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Measurement of transmission range effect to the connectivity of vehicular telematics networks

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Abstract: This paper measures the effect of transmission range on the connectivity for the vehicular telematics network. A discrete event simulator has been implemented to trace the movement of each vehicle, not using a simulated movement model but genuine movement data. The connectivity is analyzed by performing the Dijkstra's shortest path algorithm from each vehicle to a stationary gateway in multi-hop base. The experiment result indicates that the transmission range, having the great impact on the connectivity, can achieve up to 70 % connectivity on the common parameter values. The connection lasts mostly for about 2 minutes. This result provides a guideline to design a new location-based service.

1. Introduction

[1] Vehicular ad-hoc network, or VANET in short, has ever-changing topology, because the vehicles move so fast and the connectivity between the two objects also fluctuates along the time dimension[1]. However, a network planning and a new service design should be desirably based on the behavior of each vehicle in the network as accurate as possible. It is known that there is no exact model describing the movement of each vehicle, as the movement pattern is different for different vehicle types such as taxi, truck, automobile, and so on[2]. In addition, for the vehicular network, the objects can move only along the road segment, and the road network is inevitably different in different areas. Hence, the movement pattern on the specific region is unique and cannot be explained by a general mobility model.

In the meanwhile, we can obtain real location history data from the location-based service such as a real-time tracking system, a taxi dispatch system, and so on. Those services can create and collect the sufficient number of trajectories, so it can give us very valuable information in designing a network structure or a service in a specific region for the specific purpose[3]. Namely, we can use the real movement data instead of virtual movement model. The development of telematics technology makes if easier to implement such a service. Telematics is the combination of telecommunication and information technologies[4]. Nowadays, the telematics devices are penetrating into many cars, be it a taxi, an automobile, or anything else. As the computing device within a vehicle, the device can perform basic functions such as path finding, in-vehicle sensor collection and control, and the like. In addition, as the terminal device for the back-end service, it communicates with the central server via the wireless interface.

The location history data collected from a telematics service system can be analyzed and feedbacked to design a new service as the data can reproduce an actual movement pattern to the service designer. With such data, the network designer can find the most efficient network type, the number of network device installations, and the place to put a specific network equipment. There are so many ways to construct a telematics network according to the evergrowing development of the wireless communication technology. So, the analysis can maximize the efficiency of network configuration, in terms of cost, connectivity, and the quality of providable services, considering the unique feature of vehicle movement on a specific area, time duration, vehicle type, and so on.

There are some prominent configuration methods for the vehicular telematics networks. The first one is the infrastructure-based network, which makes every vehicle connected ubiquitously, but it's generally non-free. The second one is a fully ad-hoc style architecture called VANET, which is a special case of MANET (Mobile Ad-hoc NETwork). Between the two extremes, some hybrid networks can be also considered including a roadside network, a stationary gateway network, and a mobile gateway network. Each network type has its own cons and pros, and it's very difficult to decide which one is most efficient in the specific area, as this step demands a sophisticated planning to provide a reasonable quality location-based service.

In organizing a network, one of the most important criteria is network connectivity, which is the probability that a vehicle can make a connection to and exchange information with a service provider. The higher the connectivity, the better service can be designed and provided. There are so many factors that affect the network connectivity, for example, the density of vehicles, the distribution of vehicle locations, the transmission range of wireless interfaces, and geographical characteristics. Among these, the transmission range is very critical to the connectivity in ad-hoc networks, as it decides whether two adjacent vehicles can be connected. Currently, most commonly known value is from 50 m to 300 m, sometimes up to 400 m. But this range will be extended with the upgrade of wireless communication equipments.

In this regard, this paper is to design and implement a connectivity analyzer for the vehicular telematics network, with the real movement history data collected from a real-time tracking system currently in operation. We mainly focus on the stationary gateway network, in which a multi-hop connection is possible, and measure the effect of transmission range to the connectivity of each vehicle. To this end, the ex-

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periment selects the areas having significant traffics, virtually places a gateway for each area, and measures the connectivity and connection duration time by means of the Dijkstra's shortest path algorithm, for the various values of transmission range.

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 network connectivity according to the transmission range. Finally, Section 5 summarizes and concludes this paper with a brief introduction of future work.

2. Related work

Vehicular telematics networks can be characterized by rapid link topology change, frequent network disconnection, and constrained one-dimensional movement. So, many researches have made an effort to analyze the network performance on the various types of vehicular network configurations illustrated in Figure 1.

