* vehicles over that of *default* vehicles during the accident period. As expected the performance improves with increase in TTL. For TTL=1, the performance of *fastest* vehicles is very similar (slightly degraded) to that of *default* vehicles. This is to be expected because by the time the vehicles come to know of the higher trip times on road segments they are too close to the

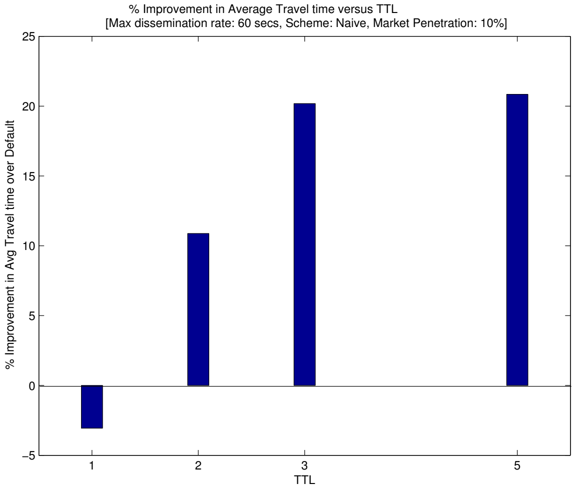

Fig. 2. Simulation results showing effect of TTL on performance of Naive scheme

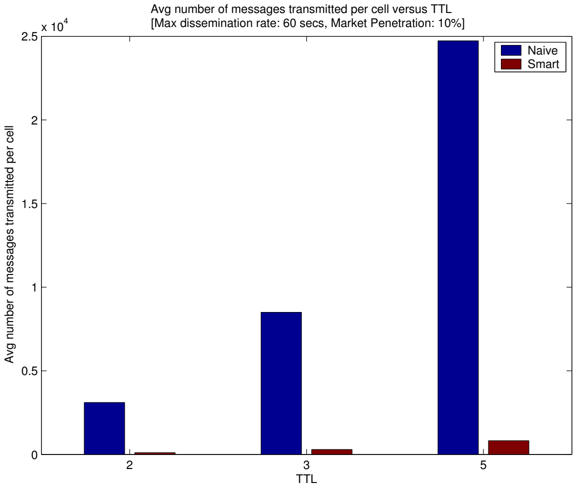

Fig. 3. Simulations results comparing the performance of Naive and Smart scheme (market penetration: 10%)

traffic congestion and do not have any better alternative route to avoid it. With larger value of TTL, the vehicles get to know of congestion state in advance and are able to avoid it by taking faster alternative route. This clearly illustrates the importance of disseminating traffic information in a wider geographic scope. The results show that beyond the value TTL=3, the performance improvement flattens out. This suggests that for the peer-to-peer solution to achieve best performance for the transportation network under study, the peer-to-peer network should be able to propagate traffic information at least 6 Kms.

Naive versus Smart scheme

With respect to the average number of messages transmitted per cell, Smart scheme outperforms Naive scheme by a wide margin, by an order of magnitude in certain cases (Figure 3). These results are to be expected because in Smart scheme vehicles transmit a message only when they have something "interesting" to communicate. With Smart scheme, even at the highest TTL, the maximum number of messages communicated in any cell only represented a bandwidth of ˜1.5Kbps (assuming that size of each TLR is 100 bits). This is much smaller than the typical communication bandwidth in WiFi. Thus, we conclude that bandwidth is not a limiting factor in this application.

With respect to the reduction in the average travel time of vehicles, somewhat counter-intuitively Smart scheme performs better with respect to travel time. This is because in Smart scheme vehicles transmit only "interesting" travel time information. With the specific policy used in updating travel time estimate (section V-B), the travel time estimates of vehicles are able to follow the true travel time more closely. We have omitted these results for lack of space.

