■ 論 文 ■

애드혹 네트워크 기반 교통 시스템을 위한 컴퓨터 모의실험 환경 설계

Designing a Simulation Framework for Vehicular Ad hoc Network Applications

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요 약

무선 통신 장비의 빠른 확산과 함께 교통 분야에도 새로운 시도가 이루어지고 있다. 무선 통신 기술의 하나인 애드혹 네트워크를 차량에 적용한 Vehicular Ad hoc Networks (VANETs)은 주행중인 차량간의 통신을 가능하게 하여 교통 안전, 혼잡 정보 등의 교통 정보 전달에 활용이 검토되고 있다. 하지만, VANET 기술은 아직 연구 수준이고, 실험에 있어 시간과 비용의 한계 때문에 컴퓨터 모의실험에 의존하고 있다. VANET 기반은 교통과 통신의 통합된 환경임에도 불구하고, 이전 연구에서는 한 분야만의 환경을 고려하였거나, 현실적인 통합 환경을 이루지 못하였다. 본 연구에서는 기존 실험의 한계를 극복하기 위하여, 실제 VANET 기반 교통 시스템에서 발생하는 차량의 움직임과 무선 통신 특성을 표현하기 위한 미시적 교통 모의실험 모형과 통신 모의실험 모형을 시・공간적으로 동기화한 모의실험 환경을 설계하였다. 사례 연구로, 실제 도로 및 교통 수요 자료를 사용하여 설계된 모의실험 환경을 적용하였고, 교통 특성과 통신 특성을 잘 반영하는 결과를 얻었다. 향후, 본 연구에서 설계된 모의실험 환경은 VANET 기반 교통 시스템의 다양한 설계에 활용될 것으로 기대된다.

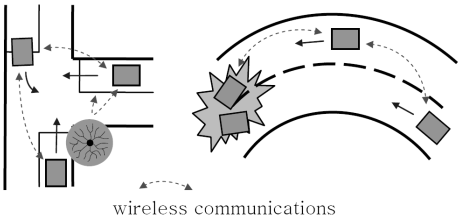
With a spread of mobile devices, the growing trend of integrating wireless communications technologies into transportation systems is advanced. In particular, vehicular ad hoc networks (VANETs) enable vehicles to share traffic information that they have through intervehicle communications. This research focused on the design of an integrated transportation and communication simulation framework to build an environment that is more realistic than previous studies developed for studying VANETs. Developing a VANET-based information model, this research designed an integrated transportation and communication simulation framework in which these independent simulation tools not supporting High Level Architecture (HLA) were tightly coupled and finely synchronized. As a case study, a VANET-based traffic information system was demonstrated based on a real road network and real traffic data. The experiment results showed that the simulation framework was well integrated. The simulation framework designed in this study is expected to contribute to developing the environment to experiment a wide range of VANET applications.

Ⅰ. INTRODUCTION

In an ongoing effort to apply advanced technologies to help solve transportation problems, there is an increasing interest in taking an advantage of the growing population of mobile wireless communications devices. A considerable success has occurred in integrating wireless laptops and handhelds into fixed wireless networks and into mobile ad hoc networks in buildings and at other fixed locations. An ad hoc network is a collection of devices (nodes) that wish to communicate, but that have no fixed infrastructure available (Ramanathan and Redi, 2002). Through this technology, traveling vehicles would communicate with each other even without infrastructure: traffic information dissemination. It is called Vehicular ad hoc networks (VANETs), a specific type of mobile ad hoc networks. 〈Figures 1 and 2〉 shows possible applications of VANETs to transportation systems.

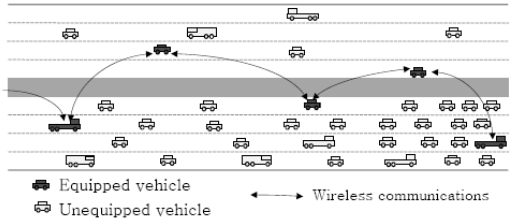
At an intersection, VANETs enable vehicles to recognize other vehicles that are hidden by buildings or trees via intervehicle communications (〈Figure 1a〉). If vehicles transmit emergency notification such as accident locations, unexpected weather, and obstacle warning to the upstream traffics, rear-end collision would considerably decrease (〈Figure 1b〉) (Chisalita and Shahmehri, 2002, Ueki et al. 2004, Yin et al., 2004, and Avila et al., 2005).

