PERFORMANCE MEASUREMENT OF CAR-TO-CAR AD-HOC NETWORKS IN THE REAL WORLD [1]

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Abstract: This paper shows the performance of car-to-car ad-hoc networks in the real world. Actually there are many irregular driving environments, so we have established some scenarios about inter-vehicle communications can happen in our actual life. And we have measured the transmission characteristics such as throughput, delay and packet loss rate of the system for each case. We have installed laptops with IEEE 802.11b wireless LAN and software for the ad-hoc network and packet transmission at each car. A test-bed has been implemented to support TCP/UDP packet transmission on wireless ad-hoc environment such as AODV (Ad-hoc On Demand Distance Vector) and OLSR (Optimized Link State Routing). Scenarios we have used in this experiment present which algorithm of ad-hoc routing and transmission is suitable in real driving environment and how performance metrics change according to different circumstances.

1 INTRODUCTION

For next generation vehicles, inter-vehicle communication is necessary. Car-to-car network is very dynamic from the point of view of mobility. Moreover, because the inter-vehicle networks must be wireless new telematics protocols and applications should be developed in a different manner compared with other wired network protocols. For this reason, many telematics companies try to develop the wireless network system that is efficient and stable.

We have researched about wireless network for next generation vehicles, too. As measuring performance metrics such as throughput, delay, and packet loss rate in the environment of dynamic car-to-car networks, we can get information as follows – first, what routing and transmission protocol is suitable for next generation vehicles and second, how performance metrics change according to different circumstances.

Many researches about our subject have been achieved by other researchers in past years, however there are few studies that measure performance metrics in the real world. Most of studies provide results by not actual measurement but virtual simulation. For the actual measurement, we have implemented test-bed with OSI 7 layer components using hardware and software.

First of all, as preparing laptop with 802.11b LAN, we could meet requirements for physical layer and link layer. And then we have used software to satisfy the conditions of network layer, transport layer, and application layer – session layer and presentation layer, too. Especially, we have installed software make nodes communicate by ad-hoc routing using the protocol such as AODV (PERKINS 1999) and OLSR (LAOUITI 2001). We have just used these programs to implement our test-bed (AODV for Windows and olsr-0.4.9). But we have developed a unique program, the throughput measurement program, used to send and receive packets and to estimate throughput of the network. The throughput measurement program is composed of two parts – packet sender and packet receiver, and

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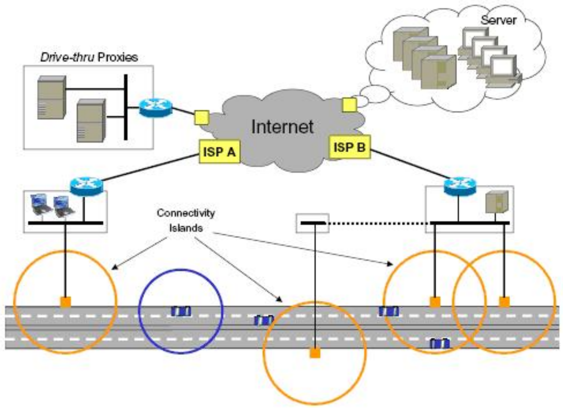


Figure 1 Architecture Overview of "Drive-thru" Internet

they have ability to adjust packet generate frequency, size of a packet, and transmission protocol like TCP or UDP.
The focus of our test-bed is to research the influence of natural driving conditions that can happen in the real world on the performance of car-to-car network. It is clear that the results of our experiments are very helpful to many developers who try to make more practical inter-vehicle application program or hardware.

The rest of this paper is organized as follows. Section 2 describe the related work and elaborates our contribution. In section 3, we discuss car-to-car communication and some limitations of previous works. Section 4 gives a brief description of the test-bed we have implemented, and scenarios we have used are shown in section 5. Section 6 displays results achieved by the experiment. Finally, in section 7, we conclude this paper confirming the suitability of WLAN-based access technologies for the vehicle network using Ad-hoc and pointing out next steps in our research.

