A Study on Gossiping in Transportation Networks

Sarit Kraus, Roni Parshani, Yuval Shavitt

***Abstract*—To alleviate road congestion suggestions have been made to equip cars with wireless communication to allow drivers to exchange information. This information is used to bypass congested areas. We study the dynamics of this solution using a hybrid micro simulation tool we have developed, and show that gossipping is an efficient method of information propagation. An increase in the number of gossiping agents leads to faster and wider distribution of information. On the other hand, as in other information models, when the number of agents obtaining information about road conditions increases, their routing performance may decrease (unless smarter algorithms are deployed) since they will all attempt to use the same uncongested roads. Nevertheless, when the number of gossiping agents is balanced (20-30% in our simulations) the average traveling time of gossiping agents is similar to those who obtain information from a centralized information center.**

I. INTRODUCTION

Road congestion is a known and acute urban menace with no signs of disappearing. There are apparently many suggested approaches to tackle this problem; one of them is to supply vehicles and drivers with up-to-date information about road conditions. There are two kinds of approaches to supply drivers with information that can aid them avoid congestion. One approach is based on fixed-structure communication networks, for example cellular networks or FM/AM radio [1], [3], [2], the other approach is based on ad-hoc communication networks; the latter save the need to deploy expensive infrastructure. Several innovative projects propose using ad-hoc networks as the communication infrastructure, for example FleetNet [10], and CarNet [19].

The advance in technology in recent years has helped bring forth sophisticated onboard navigation systems for vehicles, at a reasonable price. Such a system contains a computing device with a detailed road map, GPS for locating the vehicle on the map, and communication means. One can use ad-hoc communication networks (such as 802.11p or in the future DSRC) to exchange information between neighboring vehicles. When two vehicles are within communication range they can exchange their information regarding road conditions. Road condition information is thus propagated in the network without any need for an external or central infrastructure. Each time new information is obtained by a vehicle, the onboard navigation systems recalculate the optimal route from its current location to the destination. For example, if the navigation system receives information that one of the streets in its planned path is blocked it will plan a new path that avoids the blocked road; the new path will be the shortest path from the vehicle's current position to the destination taking into account the blockage.

Recently, Shavitt and Shay [25] studied the routing in this setting, which they termed ”gossip networks”, and showed how to optimally calculate the shortest path in a system where the edge delay distributions are known. They also assumed that the probability to gossip about an edge condition in another edge is known. While they were able to show that the trip length and information acquisition can be naturally combined in the shortest route calculation, their model overlooked important issues, most notably the feedback mechanism in the gossip network.

The feedback mechanism in gossip networks is an incarnation of load sensitive routing in data networks. Load sensitive routing was used in the ARPANET network with limited success and eventually was abandoned to minimum hop routing due to its instability (see discussion at [4]). Thus, it is important to understand how transportation networks can avoid such instabilities.

In this paper we study the gossip network model in a practical setting. We assume that drivers learn the expected congestion on the roads, which can be modeled by having an expect cost of each edge, and some of the drivers have a gossiping system that help them learn about congestion on distant roads. Unlike [25] we do not assume that the exact probability distribution function of an edge delay is known, nor do we assume the knowledge of the probability to learn about congestion. Under these assumptions we study the information propagation speed in an urban network and quantify its advantage to drivers on the road. We examine several important parameters, but mainly the car flow density and the percentage of gossiping cars. We compared our results to centralized information models.

Because of the complexity of mathematically analyzing dynamic networks the investigation was conducted via simulations. For this purpose we built a special micro simulation tool (see [15], [5], [17] for other micro simulators) that supports the use of gossiping between individual cars (see Sec. IV-A). The experimental results show that information propagation in gossip networks is very efficient even when the percentage of gossiping agents is only 20-30%. Agents are able to obtain useful information even with 5% gossiping agents. Our most interesting finding is that when the percentage of gossiping agents is about 20-30% the average path lengths of the gossiping agents are very close to that of the agents that obtain information from a centralized information provider.

