Mobile gateway effect on the load distribution of telematics networks

Junghoon Lee
Dept. of Computer Science and Statistics
Cheju National University
Email: *jhlee@cheju.ac.kr*

Abstract: This paper has measured the effect of transmission range and gateway ratio to the degree of interference in terms of MNC, namely, the maximum number of connection in a cell, on the telematics network. A discrete event simulator has been implemented to trace the load distribution behavior of the network based on genuine movement data obtained from the Jeju taxi telematics system currently in operation. The experiment result indicates that the increase of transmission range up to 220 m can mitigate the congestion on the hot spot area with an appropriate gateway allocation scheme especially in the downtown area. In addition, gateway ratio around 28 % brings a great reduction in MNC, showing reasonable load distribution and vehicle assignment.

1. Introduction

[1] Nowadays, many cars are equipped with an in-vehicle computer system called a telematics device, through which many location-based services can be provided to the driver. Since telematics devices essentially include one or more wireless interfaces, they constitute a telematics network over the vast area. A lot of prospective services can be implemented on that platform, including cooperative safety applications, car-enabled sensing, and efficient path findings[1]. Those applications necessarily make each telematics device periodically broadcast information on its current status to its neighbors. However, too many broadcast in a narrow area may result in a severe interference between them[2]. Hence, it is important to measure the load distribution in a specific area for a better service quality.

Recently, many wireless communication technologies can be employed in organizing the vehicular telematics network. For example, the cellular network is available for the telematics, but it costs sometimes too much, as each vehicle generally has to pay monthly communication fee. Second, IEEE 802.11 WLAN can be also exploited in the telematics network. However, in this network, a vehicle can be connected only when it moves around the AP (Access Point). Third, for the vehicle-to-vehicle connection, the car can be equipped with DSRC (Dedicated Short Range Communication) card, a variant of IEEE 802.11[3]. In addition to those communication interfaces, more technologies will be integrated into the telematics network, including optical light signal transmission and other family of wireless communications.

With such basic building blocks, a vehicular telematics network can be configured in several ways. First, the infrastructure-based network makes every vehicle be stuffed with a cellular network interface as shown in Figure 1. The cellular network can be GSM (Global System for Mobile) or CDMA (Code Division Multiple Access) especially in the Republic of Korea. As the cellular network is originally designed for the telephony service with lots of base stations installed over a wide area, it can provide a ubiquitous access to each vehicle. Moreover, data communication is also available over the audio channel via the appropriate internetworking gateway, making it possible for a vehicle inside the telematics network to exchange data messages with a service provider in the Internet domain. Most embedded operating systems support such a functionality. For example, Microsoft's Windows Mobile provides RAS (Remote Access Service) API, over which the classical socket connection can be established[4]. However, the drivers should pay the communication fee.

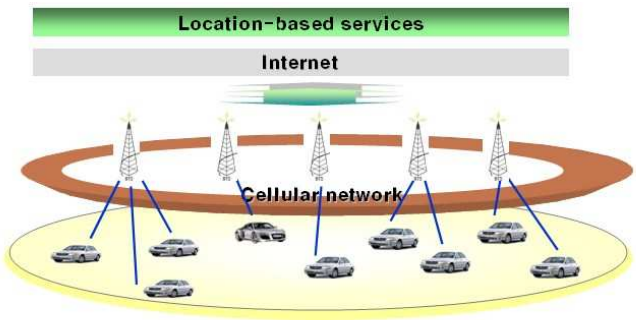

Figure 1. Infrastructure network

Second, Figure 2 illustrates the architecture of vehicular ad-hoc network, or VANET, in which each vehicle sends its message via the DSRC protocol. A vehicle can communicate just with its neighbors within its transmission range. So the transmission range of wireless communication interface is very critical to the network connectivity. The topology as well as the connection path changes dynamically according to the movement of each vehicle. Furthermore, VANET lacks a network-wide coordination function, so it may suffer from frequent disconnection and throughput fluctuation due to increased interference. It is also known that the connection of more than 3 hops can be rarely established. This network is able to carry a urgent message promptly without any intervention of other network components, so it's suitable for the application like accident information propagation.