2 RELATED WORK

There are many trials to get information about the performance of network in the car. Recently, research about the "Drive-thru" Architecture by University Bremen has been done (OTT 2004). This study is about usage of internet in the car through infrastructure like access points on the road. Figure 1 shows the architecture of "Drive-thru" internet. And the study named "IMPORTANT (Impact of Mobility on Performance of RouTing protocols for Adhoc NeTworks)" is also the research about car-network (BAI 2003).

However, the researches as stated above have limitations. In the study "Drive-thru" internet, there is of infrastructure for network between cars. Besides, cars must be in the range of access point installed on the road simultaneously to communicate each other. And because study named "IMORTANT" is by virtual simulation, the environment and result can be different from those of research in the real world.

3 BACKGROUND

Inter-vehicle communication

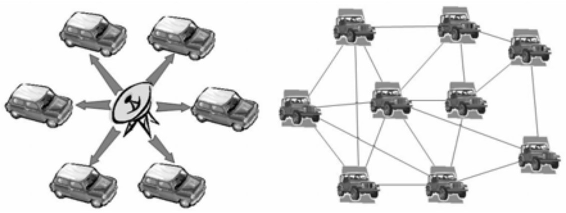


Figure 2 The current network using access point versus ad-hoc network without access point

Inter-vehicle communication can be used to facilitate applications improving driving safety and convenience. Potential uses of such applications are dynamic traffic routing, driver assistance and navigation, entertainment, co-operative driving, etc. The existing ad-hoc networking infrastructure can be leveraged and performance enhancement measures can be innovated for provisioning seamless inter-vehicle communication. As opposed to centralized service, and ad-hoc network is much better suited for vehicle-related applications that exchange data having local relevance. The existing 802.11 compliant devices can be used for providing wireless connectivity between moving vehicles. With the advent of 802.11a hardware, bandwidths of up to 54 Mbps have become realizable. However, Vehicular traffic scenarios pose greater challenges than the indoor WLAN applications, due to associated driving speeds, varying vehicular traffic patterns and driving environments. Performance measurements for 802.11 based wireless LANs have been done in indoor office and industrial environment. These results do not provide performance indication for the more challenging vehicular scenarios. Through the test we conduct, we investigate the performance achievable by an 802.11b-based WLAN in vehicular scenarios.
There are two types of inter-vehicle communication network using Ad-hoc [Figure 2]. One is Inter-

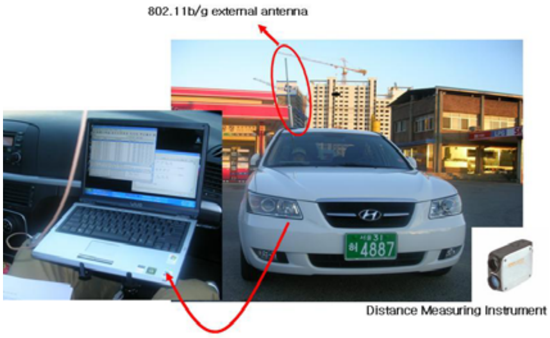


Figure 3 Hardware for test-bed

vehicle communication supported by AP (Access Point), which has been discussed. However, this approach is not cost-effective. It requires development of exclusive infrastructure. Access points may be provided at each street corner, co-located with traffic lights, or emergency phones, be placed in parking lots or in rest areas or may be co-located with gas stations or other shops in service areas. The other is inter-vehicle communication supported by ad-hoc routing algorithm (SINGH 2002). In this approach, it is important that each mobile node can detect other's position and routing path continuously.

In this paper, we focus on plain WLAN connectivity and transport protocol behaviour-and only briefly address implications on applications in the end. Our goal is to prove that WLAN technology is capable of enabling the vehicle network using ad-hoc in the first place and to document the communication characteristics we have observed with different measurement configurations using UDP and TCP as standard transport protocols. After simulation and measurement of transport protocol in ad-hoc mode, we describe the multi-hop mobile vehicular test-bed, our design decisions and driving experiences

4 TEST-BED IMPLEMENTATION

We have implemented a test-bed to measure the performance of wireless ad-hoc network and to get knowledge about the influences of driving environment upon the state of network. Because the test-bed has not only hardware but also software, we could implement the network system with entire components of OSI 7 layers.