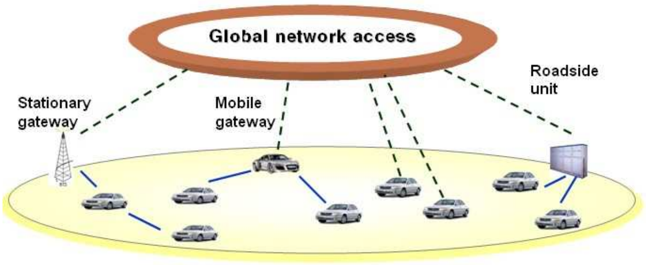

Figure 1. Telematics network architecture

First, in the infrastructure-based network, every vehicle is equipped with a cellular network interface, so it can be connected to a central server, outside world such as the Internet, and other vehicles, whenever it want, wherever it goes. The example of infrastructure, or wired backbone network is the cellular network, particularly CDMA (Code Division Multiple Access) in the Republic of Korea. In this network, every telematics device is connected directly to the central server via the specific telecommunication carrier[5], showing 100 % of connectivity. But this connection is generally not free. The bandwidth is negotiated and bought from the telecommunication company by monthly-base. This network is appropriate to provide a service that needs a continuous interaction between a vehicle and a central service provider such as a real-time tracking system.

Second, V2V (Vehicle-to-Vehicle) network forms a VANET (Vehicular Ad-hoc NETwork) based on IEEE 802.11 protocol including DSRC (Dedicated Short Range Communication). Each device directly communicates with its neighbors residing in its transmission range[6], while it has to communicate with other telematics devices not residing in the range through multi-hop routing. Even though network connectivity is not fully supported, this network eliminates the connection fee and extends the coverage of vehicle management or sensor data collection. However, it is very hard to maintain an ad-hoc network topology of more than 3 hop neighbors. This network is mainly targeting at the vehicular safety applications such as accident information propagation, pre-crash warning, and curve speed warning, as it can exclude the intervention of intermediate network components and promptly broadcast a urgent message to the adjacent vehicles.

Between the two networks, we can build a hybrid network that can compromise the cost and connectivity trade-off. To begin with, R2V (road-to-vehicle), enables each vehicle to access the RSU (RoadSide Unit) installed in the fixed location on a road[7]. RSU can be an 802.11 access point, which typically plays a role of router. In addition to the global connection, through this buffer point, all data on the RSU can be uploaded and downloaded, including location-dependent advertisement, real-time traffic, and vicinity digital map downloading. USDOT (US Department of Transportation) is known to have invested a large amount of fund to roadside network, for the purpose of making the current transportation system more intelligent. Some high-quality cars are stuffed with a communication module for the roadside network[8].

In mobile gateway networks, some vehicular nodes have connectivity to both infrastructure and V2V networks, while others have only V2V interfaces[9]. In this architecture, the telematics device having the infrastructure interface acts as a mobile gateway. Other nodes can be connected to the central information server only via this gateway. This network can compromise the communication fee and network connectivity, while distributing workload to individual gateways. As the mobile gateway and other vehicles have similar movement patterns, it is highly possible for a vehicle to find a connectable gateway node almost every time. The number of gateways is a tunable parameter decided by the connectivity requirement and the budget. This network should reduce the ill-effect of frequent route breakage by reinforcing the underlying route management protocol.

Stationary gateways can be installed to allow the vehicles inside the telematics network to access the outside world such as the Internet. Some vehicles can make a connection directly to the gateway when they stay in the transmission range of the gateway, while others can do only via the multi-hop connection. A vehicle is said to be connectable when there exists a path form a gateway to the vehicle, or vice versa. Two entities can be 1-hop connected when they lie within each other's transmission range. Whether a vehicle can be connected or not depends on the distribution of intermediate vehicles. Consequently, the transmission range and vehicle distribution are the two most critical factors to the network connectivity. The change of vehicle distribution is too dynamic to formalize its influence accurately. It can be just estimated by the vehicle density in the specific area. In addition, the multi-hop transmission is commonly reinforced by geographical routing protocols, which push messages between their destinations, namely, a vehicle or a gateway[10].