II. RELATED WORK

Xu *et al.* [27] studied a similar model in which vehicles exchange knowledge about the environment which is time varying and has spatial relevance, both features of our model. While we are looking at road conditions which change the vehicle routing, they discover resources (like vacant parking spots) which changes the vehicle's destination. Their simulation was performed on a square area where the vehicle may go in any direction, while our study took a more realistic approach and simulated vehicle movements along a city street map, where road capacities and traffic light operations are taken into account. Similar to Xu *et al.*, Datta *et al.* [9] and Papadopouli and Schulzerinne [22] also studied information dissemination via gossip.

Gossiping has been studied in general graphs and in communication networks [14]. It is important to note that the method of gossiping used in communication networks is significantly different from the gossiping of mobile agents. While gossiping in communication networks is invoked by the network nodes (or routers) and thus is done between static entities, in our case the gossiping is between mobile agents traveling in the network. Thus, while in the static case the propagation of the information can be predicted, given the gossiping algorithm, it is hard to predict how information will be expanded in the mobile agent situations that we study. Gossip can also be used to describe the communication in wireless ad-hock networks [12]. However, in such domains there is no fixed network, and most information exchanged is on locating agents. There is a thread of works that utilize gossip to improve multicast communication in ad hoc networks [8], [18]

Ganesh *et al.* [11] who also consider a fixed network, present the Scalable Membership Protocol (SCAMP) in a gossip algorithm. As opposed to other protocols, which assume that the subset of nodes with which a node gossips is chosen uniformly among all participating nodes, they provide each node with a partial random view of the system without any node having global knowledge of the membership. The size of the partial view automatically adapts when the total number of participating nodes changes. Furthermore, in our case, who the agents gossip with is determined by who they pass, whereas in their case the protocol can determine this number. Thus, they focus on how large the partial view should be in order to ensure reliable propagation of the message to all the nodes in the network.

Olorunleke and McCallas [20] investigated models for sharing information about stationary agents via gossip. Similar to our results they show that gossip between mobile agents is an efficient way of sharing information. However, they focus on the problem of the spread of delusion in situations simpler than ours (e.g., the information does not change over time). We assume that agents share only true information, but our model is much more complex and the shared changed information influences the agents' behavior.

The concept of gossip is commonly used by multiagent researchers for communication about the reputation of others [21], [6], [24]. They study how gossip influences group structure, norms and performance. Our agents exchange information about road conditions and it is assumed that they report only true conditions.

III. MODEL

The transportation network is represented by a directed graph $G = (V; E)$, where V is the set of vertices representing junctions, and E is the set of edges representing roads. An edge $e \in E$ is associated with a weight, which specifies the time it takes to traverse the road associated with the edge. The road's weight varies in time according to the traffic load. Each mobile agent, namely a car, is associated with a pair of origin and destination vertices. A *journey* is defined as a path between an origin vertex and a destination vertex. A *path length* (or a *journey length*) is defined as the sum of the weights of the edges composing the path. Every agent has to travel once between its origin and destination and aims to minimize its path length. The network is modeled as a non-cooperative game [16] and thus agents do not try to optimize network performance [13], [25], but rather each agent attempts to minimize its own journey length.

At a given time, an agent may have inaccurate information about the weights, and no information on how the weights may change over time. We assume that an agent, which travels from vertex $v_1 \in V$ to $v_2 \in V$, will search for the shortest path between these two vertices, based on its current available information, and will move accordingly. Once, its information about the network has been updated, it will stochastically decide whether to recompute the shortest path or to keep on moving and follow its current route. If there is more than one path that is associated with the shortest distance, one of them will be chosen randomly.

An agent may update its information on the network in one of the following ways:

1) When traversing an edge - the information about the edge's weight is obtained.
2) Non traversable edges - if the weight of an edge is very large, this information is available to the agent at the vertex where one can enter the edge, even though it hasn't traversed the edge. Intuitively, this refers to jammed roads where agents can hardly enter.
3) Information received from other sources.

For the third category, we focus on information that is obtained by gossiping. However, for comparison we also consider centralized information providers.

A. The Gossip Model

The exchange of information using gossiping is done in one of two ways: between mobile agents passing one another or between agents located at the same edge. The amount of information traveling in the network depends mainly on two factors: the percentage of agents participating in the gossip process and the amount and type of information exchanged in each act of gossiping.