We still have another alternative, combining the advantage of the above two. In this architecture, some vehicular nodes have both cellular network and DSRC interfaces, while others have only DSRC interface[5]. The telematics device having two interfaces acts as a mobile gateway. Other nodes can reach a global resource only via this gateway. Around a mobile gateway, the adjacent vehicles form a cell, that is,

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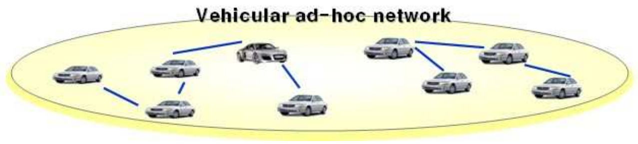

Figure 2. Vehicular ad-hoc network

they exchange messages via the common frequency channel as shown in Figure 3. The cell of another gateway uses different frequency band, even though the two gateways are very close. This mobile gateway network can compromise the communication fee and network connectivity, while distributing workload to individual gateways. It can also significantly enhance the connectivity, compared with VANET. Moreover, as the number of mobile gateways is a tunable parameter, the mobile gateway network can flexibly adjust to the demand of many environmental factors such as the budget, connectivity requirement, and so on.

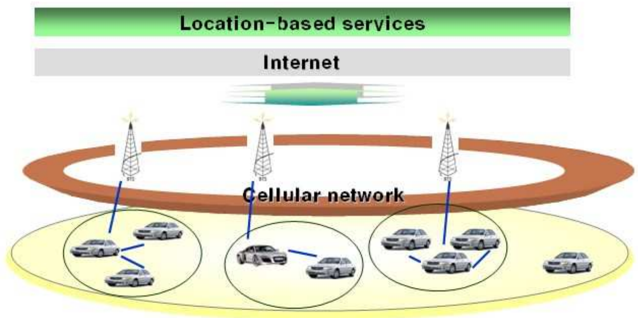

Figure 3. Mobile gateway network

If too many vehicles are located in a cell, a message transmission can interfere other ones. The short broadcast interval and massive data can also lead to message collisions and throughput degradation. Even though these factors are different application by application, the measurement on the number of vehicles in a cell is necessary to predict the network behavior and to design a new application, as the designer wants to know whether a network suffers from bandwidth shortage[6]. Due to the high mobility of each vehicle, the number of vehicles attached to a gateway changes dynamically and is almost impossible to exactly model or trace the movement of vehicles[7]. Meantime, the real trajectory data, obtained from the vehicle tracking system currently in operation, can help to estimate the effect of various parameters to the degree of interference[8]. By means of the estimated interference, we can decide the proper number of gateways delegated to the target network as well as the effective transmission range of wireless interface.

This paper is organized as follows: After describing the scope of this paper in Section 1, Section 2 explains some background and related work on the vehicular telematics network. Section 3 gives a detailed description on the experiment environment and subsidiary assumptions. Then Section 4 demonstrates and analyzes the experiment result on load distribution in terms of the maximum number of connections according to the transmission range and gateway ratio. Finally, Section 5 summarizes and concludes this paper with a brief introduction of future work.

2. Related work

Vehicular telematics networks have diverse configurations between infrastructure-based and fully ad-hoc style networks according to the development of the wireless communication technology. The example includes mobile gateway network, roadside network[9], and multihop-based stationary gateway network[10]. In the roadside network, RSUs (RoadSide Unit) such as an IEEE 802.11 access point are installed along the road to provide the passing-by vehicle with the accessibility to the global network. The stationary gateway network is based on the multi-hop routing protocol to the fixed-location gateways, which can complement the isolated connection of pure VANET. Each network has its own characteristics and provides different levels of connectivity, and tt is also possible to integrate sensor devices such as an RFID, traffic sensors, and the like.

With such a connection, many applications and services can be developed and provided to the driver. For example, US-DOT (Department of Transportation) defined the basic vehicular applications and corresponding message elements[11]. The application includes traffic signal violation warning, curve speed warning, emergency electronic brake lights, pre-crash warning, cooperative forward collision warning, left turn assistant, lane change warning, and stop sign movement assistant. In addition, the message element includes signal status, surface heading, position, velocity, timing, and so on. Each application exchanges information with its own period. Up to now, the message carries text information mostly, but soon it may deliver audio and video data to support such an application as teleconferencing between drivers in the vicinity.