4.1 Hardware

We have used the cars with laptop as shown in Figure 3. Because range that can be covered by 802.11b WLAN card we have used is only about 10m, we have equipped the PCMCIA card with an external antenna that has been placed at the right hand side of the vehicles. By the experiments for reference we have done before the planned measurement, we have already know that the range of PCMCIA card with an external antenna come close to about 100m. Owing to the external antenna, we could perform experiment without limitation on range of electric wave.

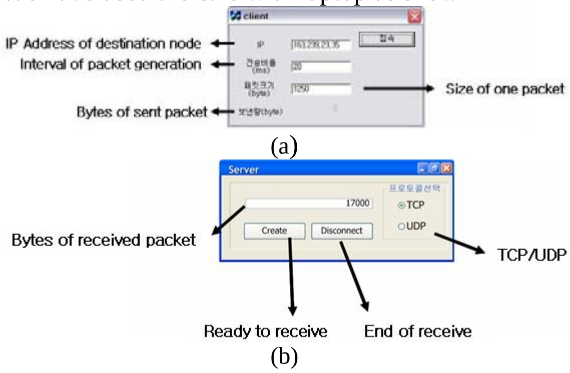


Figure 4 Software for test-bed (a) Packet Sender, (b) Packet Receiver

4.2 Software

We have installed software for wireless ad-hoc routing and sending and receiving packets. The program for ad-hoc is not developed by us, we have used only. However we have developed unique program for sending and receiving packets – the name of this program is Throughput Measurement Program.

As shown in Figure 4. The Throughput Measurement Program consists of two parts – Packet Sender and Packet Receiver. Figure 4(a) describes the Packet Sender and Figure 4(b) describes the Packet Receiver and their functions.

5 SCENARIOS

Most important point of this study is that experiments have been done under the driving environment in the real world. But there are lots of situations that can be happen in our real life. So we have established some scenarios treated as important. Basically, we have used 3 cars for these experiments, and cars can participate ad-hoc routing and network. These 3 cars run in order of source node (S) - relay node (R) - destination node (D) in a line, and source node sends packets to destination packet through TCP or UDP protocol.

5.1 Variable Distance and Velocity

Our first scenario is changing distance between cars and velocity of cars. Because the environment of network is wireless ad-hoc with limitation of range, distance and velocity are very important variables. We have changed the distance between each car from 30m to 70m, and velocity of each car from 30km/h to 70km/h

5.2 Overtaking

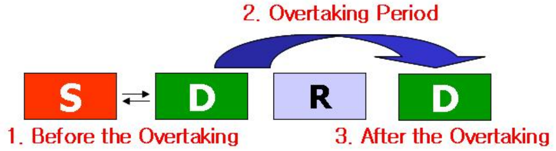


Figure 5 Scenario description about the overtaking

When many cars run on the road, a lot of situation can happen. Second case we have assumed is seen in Figure 5. At the beginning of experiment, a destination node (D) and a source node (S) run in a line. After a few seconds, node D overtake the car were running ahead of node D, and these 3 cars run in order for several seconds.

5.3 Breakaway and Re-entry

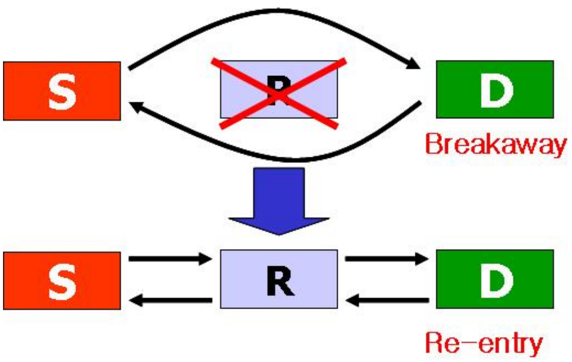


Figure 6 Scenario description about the breakaway and re-entry

Figure 6 shows third scenario of us. Like the preceding scenario, 3 cars run in order, S-R-D, as source sends packets to destination. After some time from the beginning of communication, an experimenter disables the LAN of node R. And after some time again, the experimenter turn the LAN of node R on. We set the interval between each state for 15 seconds.