We assume that each agent maintains an internal database where it stores the most recent information about all the edges in the network. For every edge, the agent stores the most recent weight of which it is aware and the time this weight was generated by the agent that traversed the relevant edge and observed its associated weight. Every time an agent traverses an edge it updates its database with the new information about the edge. When gossiping, both the edge and its associated gathering time is sent. Not all the mobile agents are expected to participate in the gossip process since gossiping may require special capabilities. We refer to the agents that do not gossip as *regular agents* and to the gossiping ones as *gossiping agents*.

In many situations the gossiping agents cannot exchange their entire database when gossiping since they may pass one another at such speed that leaves a short window for effective wireless communication. If during this window there is increased noise, congestion, or any other disturbances only a few packets may be exchanged between cars, and thus, it is necessary to determine which part of the database to send.

There are at least three policies:

1) Randomly selecting a fixed set: when entering the network each agent randomly selects a subset of edges on which it will send information.
2) Dynamically, randomly selecting a set: each time an agent needs to send information it randomly selects a subset of the edges. This may increase the overall exchange of information in the network compared to policy (1).
3) Ranking - each agent ranks all the edges in its database and sends information on the highest ranked edges. One possible ranking algorithm is based on the assumption that the edges with the largest weight change amplitude are the most important ones because they would have the largest effect on the routing. So every time an agent receives new information it calculates the change, δ, between the edge's current weight and the weight known when it entered the network. Then the edge's new ranking is calculated as follows: $rank(t_i) = \max\{rank(t_{i-1}), \delta\}$.

IV. SIMULATION STUDY

A. The Simulation Tool

Transportation network simulations are divided into two groups: macro simulations and micro simulations. Macro simulations [26], [15] mimic traffic behavior by using mathematical calculations of flows, while micro simulations simulate the movement of individual cars. Micro simulation models can be divided into a few groups that differ by the level of fidelity [7], [5], [17]: CF, CA, CTM and the queue model. CF (Car Following) is the most accurate model. It uses realistic driver behavior, detailed vehicle characteristics and includes a complicated acceleration and deceleration algorithm. The problem with this model is that even with today's advanced computers, the simulation, using many cars, takes more time than it would in a real world transportation network. The next model, the CA (Cellular Automata) is much faster, yet it is still a high resolution model. Each road is divided into small cells that allow only one car at a time. In CTM (Car Transmission Model), the cells are much larger and contain many cars. It is not necessary to know where the cars are located in the cell because the traffic flow is calculated using more general rules. Finally, the fastest and simplest model is the queue model. In this model the roads are represented by finite queues and are not divided into cells. The velocity and distance between the cars are irrelevant in this model.

Our model is a combination of a few different models [23]. On the one hand, a simple queue model is inadequate since the act of gossiping is done between passing cars, so each vehicle's location on the road is important. On the other hand, a full CF or even a CA model is too heavy if we intend to support gossiping between every two individuals. Thus, we propose a combination where each road is divided into small sections and the cars are moved from section to section. However unlike a CF or CA model, our model's velocity (and therefore the road's capacity) does not depend on the distance between the cars. Instead, each road is modeled by a finite queue, and when a car has finished traversing a road, it is put into the queue until it is allowed to enter the next road.

The input of the simulation is a graph and a configuration which is specified via rules. The rules specify constraints on parameters associated with agents, their origins and destinations and the time they enter the network. There are also rules that are associated with changes of the edges' weights at specified times. They model incidents that slow down the traffic at certain points. Given a configuration, many specific runs of the simulation that satisfy the rules can be created randomly.

The network chosen for our experiments is an illustration of the central part of Jerusalem. It contains about 50 junctions and 150 roads which are approximately the number of main streets in the center of Jerusalem. The basic time unit of the simulation is a step that is equivalent to about 30 seconds. Each run of the simulation simulates six hours of movements on these roads. The average number of cars passing through the network during a simulation run is about 70,000 and the average number of cars in the network at a specific time is about 3,500 cars.