WiFi Range

We investigate the effect of WiFi range on the diameter of region in which information propagates within a certain time interval. We are not only interested in the final diameter of the region that is covered by information, but also the rate at which the information spreads. Both the rate of spread and the final diameter are function of WiFi range, market penetration, and the density of vehicles in the region where the information dissemination is initiated. In order to eliminate the influence of specific forwarding algorithm used by vehicles in propagating information, we consider an ideal forwarding algorithm where each vehicle instantaneously forwards any received information. Figure 4 shows the results for the case when information dissemination is initiated in a dense region. The figure shows the increase in diameter of the covered region with time, for two different WiFi ranges (100m and 200m), and for two different market penetrations (3% and 10%). As expected, both higher market penetration and larger WiFi range increase the rate of spread of information. For even modest WiFi range (100m) and small market penetration (3%), within 5 mins the information propagates to a region of size 12 Kms. Figure 5 shows results for the case when information dissemination is initiated in a region where density of vehicles is very low. In this case, it takes approximately 8 mins for information to propagate within a region of 12 Kms. Note that these results are better than what we expect in reality for two reasons: firstly, we assumed that each vehicle uses ideal forwarding scheme. Secondly, the simulated traffic is for peak afternoon traffic, resulting in higher than typical vehicle density. Use of ideal forwarding scheme results in higher wireless traffic. However, given our earlier result that bandwidth is plentiful, this should

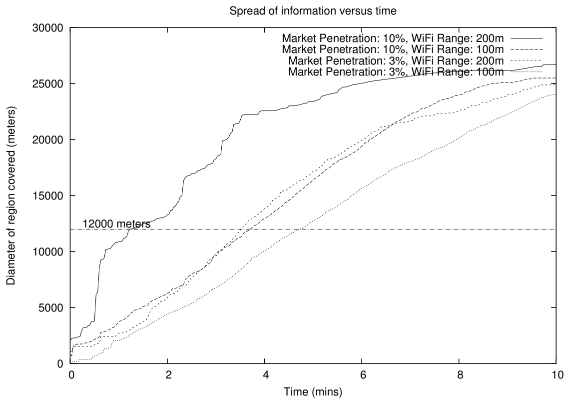

Fig. 4. Dissemination starts in a region with *high* vehicle density

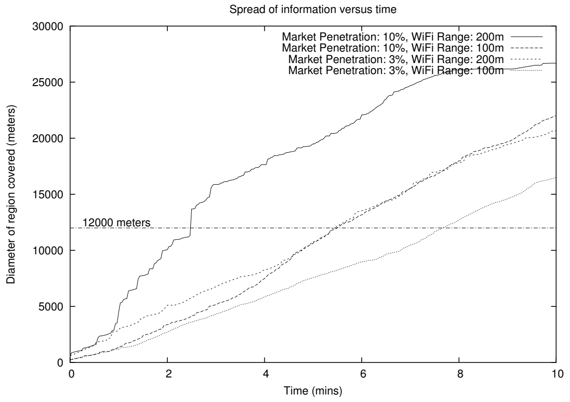

Fig. 5. Dissemination starts in a region with *low* vehicle density

not be an issue. Scenarios with lower vehicle density would require either larger WiFi range or higher market penetration to spread the traffic information in target geographic scope with acceptable delay.

VIII. Discussion and Conclusions

Traffic information is considered as one of the essential tools to relieve the ever increasing congestion problem in our roadways. Current strategic plans drafted by various transportation agencies consider the deployment of traditional static sensors at the important locations of the transportation network. However, this is a very long term and costly deployment strategy that might never achieve full coverage of the vast transportation network in the USA. Moreover, variable message signs that limit the coverage area and pose maintenance and operations problems are still considered as the main information dissemination tools. Thus, shorter term and more cost efficient solutions are needed.

Our simulation results clearly show that for market penetration of 3% and the current range of WiFi technology (100m), one can spread the information in a sufficiently large region. Increasing WiFi range quickly increases the rate of spread of information and thus the benefits. Thus, following conclusions can be drawn regarding the WiFi based solution studied in this paper:

1. Depending on the time interval and the geographic scope in which traffic information needs to be disseminated, the current range of WiFi technology (100 meter) may require market penetration between 3% and 10% to obtain full benefits for traffic information.
2. With very simple distributed dissemination schemes (like the Smart scheme proposed in this paper) the bandwidth ceases to be a limiting factor, contrary to the argument made in [12].
3. The proposed system which depends on a relatively low level of user investment, is a realistic one given the declining prices of hand held devices and phones that include WiFi and GPS technologies, as part of a basic or enhanced package. Based on this assumption, increased levels of market penetration which can produce full benefits can also be realistically achieved in the near future.

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