Delivered traffic information could be of congestion states on surrounding roadways. Vehicles participating in this system record and transmit their own travel experiences to other vehicles so that they can develop an overall understanding of the congestion picture (〈Figure 2〉) (Yang, 2003, Blum et al., 2004, Goel et al., 2004, Wischhof et al., 2005, Wu, 2005, Xu and Barth, 2006, Saito et al., 2007, and Kim, 2007).



a) Intersection collision b) Rear-end collision

〈Figure 1〉 Traffic safety application



〈Figure 2〉 Traffic condition dissemination

Although there are many interests in VANET applications, it is hard to conduct real experiments due to its high cost in both time and expenses. For these reasons, most studies conducted VANET experiments over computer simulation. The simulation of VANET-based transportation systems requires to replicate a real system that functions as a proxy for vehicle movements such as car following, lane changing, shock waves, and queuing and wireless communications such as path loss, fading, interference, and communication collision. To date, however, no single simulator alone can simulate a VANET-based transportation system. Prior attempts to combine two simulators have limitations on practical communication simulation and complexity of experiments. The goal of this study is to design an integrated transportation and communication simulation framework for vehicular ad hoc network applications. In this framework, a transportation simulator and a communication simulator are tightly coupled and finely synchronized without High Level Architecture (HLA), in which computer simulations can communicate to other computer simulations regardless of the computing platforms.

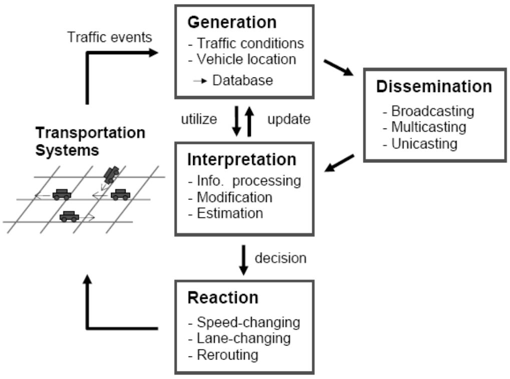
Section 2 describes how this study designed a simulation framework based on an information model for VANET-based transportation systems with the introduction to simulation tools and synchronization schemes. In sections 3 and 4, the simulation framework designed in this study is applied for a traffic information system based on a real road network and traffic demands. Section 5 concludes the entire research.

Ⅱ. FRAMEWORK DESIGN

The first important task to be conducted as a part of this research was to develop an information model that describes the types, frequencies, etc. of the information packets that are expected to be used by models supported by VANETs, as well as their collection and distribution mechanisms. With this information, it was then possible to design a cooperative architecture expected of the two domain simulators. Specific details depend on the simulators chosen, of course, but the general guidelines of the interfaces, data dictionary, etc., were determined at this point. The following subsections describe the information model and simulation platform configuration for designing a simulation framework.

1. Information Model

In order to understand the target system of the proposed simulation framework, an information model in transportation systems based on VANETs is presented in this study. In the information model, various traffic events – such as vehicle movements – are collected as data, in some manner, from the transportation systems and are then fed back to the transportation system according to some collection of preset logics. The information model considers traffic events as information (thereby assuming that the means to collect the information accurately are available) and processes the information to decide reactions. 〈Figure 3〉 shows a diagram of the information model which this study focuses on.



〈Figure 3〉 Information model for VANET-based transportation systems

The proposed information model for VANETs consists of four stages: generation, dissemination, interpretation, and reaction. To support VANETs, the first stage of the information model is the generation of information which describes traffic states (conditions) for transportation mobility purposes, and vehicle locations for transportation safety purposes.

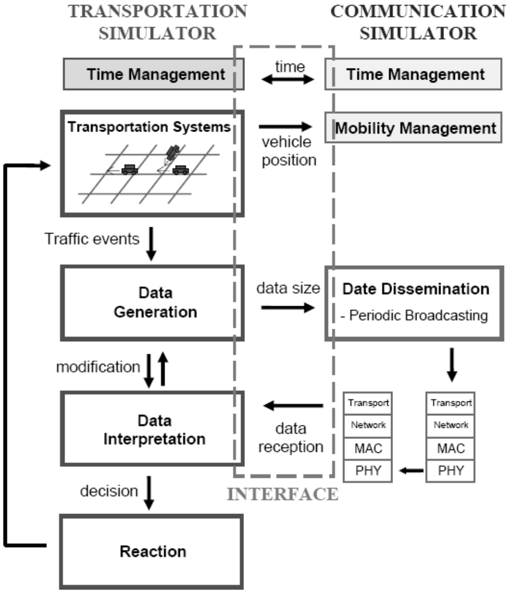
Information generated is disseminated to appropriate recipients at the second stage. Depending on the applications, information would be destined either to specific vehicles (unicasting or multicasting) or to all other vehicles within transmission range (broadcasting). When a vehicle receives new information from other vehicles, it would either discard or assimilate the information, depending on its interpretation. At the stage of interpretation, procedures for understanding what the new information means and what to do with it are conducted. The interpretation may cause an update or modification to a vehicle's own information base with new information. At the final stage, accumulated information should result in some reactions from vehicles (or their drivers) such as speed changing, lane changing, or rerouting. The reaction defines rules for such responses to new information. This reaction usually feeds back to the transportation system, possibly generating new traffic situations.