This paper makes use of the the movement history data collected from the taxi telematics system currently in operation in Jeju city, Republic of Korea. As one of the most famous tourist attractions in East Asia, Jeju Island is a popular vacation spot for Koreans and many international visitors. It has a well maintained road network which essentially follows the entire coast (200 km) and crisscrosses between the island's major points. The *taxi telematics system* has been developed to provide a real-time tracking, an efficient taxi dispatch[5], and the systematic management of member taxis. To this end, the system continuously collects the location of each taxi and accumulates the movement history of each vehicle. These data are stored in both relational and spatial databases to be analyzed with diverse tools. This paper used the data of 3 months for 200 taxis, and the number of records amounts up to 1.3 million.

3. Experiment setup

The analysis begins with the placement of stationary gateway stations. To enhance the connectivity of the network, the gateway location must be selected so as to make vehicles connectable as many as possible. With this history data,we can select the area of high vehicle density either by roughly drawing a rectangle covering many location reports or by a clustering tool. In addition, for the sake of easy maintenance, the governmental buildings or facilities are considered to be good candidates. Usually, their vicinities, including international airport, government office, and broadcasting station, have many visitors and passing-by vehicles. Taking into account above factors, Jeju city area has three locations for the gateway installation, namely, Area A, B, and C. Not to mention, some location can be changed or another location can be added.

Area A is the international airport. As Jeju city is the famous tour place and the airplane is the most common way to go to the other part of the nation, the airport area gathers many cars and people. Taxis also carry many people to or from this area for the connection of the airplane lines. Hence, the taxi density is closely related to the airplane time schedule. Second, Area B is the residential area having many commercial companies, shopping centers, restaurants, and tourist hotels. This area has heavy traffic generated from daily commuters and visitors. Traffic around this area is generally increasing especially in the evening and night time. In addition, a broadcasting company and telecommunication facilities are located here. Third, Area C includes many public institutions such as the city hall, the bus terminal, governmental offices, and the like. Due to these characteristics, this area shows a constant number of taxi reports from the early morning to the late night.

Figure 2 summarizes the experiment setup. The background picture being the road map of Jeju city, the actual shape of road segment not being shown. The figure intuitively shows the areas which have dense road distribution and cars. Our experiment assumes that three gateway stations are installed in those spots as shown in Figure 2, where each station is marked with an antenna image surrounded by a circle representing the transmission range (400 m in this figure). Actually, the three spots coincide with the location of the airport, the telecommunication company, and the city hall, respectively. Area A is 0.60 $km \times$ 0.36 km wide, Area B 3.64 $km \times$ 1.60 km, and Area C 4.83 $km \times$ 2.97 km. The total area shown in Figure 1 in Jeju city is 9.097 $km \times$ 4.316 km.

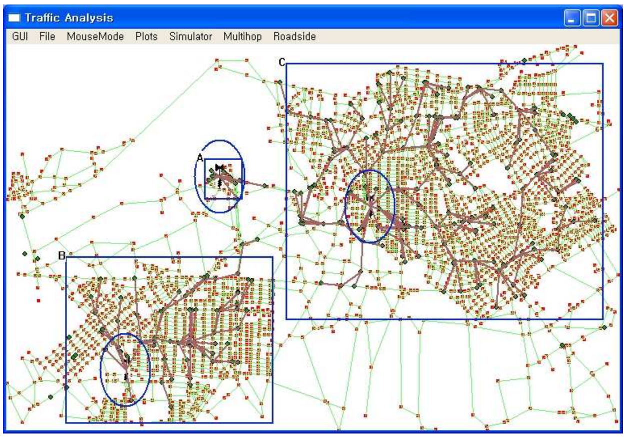

Figure 2. Target area map

In the ad-hoc network, each vehicle tries to make a connection to the gateway by means of a specific routing protocol. THe routing protocol can find the path only if it exists. Dijkstra's algorithm is an optimal solution for the shortest path problem, so it can find whether the shortest path. By this step, the analyzer can not only find whether a vehicle is reachable but also calculate the minimum bound of hop counts. The path can be found only if the vehicle is connectable. We can know the upper bound of routing algorithms in their performance. To decide whether a vehicle can be connectable at a given moment, the analysis procedure builds an $n \times n$ adjacent cost matrix, J, where n is the number of vehicles currently active at the specific time instant. Each element J_{ij} is set to 1 when vehicle i and j are within the transmission range of each other. Then, Dijkstra's algorithm is executed from the respective gateway stations.