5.4 The Relay Effect

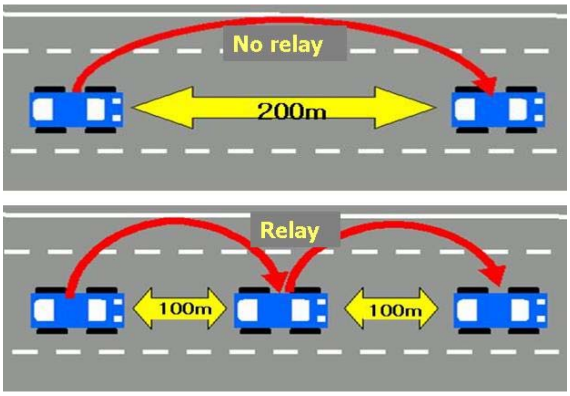


Figure 7 The relay effect experiment 1

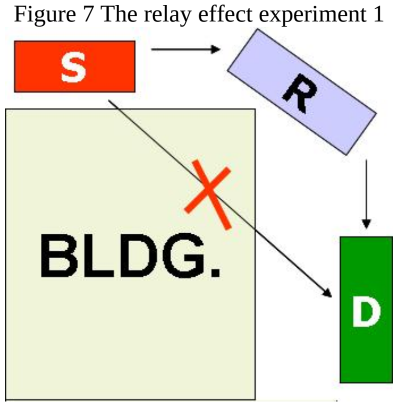


Figure 8 The relay effect experiment 2

This scenario has two parts of experiments. First, on one line of the road, we have compared with S-D communication and S-R-D communication. That is, performance of network with relay node and without relay node is compared. Figure 7 shows this scenario. In this case, we have kept all of the cars being stop, and set distance between each car 50m.

Secondarily, because we have used wireless LAN, we have chosen the scenario that can show influences of any obstacles such as walls, trees, and buildings. As shown in Figure 8, we set up the environment that the tall building block the electric wave between node S and node D. The main purpose of this example is to know how many influences relay node give to the wireless ad-hoc network.

6 MEASUREMENT

We have measured performances such as throughput, delay, packet loss rate in each case abovementioned.

For the transport protocol, TCP and UDP have be used, and AODV and OLSR have be used for the ad-hoc routing protocol. But because the case of OLSR displays more efficient performance than the case of AODV, we present the results gotten by OLSR only. Figure 9 shows the map the experiments were accomplished.

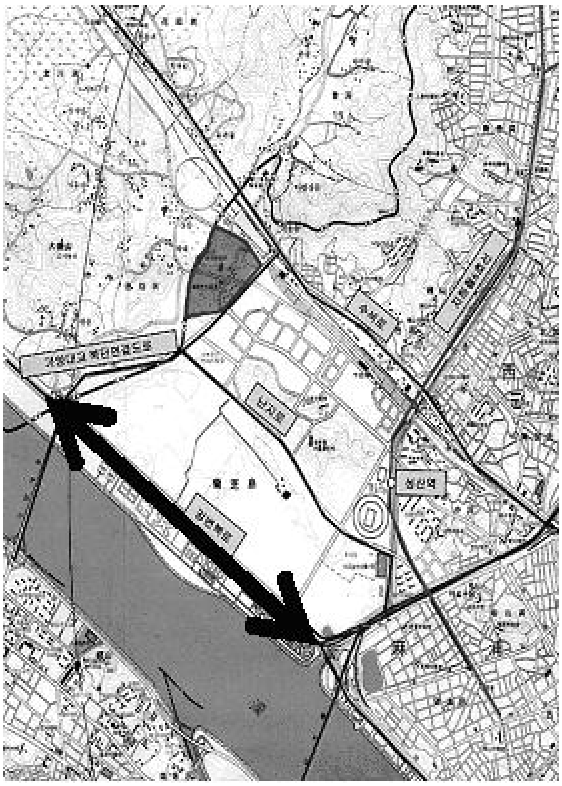
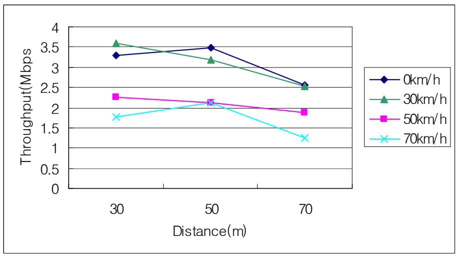
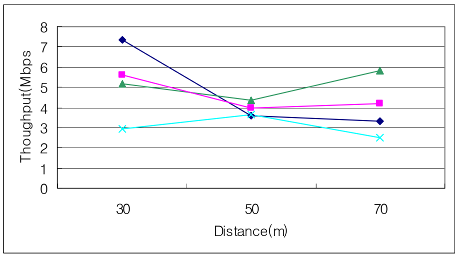