This information model can cover most applications of VANETs which base the individual vehicle's reaction to the transportation system on collecting, processing, and disseminating traffic events. The simulation framework is designed according to the presented model and, therefore, most of VANET-based transportation systems can be properly simulated within this framework.

2. Framework Architecture

This section describes the simulation framework designed to work with the information model presented in the previous section. The simulation framework was designed with the notion that a simulator for VANETs should provide the followings: simulation for the transportation system, simulation for the vehicular ad hoc network, and an interface logic. 〈Figure 4〉 shows the architecture of the transportation and communications simulator components.

As shown in 〈Figure 4〉, upon the occurrence of traffic events in a transportation system, the transportation simulator generates data, decides on the intended recipients, and lets the communication simulator present inter-vehicle communications. At this point, we can assume that the system disseminates information through unicast, multicast or periodic broadcast addressing according to communication purposes. The communication simulator informs the transportation simulator about data receptions, and the transportation simulator then interprets the information, modifies it, and reacts if needed.



〈Figure 4〉 Framework architecture

3. Simulation Tools

In order to simulate vehicles' mobility in transportation systems and ad hoc networking among vehicles, simulators oriented to these specific purposes are employed. For these purposes, the transportation simulator should be a microscopic simulator capable of describing correlated movements of individual vehicles. The communication simulator should simulate the seven layers in the open systems interconnection (OSI) reference model proposed by the International Organization for Standardization (ISO), and should be able to handle large communication networks composed of equipped vehicles.

Corsim, VISSIM, AIMSUM, and Paramics are well-known microscopic transportation simulators. These simulators can be used to produce movements and behavior of each individual vehicle and replicate traffics on a wide variety of transportation networks. In particular, a primary flexibility of those simulators is that it allows users to access its internal mechanisms via a convenient Application Programming Interfaces (API). Most sources in the literature in mobile wireless networks use ns-2, OPNET, GloMoSim, or QualNet for communications evaluation tools. These tools can simulate large scale wireless networks as a packet level simulator for wired and wireless networks. These should support all seven layers from the physical layer to the application layer in the OSI reference model.

A transportation and communication simulation framework for VANET applications should contain the characteristics of transportation and communication as mentioned above. None of simulators have satisfied both characteristics simultaneously. It would play a role as a simulation framework for VANET applications if two independent simulators are tightly coupled and finely synchronized. That is the reason why this study intends a conjoined simulation framework.

4. Synchronization

Synchronization would be most important to develop a integrated simulation framework. To synchronize the simulation time between both simulators, they exchange current simulation times at a given precision. Since the communication simulator does not support vehicles' movements, the transportation simulator periodically provides the communication simulator with vehicles' locations. Unlike many communication simulators, transportation simulators do not, normally, support the HLA, in which independent computer simulators can communicate with each other via Run-Time Infrastructure (RTI), a middleware to implement HLA (Dahmann et al., 1998). Therefore, it is required to develop our own methodology to combine. In the simulation framework, a transportation simulator and a communication simulator proceed independently (as different processes), but each with constraints imposed by the other. In particular, each has the ability, through the API, to suspend execution of the other long enough for the non-native data to be updated appropriately. When this synchronization scheme is executed with sufficient resolution, it has the effect of mimicking a combined simulation environment.

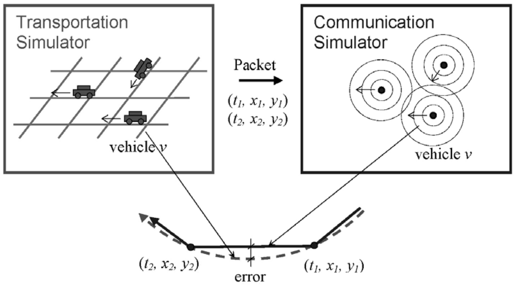
Ⅲ. FRAMEWORK IMPLEMENTATION

In this section, the specific modes to implement the simulation framework designed in the previous section are described. Proper tools for transportation and communication simulations are synchronized with respect to simulation time and node locations. The last part shows data communications between the simulators for updates of traffic data via intervehicle communications.