At the beginning of each run the simulation is activated for 42 simulated hours where the incident rules are not activated in order to reach the steady state of the network. When entering the network, each agent has information about the average time it takes to pass each edge of the network in the steady state. During the run, randomly selected junctions are partially or fully blocked and as a result traffic jams are formed. Each result below presents the averages of at least 30 randomly generated settings of the relevant simulation configuration (i.e., 180 simulated hours, 7,350,000,000 mobile agents). Seven different percentage levels of gossiping agents were considered: 60%, 40%, 30%, 20%, 10%, 5%, 2%.

The simulations are all done at the system level, abstracting the effect of layers 1 and 2. In particular, we did not model the MAC performance and signal propagation. All these low layer effects were abstracted by the fact that only a certain percentage of the packets can be transmitted. The simulator with documentation is available at `www.eng.tau.ac.il/~shavitt/Transport.html`.

B. Routing in Gossip networks

Using extensive simulations, we found that information propagation in gossip networks[1] is effective. In particular, with only a small percentage (as low as 10%) of cars that participate in the gossiping, information is disseminated fast and with a high rate of updates. We report these results in [23]. In this

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[1] Information is propagated through two processes, the movement of vehicles and car-to-car communication. Some papers term this "message ferrying" [28].

work we concentrate on assessing the effectiveness of the data dissemination on the agents routing performance. Since the traffic load changes over time the agents need to change their routing paths in order to decrease their journey time.

Next we present two scenarios that illustrate the way gossiping agents are able to overcome road (edge) blockage, e.g., due to accidents or road maintenance. In both scenarios (Figures 1,2) two of the edges were partially blocked and the flow of agents that could pass through was decreased by 70%. The blocked edges were randomly selected from a group of edges which ranked between 10 – 50%. Selecting overly loaded edges did not leave enough room for recovery, while selecting lightly loaded edges had no significant effect. Gossiping agent percentage was set at 20%. The graphs present the journey time as a function of the time of departure of both the gossip agents and the regular agents.

In the first scenario (see Figure 1) the first partial blockage began after 200 steps and ended at the 300th step. The second partial blockage began after 450 steps and ended at the 500th step. As a result of the partial blockage after 200 steps, several traffic jams occurred and the average journey length value increased gradually from that point. However, the average gossiping agents' journey length began to decrease after a short time, indicating that the agents realized that there was a traffic jam and adjusted their routes, accordingly. The decrease of the curve of the gossiping agent was to the original level, meaning they had completely learned the new weights and found alternative paths. At about step 300 the regular agents' journey cost also began to gradually decrease since the blockage was opened. At about 450 steps the same process started again except that this time the gossiping agents were not able to completely recover from the jam.

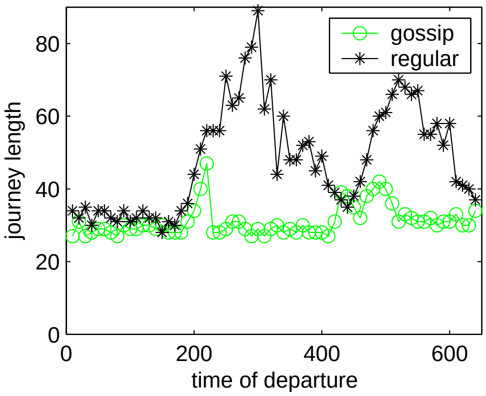

Fig. 1. Gossiping and regular agents in scenario 1

In the second scenario the partial blockage started at the 200th step and ended at the 400th step. Again, the percentage of gossiping agents was 20%. The regular agents' curve increased gradually until step 400 and then gradually decreased. An interesting phenomenon, is that the gossiping agents' curve eventually started climbing. As in the previous scenario, the agent learned about the blockage and avoided it (see the low peak at time 250), but at a later stage (at time 370) the blockage must have spread to larger areas of the network and thus the gossip agents could not bypass it resulting in an increase in their average travel time. When congestion abated, the gossip agents were much quicker in finding shorter paths.