Figure 9 Map of the road the experiments were accomplished

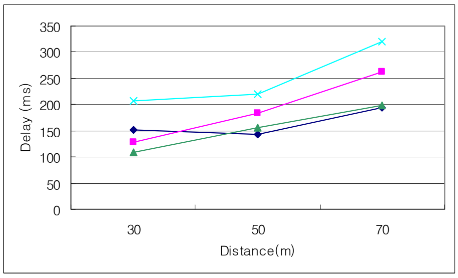
At the first, we have measured transmission characteristics such as throughput, delay and packet loss rate as change the distance between cars and velocity of cars. Figure 10 shows the results of the experiments related to distance and velocity. Figure 10(a) and Figure 10(b) display the result of throughput. According to the results, basically, the effect by velocity is more remarkable than by distance. The reason of these results is by characteristic of 802.11. 802.11 send RTS (Request to Send) and CTS (Clear to Send) before sending the main data to make the most suitable condition of data transmission. If the vehicles speed up, optimal conditions change, so, the difference of performance is notable. The phenomenon like this is seen in the result about the delay and the packet loss rate as shown in Figure 10(c) through Figure 10(e). By the way, as we can see through Figure 10, UDP make system more efficient than TCP. This is because UDP does not have the process of dividing the message into packets by one end point and re-assembling divided packets into a message by the other.