In this simulation framework, the locations of nodes (vehicles) in a communication simulator are synchronized with those of equipped vehicles in a transportation simulator. The transportation simulator is programmed to periodically send the communication simulator the positions of all equipped vehicles that are currently active in the system with a time stamp. 〈Figure 5〉 shows how these simulators synchronize vehicles' movements and graphically illustrates an expected error from this method.

In Figure 〈Figure 5〉, the communication simulator moves vehicle (node) positions along a linear path with time-stamped vehicle positions. For example, if it received (v, t1, x1, y1) and (v, t2, x2, y2) at the next period, where t2 〉 t1, then the vehicle v is assumed to depart from location (x1, y1) at time t1 and arrive at location (x2, y2) at time t2 and to have done so along the straight line between (x1, y1) to (x2, y2). This "interpolated mobility" could cause incorrect vehicular positions if the actual vehicle trajectories are non-linear. This error depends on the updated time, an error tolerance e, which would be determined according to applications. This error is controllable since it can be determined according to transportation systems to apply.

Many communication simulators are Discrete Event Simulation (DES) software, in which the simulation time proceeds only when an event



〈Figure 5〉 Movement synchronization and expected error happens. On the other hand, most transportation simulators are based on a time-driven structure. In this study, the time-driven transportation simulator controls simulation time of the event-driven communication simulator. Given a maximum time error ε between both simulators, the transportation simulator time (tt) is always kept ahead of communication simulator time (tc), by at most ε: $0 < tt - tc \leq \varepsilon$. The transportation simulator periodically sends the current simulation time tt to the communication simulator every ε seconds. The communication simulator sends an acknowledgement message to the transportation simulator in order to inform that it has processed all events happening before time tt. Since the communication simulator is a discrete event simulator, it processes events until tt and stops if the time of the next event to process is later than tt. Assuming there is at least one event in each ε period, the time difference between these simulators is always less than ε. This synchronization method guarantees that the delay of data delivery can be constrained above by the parameter ε.

In the simulation environment synchronized in terms of time and mobility, equipped vehicles communicate, meaning that data are transmitted. If multiple entities try to transmit simultaneously, all of their communications will be collided and garbled - this is called “communications collision.” An improvement involves the utilization of a transceiver to “listen” to the channel first to make sure it is not obviously busy, and if not, then try to send its packet - this is called “carrier sense multiple access” (CSMA). Typically, a node that detects a collision first terminates transmission immediately, so as not to waste any time. An individual node now waits for a random period called the “back-off” time and then tries again. In some systems, this process of re-trying packets can continue a number of times, but the back-off time doubles for each collision, resulting in what is known as an “exponential back-off” scheme. After some number of failed attempts, the packet is “dropped.” This is very important in applications such as file transfer, because arguably each packet is very important. It might contain a chunk of data or code that is part of a larger file, and thus it is critical for it to be communicated accurately (Murthy and Manoj, 2004).

A communication simulator simulates the vehicles' broadcasts of their data via an ad hoc network including communications collision which could happen on a MAC layer. In the aftermath, the communication simulator sends a transportation simulator the results of the broadcasts to update traffic data based on the broadcasting time.

Ⅳ. CASE STUDY

This section applies the integrated simulation framework designed in this study for a traffic information system. In a VANET-based traffic information system, travel time data are generated by equipped vehicles and stored in their database. Through broadcasting, vehicles share travel time data which they have in their database. The delivered travel time data are processed, which might include assimilation into an existing data set, discarding of stale data, modification, and calculation.

The highway network (a total of 22 km) selected for this simulation is located between Washington, District of Columbia and Baltimore, Maryland in the United States. Using 2006 Annual Average Daily Traffics (AADTs) produced by the Maryland State Highway Administration, a variety of traffic demands are established. For example, DL (Demand Level) 1 is the lightest condition and DL 7 is the heaviest condition. For this experiment, Paramics containing many API functions and QualNet supporting all seven layers in the OSI reference model were employed as a transportation simulator and a communication simulator respectively. Paramics and QualNet