As a study on mobile gateways for VANET, V. Namboodiri et al. have proposed a prediction-based routing scheme on 802.11 and 3G networks[5]. This scheme takes preemptive action by predicting when a route will break and try to create an alternative route before the actual breaks. In addition to basic AODV (Ad hoc On-Demand Vector) header information, the protocol part makes each RREP (Resource REPly) include velocity and location of the destination. With this, the sender can estimate the lifetime of the route based on their own temporal speed model. The behavior of a vehicle is modeled in terms of a first order Markov chain in which each vehicle transits from one speed state to another with a certain probability. However, this scheme has advantage only when multi-hop route is available, while this was pointed out to be impractical especially when vehicle density is low.

Lee et al. have proposed a message scheduling scheme for periodic sensor streams in hybrid telematics network system consist of infrastructure and ad-hoc network[12]. To meet the fairness requirement of traffic information system, the proposed scheme classifies each message into 3 groups, and picks the message according to the previous success ratio and future behavior estimation, compensating for degradation during the past interval. Degradation is quantified by the deadline miss ratio, while the future estimation is calculated by the headings of a vehicle and its gateway.

Even in same network, how to configure the network, for example, where to put a specific device, how to decide the number of routers, is so complex and it is very difficult to design and assess the corresponding network performance. The performance evaluation significantly depends on the movement pattern of fast-moving vehicles. The real-time tracking system accumulates the location data of many vehicles, generating a lot of trajectories that contains the real movement pattern of each vehicle[13]. The real location history data of many vehicles can help to estimate the various network performance metrics. The Jeju taxi telematics system is now currently in operation in Jeju island, Republic of Korea, and accumulating a lot of actual trajectories[8].

3. Experiment setup

Based on the real movement trajectory, we have implemented our own discrete event simulator, which takes the movement of each vehicle as a single event[14]. Hence, for each movement, the simulator updates the location of a vehicle. During simulation, at the specified moment, the simulator triggers an analysis procedure that decides whether and to which gateway a vehicle can be connected. This action accounts for the operation of a vehicle which tries to connect to a mobile gateway constantly. As specified in DSRC, the control packet is exchanged via the additional frequency channel[5]. So, we can assume that the transmission of connection establishment messages is independent of other data message transmissions.

Sometimes, a vehicle can find more than one gateway available. As the mobile gateway has the similar trajectory with the other vehicles, they also gathers at the hotspot area especially in the urban area. In this case, there are multiple options for the vehicle. First, the gateway can be chosen randomly, and we call this scheme RS (Random Selection). Second, in MS (Minimum Selection), the vehicle selects the gateway that has the minimum number of currently connected vehicles. The gateway selection step is performed via the control channel with a predefined message set. It is true that there are many factors to consider in gateway selection, for example, the amount of pending messages, the emergency of message, and the possibility that a connection may be broken. Accordingly, a lot of a new selection scheme can be designed. However, this paper compares MS and RS schemes in terms of the maximum number of connected gateways, focusing on the performance evaluation function.

We consider two performance parameters, namely, gateway ratio and transmission range. Gateway ratio means how many vehicles play a role of gateway. Intuitively, the more gateways, the better connectivity we can expect, but its cost also increases. In addition, beyond a saturation point, we cannot expect the improvement of network performance such as connectivity and load distribution, even with more gateways. Additionally, the transmission range of a wireless interface is set to have the distance of 50 through 300 m. Even though some network interface is able to adjust the transmission range for the purpose of optimizing power consumption, the telematics device doesn't have to worry about the power shortage as its power is supplied by the engine battery. So, each experiment just assumes that every vehicle has the same transmission range.

The simulation retrieves the trajectory of 500 vehicles for 2 hours from the movement history and some vehicles are made to play a role of mobile gateway. Even if the number of tracked vehicle is 200, the data of two or more days can be merged to generate a sufficient number of trajectories. This experiment does not consider multi-hop connection and just the vehicle within a transmission range of a mobile gateway can be connected. Finally, the target city area is as wide as 9.097 $km \times$ 4.316 km. Figure 4 shows the user interface of the simulator implemented via Microsoft's Visual C++ 6.0. The simulator plots the location of each vehicle, be it a gateway node or a general node. The background of this figure is the road network of Jeju city area, and we didn't present the detailed shape of road segment but the end points. This user interface provides the basic map functions such as zoom-in, zoom-out, pan, and so on. Around the gateway node, a circle drawn, with its radius set to the transmission range. The simulator can change this length at any time.