After all, we have implemented our own discrete event simulator, where each movement of each vehicle constitutes an event. The additional events such as timeout, performing an analysis, and gathering statistics information can be inserted to the appropriate time instant. For each movement, the simulator catches up with the location of a vehicle. At every minute of the simulation time, the simulator triggers the connectivity analysis procedure described above. The simulator also maintains the status of each vehicle, namely, $connected$ or $disconnected$, so by checking the status changes, we can know the duration of the connection time and disconnection time.

4. Experiment analysis

Figure 2 also shows the path from a vehicle to the gateway, and the paths looks like a tree whose root is the gateway. Figure 3 plots the connectivity values according to the transmission range, which is set to have a value from 50 m to 400 m. 3 curves are shown for the case of 300 nodes, 400 nodes, and 500 nodes, respectively. The trajectories of more than one day can be merged to make the sufficient number of trajectories. The connectivity begins to sharply increase at the point that transmission range is 200 m. When the range is 300 m, the typical transmission distance, we can expect about 70 % with 500 vehicles and 30 % with 300 vehicles. For the case of 400 m, about 80 % of vehicles become connectable, indicating that the extension of transmission range will greatly contribute to the improvement of the network connectivity.

Figure 4 plots the probabilistic distribution of connection duration. This information can give us a hint on the running time of a location-based service. The number of established connections for the case of 200 m transmission range is less than that of 300 m transmission range. However, if we plot the probabilistic distribution, two curves look almost same. In the figure, 50 % of connections last for about 2 minutes. So, the running time of a location-service had better not exceed 2 minutes. We think that the connection time is dependent on the speed, heading, and the status of the vehicle as well as the connected gateway. Further experiment is scheduled considering additional factors such as the speed, heading, and status of a vehicle.

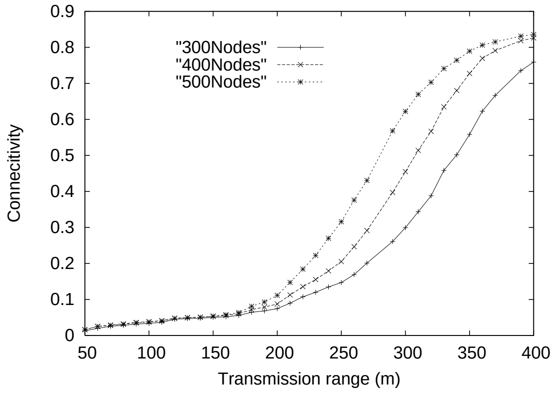

Figure 3. Transmission range effect

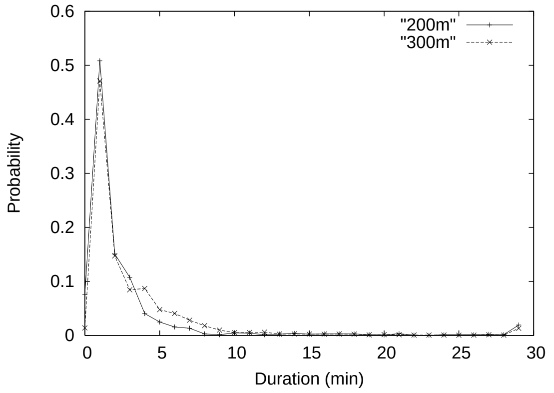

Figure 4. Connection time distribution

5. Conclusion

This paper has measured the effect of transmission range on the connectivity of vehicular telematics network. A discrete event simulator has been implemented to trace the movement of each vehicle, not using a simulated movement model but genuine movement data. The experiment result indicates that the transmission range, having the great impact on the connectivity, can achieve up to 70 % connectivity on the common parameter values. In addition, once connected, the vehicle stays connected mostly for about 2 minutes, so the running time of the location-based service consider this result. The experiment model will combine geographical factors which have a non-negligible effect on the transmission range.

As future work, we will measure the connectivity of ad-hoc routing protocols such as AODV (Ad-hoc On Demand Vector), DSDV (Destination-Sequenced Distance-Vector), and so on[11]. To this end, the integration of our history data with the existing network simulator such as ns-2 is needed[12]. Based on this analysis, we will design a location-based service that can estimate connectivity and connection time of a vehicle when connection is first established, and select the content, for example, advertisement lists, to the vehicle.

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