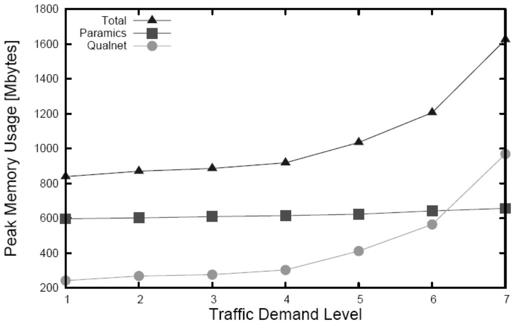
〈Table 1〉 Primary simulation parameters

Market penetration	1, 3, 5 and 10 [%]
Broadcasting interval	1 second
Protocol	Transport layer: UDP Network layer: IP MAC and Physical layer: 802.11a
Transmission range	250 meters
Simulation time	40 minutes

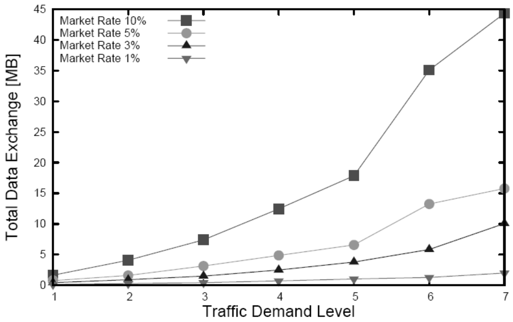
run with reciprocal communication via shared memory. 〈Table 1〉 contains the key parameters in this case study.

In this simulation framework, vehicles are released according to a release algorithm, which uses a number generated from a uniform random distribution, to determine the headway between released vehicles. A vehicle is determined to be equipped or not on the basis of a Bernoulli random variable sampled for each vehicle upon its entrance to the network, with a parameter equal to the intended market penetration rate. The retention of travel time data for each vehicle is limited up to 30 of the most recent observations per link. Travel time data packets over 15 minutes old are expired in the current simulation framework. The point of this study is to showcase the integrated transportation and communications simulation framework, so the parameter choices are not optimized in any systematic way.

The VANET simulation is computationally expensive, partly because it needs a large amount of memory space because thousands of vehicles communicate with each other every ε seconds. The performance of this simulation framework was measured in terms of computer memory usage. 〈Figure 6〉 shows computer memory usage.



〈Figure 6〉 Computer memory usage

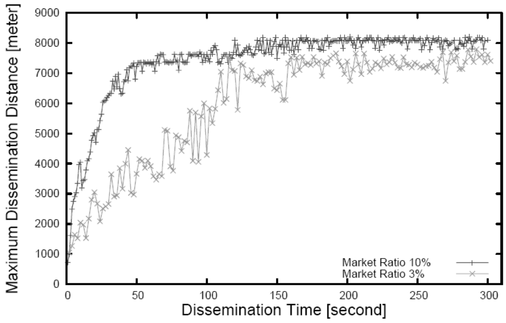


〈Figure 7〉 Data exchange between simulators

In 〈Figure 6〉, the results of memory usage were obtained in 10 % market penetration rate. Memory usage in Paramics did not change very much, whereas that in QualNet significantly became higher from the traffic demand level 5. This reflects that an increase in traffic density considerably boosts communications among equipped vehicles. When approximately 4,000 vehicles (400 equipped vehicles) in the demand level 7 were on the road network, the memory spaces needed for Paramics and QualNet were about 0.7 Gbytes and 1 Gbytes, respectively. 〈Figure 7〉 shows the amount of data which Paramics and QualNet exchanged each other.

Data exchange as well as memory usage mentioned above depends on the number of vehicles traveling on the road network. In 〈Figure 7〉, the total amount of exchanged data increases as traffic demand level increases. Although they stiffly increased at the demand level 6, the total of exchanged data increased less at the demand level 7. This result explains that more communication collisions occurred in a high density traffic condition. 〈Figure 8〉 shows traffic information dissemination in the road network.

As shown in 〈Figure 8〉, the maximum distance of traffic information dissemination converged at



〈Figure 8〉 Information dissemination distance

8,000 meters, which is the maximum distance between the two locations farthest away on the road network. It shows that data reach convergence at around 50 seconds and 150 seconds with market penetration rates 10 % and 3 % respectively.

Ⅴ. CONCLUSION

Many studies have been conducted on VANETs since it is certainly a very promising technology. This study designed an integrated transportation and communication simulation framework for VANET applications. In this framework, the transportation and communication simulators embodying transportation and communications models were conjoined through our own methodologies. In order to examine our simulation framework designed in this study, a VANET-based traffic information system was applied. We obtained the result that communications performance decreases in congested traffic conditions due to communication collisions.

By designing an integrated transportation and communication simulation framework for VANET applications, this study has contributed to the research on VANETs. The system model that was designed through this study can include most applications in VANETs. It is expected to be used as a base to develop applications for VANETs.

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