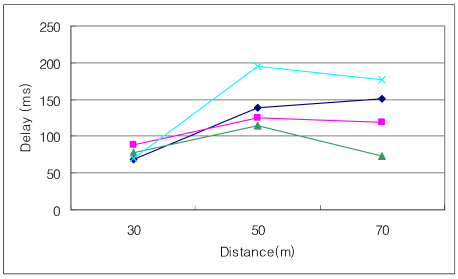
(a) Throughput - TCP



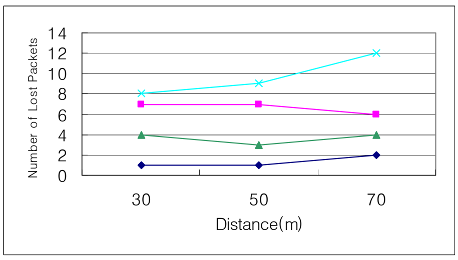
(b) Throughput - UDP



(c) Delay - TCP

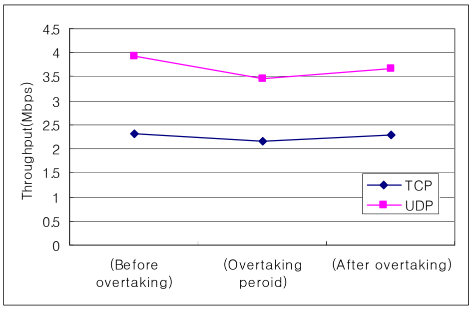


(d) Delay - UDP

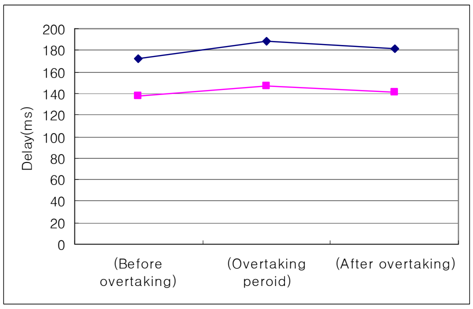


(e) Number of lost packets – UDP

Figure 10 Results of experiment for various distance and velocity

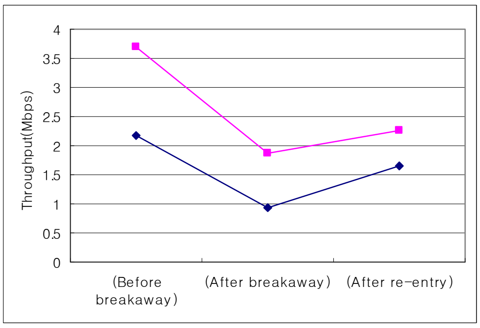


(a)

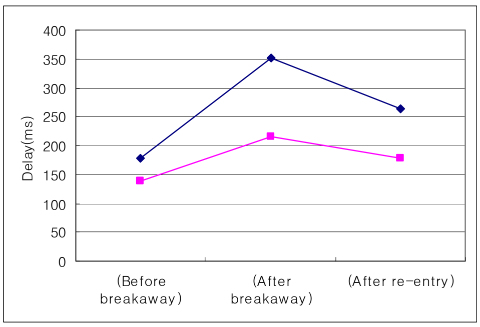


(b)

Figure 11 Results of experiments about the overtaking (a) Throughput, (b)Delay



(a)



(b)

Figure 12 Results of experiments about the breakaway and re-entry (a)Throughput, (b)Delay

Section 5.2 describes a scenario about the overtaking, and Figure 11 shows the results of this. We can discover that the performance in the overtaking period goes down compared with before and after the overtaking. This result is by the sudden increase in velocity of vehicle pass ahead. The influence of velocity is seen in a previous experiment and the result.

Figure 12 displays the results by the experiment performed according to our third scenario – breakaway and re-entry. In this case, efficiency of the network after the breakaway of relay node is worst. This is because this after-breakaway-period (before re-entry) is the stage each node reset the ad-hoc routing table and relay node does not exist. And after re-entry of the node broken away from the network, the system could not recover the performance of before-breakaway-period because the need of processing time to reset the routing table.

Lastly, experiments for get information about the role of the relay node produce results shown in Table 1 and Table 2. As we can show, when the relay node exists, the performance is more efficient. Especially, the case that a building disturbs the communication between source and destination node produces remarkable results, because the communication is impossible under the environment without the relay node. But if the relay node is placed at the edge of the building, the destination node can receive packets sent by the source node.

Transmission Protocol	TCP			UDP		
Relay	O	X	Rise Rate	O	X	Rise Rate
Throughput (Mbps)	1.2	1.36	13%	1.03	2.1	104%
Average Delay(ms)	214	187	14%	165	80	106%
Packet Loss Rate(%)				6	3	100%

Table 1 Results of experiments about the relay effect 1

Transmission Protocol	TCP	UDP
Throughput(Mbps)	2.84	3.45
Average Delay(ms)	216	145
Packet Loss Rate(%)	—	1

Table 2 Results of experiments about the relay effect 2

7 CONCLUSION

In this paper, we present a test-bed for wireless ad-hoc network for car-to-car communication. Due to the test-bed we have implemented, we could get results of the experiment designed to know the influences of driving environment on the performance of the inter-vehicle network. The core of this paper is that all of the experiments and measurements are accomplished in the real world, not in the virtual world by simulation.

Because of inter-vehicle ad-hoc network have to use the wireless LAN with limitation of bandwidth, more efficient routing and transmission protocols are necessary. So, our study to measure the performance of wireless network on the various environments has meaning. But there are more limitations yet. We would like to investigate into this issue further in the future and improve this limitation of MANET over vehicles.

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