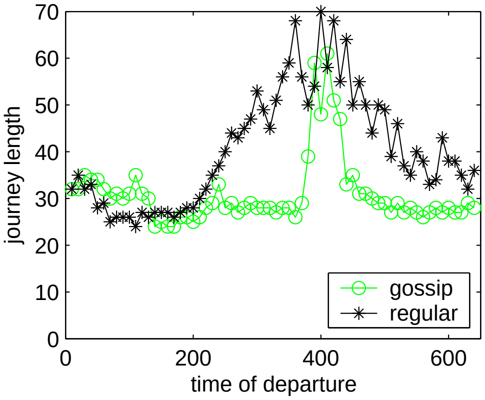

Fig. 2. Gossiping and regular agents in scenario 2

We studied how the percentage of gossiping agents influences the routing efficiency of the agents. Since we showed above that as the percentage of gossiping agents increases, the propagation of the information is more efficient, we expected to find that the higher the percentage of gossiping agents, the lower the average length of the journey. However, as the lower curve of Figure 3 indicates, the minimal journey length is obtained for 20% of the gossiping agents (see also, the second upper curve of Figure 4). This could be explained by observing the two aspects of efficient routing. First, as mentioned above, as the percentage of gossiping agents increases, the propagation of information is more efficient. Second, when there are many gossiping agents there is a ping-pong effect [4] where most of the gossip agents rush to the same paths that currently seem lightly loaded. The combination of these two conflicting aspects causes the optimum results to be obtained somewhere in the middle, with 20-30% of the gossiping agents. A large number of gossiping agents made the second aspect dominant, but too few gossiping agents caused the information distribution to be too slow. This behavior can be seen radically by the fact that with 60% of the gossiping agents, the journey length was as bad as with 3%.

We also considered situations where the amount of information passed between the agents was limited which allowed the agents to report on only 15 edges (which was 10% of the edges in the simulated network). The decision procedures to decide which information would be sent are specified in Section III-A.

As can be observed in Figure 3 the ranking algorithm leads to much more efficient routing than the random algorithms. The ranking algorithm is much better with the low percentage levels of gossip agents. The ranking algorithm, as expected (see introduction to the test), behaves well, despite the fact that it exchanges only 10% of the information. It behaves very similarly to the full information exchange - the optimum value is at 20% and then it rises on both sides. The random algorithms perform better as the percentage of gossiping agents increases. At 40% there is a sufficient exchange of information in the network for the dynamic random algorithm

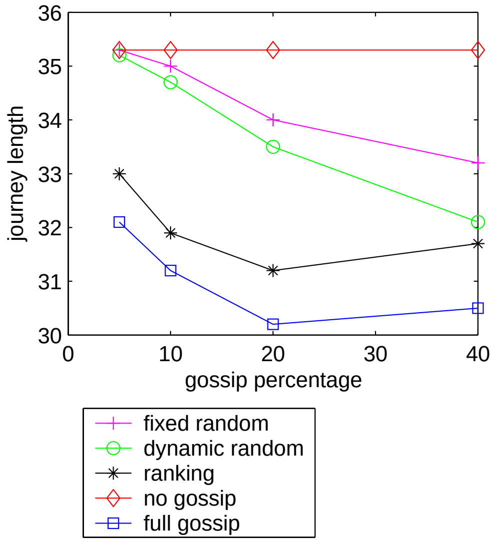

Fig. 3. Journey length as a function of the gossiping agents percentage for different procedures of information exchange.

to perform in nearly the same way as the ranking algorithm. The difference between the dynamic random algorithm and the fixed random algorithm is that the dynamic random algorithm is much more sensitive to an increase in the percentage of gossiping agents.

1) Comparisons with other information models: We compared the routing performance of the gossiping agents with two information acquisition models:

1) Centralized Information Model - Some of the mobile agents obtain information from a central information provider when entering the network. The information provided includes the current weights of all the roads in the network. For example, a driver may download updated road conditions before leaving home.
2) Online Centralized Information Model - The same as in (1), but an agent is provided with updated information each time it reaches a vertex. For example a driver may be subscribed to an update service for her car through a cellular network.

To show the effectiveness of the gossip model, we used idealized centralized information models where changes in the network are immediately available to the user. In practical systems there is a significant delay of 15-45 minutes from the time congestion occurs until information is disseminated to the users via the system.