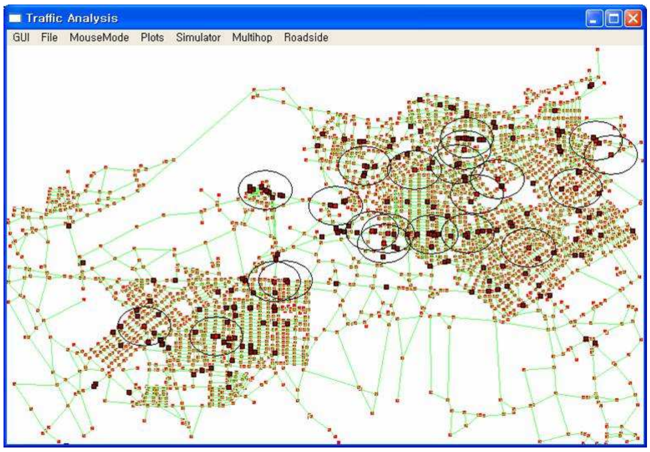

Figure 4. Simulator implementations

4. Experiment result analysis

Figure 5 plots the maximum number of connections (MNC) among all gateways observed during the whole simulation time according to the transmission range from 50 m to 300 m. In this experiment, the gateway ratio is fixed to 10 %. MS always shows smaller MNC for all transmission ranges. In some dense area, when just one gateway stays, MNC increases sharply regardless of the selection scheme. Even though the larger transmission range can increase MNC, it also improves the connectivity, that is, making more vehicles connected. When the transmission range is less than 100 m both schemes show almost the same MNC, as there exists a hot spot area such as passenger waiting line in an airport. However, the increase of transmission range mitigates the temporary congestion beyond this point.

Figure 6 plots MNC according to the gateway ratio ranging from 5 % to 50 %. In this experiment, transmission range is set to 250 m. For the larger gateway ratio, the gap between the two schemes gets larger, indicating that MS can benefit from the increased number of gateways. This analysis also can find the area that has longer MNC. Thus, the network planner can dispatch more mobile gateways, for the sake of avoiding network overload and providing stable network access to each vehicle. This function gets more important according to the appearance of an application that needs a large amount of message exchange.

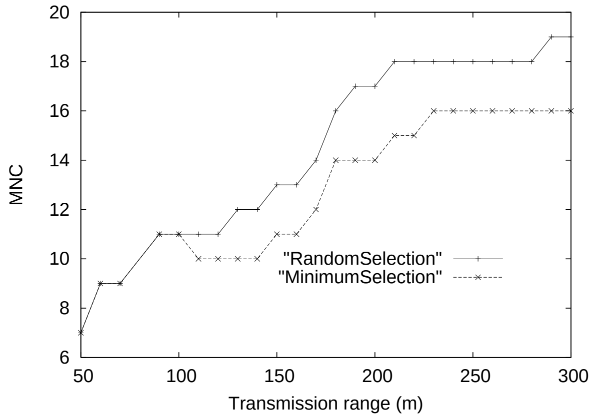

Figure 5. Transmission range effect

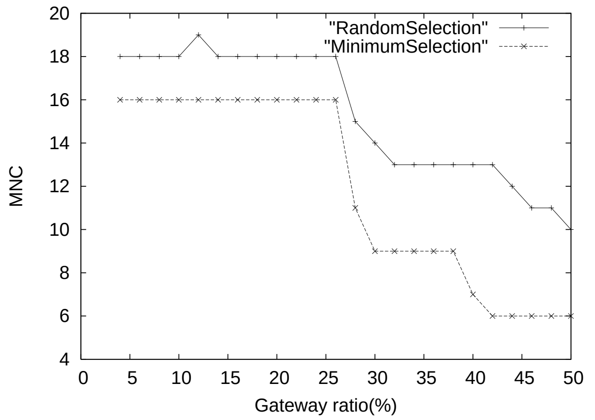

Figure 6. Gateway ratio effect

5. Conclusion

This paper has measured the effect of transmission range and gateway ratio to the degree of interference in terms of MNC, namely, the maximum number of connection in a cell, on the telematics network. A discrete event simulator has been implemented for the performance assessment based on genuine movement data obtained from the vehicle tracking system currently in operation. The experiment result indicates that longer transmission range can mitigate the congestion on the hot spot area with an appropriate gateway allocation scheme in the downtown area. In addition, gateway ratio can bring a great reduction in MNC around 28 %.

As future work, we will extend the experiment and add the vehicle assignment scheme for a gateway, considering the amount of current messages, as the actual load is the message amount and its priority rather than simply the number of connected vehicles.

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