As in the gossip model, some of the agents have access to centralized information, and we refer to them as *special agents*. Other agents gather information about edges only when traversing them and they are called regular agents. Figure 4 presents the average journey length of the special agents in the different information models as a function of the special agents' percentage. The effect of the percentage of special agents in the two centralized models is different from that of the gossip model. As the special agents percentage increases, the journey length also increases. This is because increasing the number of special agents in the centralized model does not decrease the information available to the agents (as in the gossip model). However, when there are only a few special agents they can select the best edges without anyone disturbing them. Moreover, when there are many special agents and all of them want to select the same believed to be free roads, the selected roads themselves will become crowded and therefore less attractive. Another interesting observation is that with the best percentage of gossip agents, the gossip network is nearly as good as the centralized models.

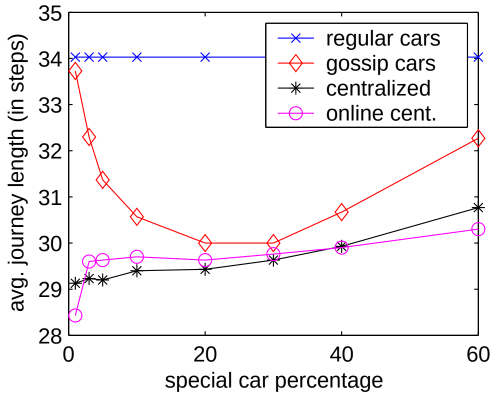

Fig. 4. Journey length of all the agents as a function of the percentage of special agents.

We also considered the road network load in all the above cases. The road network load is defined as the average number of agents (including both special and regular agents) per edge. Surprisingly, for the centralized model the load decreases with the increase in the percentage of special agents. The reason for behavior different from the average journey length is that the road network load takes into account all the agents in the network, while the journey length considers only the special agents. Therefore, when the special agents are the majority, the load on the roads spread more evenly, even though the special agents receive slightly less favorable paths. It is interesting to observe that when the percentage of gossip agents is 60% the load is higher than when there are no special agents at all. This is because the gossip agents take longer paths, aiming to save time; however, since there are so many of them they increase the load.

V. Conclusions and Future Work

This paper presents a simulation study that supports the efficiency of the gossip model for information exchange and the routing of self interested mobile agents in urban networks. The model is efficient even when only a relatively low percentage of the agents is able to gossip and when only partial information about the environment can be exchanged between the gossiping agents. An interesting finding is that increasing the percentage of gossiping agents in the environment is not always beneficial for routing. On the one hand, more gossiping agents increase the efficiency of the propagation of the information. On the other hand, if some edges become non transferable and the many gossiping agents become aware of the blockage, they will try to bypass them using the

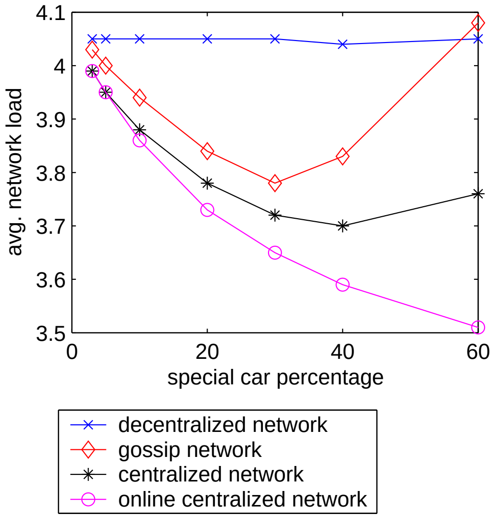

Fig. 5. Road network load as a function of the percentage of special agents

same believed to be available edges. Consequently the average journey length will increase. In other words, stability may not be achieved with the simple algorithms examined in this paper. Thus, there is room for designing better algorithms, such as an algorithm that can select a path with some probability that increases with its attractiveness. The gap between the probability to chose a better path over another can change based on the estimated percentage of gossiping vehicles. However, it will take time until such situations become reality.

In our experiments, a percentage of 20-30% of gossiping agents has led to the most efficient routing results. The average journey length in this setting was very close to that of agents that obtained information from an idealized centralized information provider. This was the case even when only 10% of the information available was exchanged by the gossiping agents.

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