

## eMANEMO: An Efficient Multi-path Selection Method for MANEMO Applying to Vehicle-to-Vehicle Communication Network

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In the recent years, In-vehicle Mobile Gateway with MANEMO technique has been introduced to answer the demand for optimizing the performance of Vehicle-to-Vehicle communication networks. However, though path quality parameters (e.g. available bandwidth, delay, error rate) have been used to evaluate the network performance, a method to calculate metric for MANEMO from these parameters has not been taken into consideration. This paper proposes eMANEMO method, which utilizes the path cost in order to enable the mobile gateway to choose the best route between MANET and NEMO. The efficiency of eMANEMO system was evaluated in the indoor experiments with traffic control tools. In addition, proper behavior of eMANEMO in the field test was also verified. The path quality based route switching execution in eMANEMO is proved to help with preventing the inefficient path switching, achieving the highest performance for V2V communication network.

### 1. Introduction

The Intelligent Transport Systems(ITS) (e.g. traffic jam avoidance, safety driving assistant, road weather management) have become an important part of the human life. In order to support the ITS services, many researchers have been working in the vehicular communication network field across the world.

Vehicular communications have two types : Vehicle-to-Vehicle(V2V) communication and Vehicle-to-Infrastructure(V2I) communication. In V2I communication, NEMO protocol (standardized by IETF)<sup>7)</sup> is introduced; meanwhile, V2V communication is well-known with MANET routing protocols, which support

the non-infrastructure communication for mobile nodes. In order to answer the demand for a new optimization technology for the V2V communication network, the In-vehicle Mobile Gateway with MANEMO technique has been introduced. MANEMO is designed to take the advantages of two independent technologies, MANET and NEMO, to optimize the network performance, and ensure the connection among vehicles.

In mobile network environments, the mobility of vehicles often causes the change in the network topology of MANEMO systems. Though MANET could provide shorter routes to vehicular destinations without depending on network infrastructures, recent studies have shown that the qualities of MANET paths are not always higher than the NEMO paths<sup>2)3)</sup>. As a result, the priority of the MANET paths in traditional MANEMO systems may cause inefficient path switching decisions. For that reason, a flexible path selection method based on path quality metrics is required to achieve the highest performance for V2V communications.

This paper first reviews in depth the in-vehicle mobile gateway systems to understand how it could be implemented to support the V2V communications. Then we propose eMANEMO method, which utilizes the path cost for the multi-path selection between MANET and NEMO. Next, the system design and implementation based on the eMANEMO will be detailed. And the evaluation of the system will be reported. Finally, the last section will provide the conclusion and future works of our research.

### 2. In-vehicle Mobile Gateway Systems

In in-vehicle mobile gateway systems, a set of mobile routers and home agents is used as a element of the vehicular communication network. Each mobile router acts as a gateway for all mobile nodes inside vehicles (Figure 1).

The home agent uses two interfaces: one to serve the home network, and the other to provide the connection to the internet. The mobile router has three interfaces: egress interface runs in NEMO mode, stores the home address, and being connected to the home agent, MANET Interface runs in ad-hoc mode, plays the role of connecting with other mobile routers by ad-hoc connection, and ingress interface connected to mobile nodes inside the vehicle.

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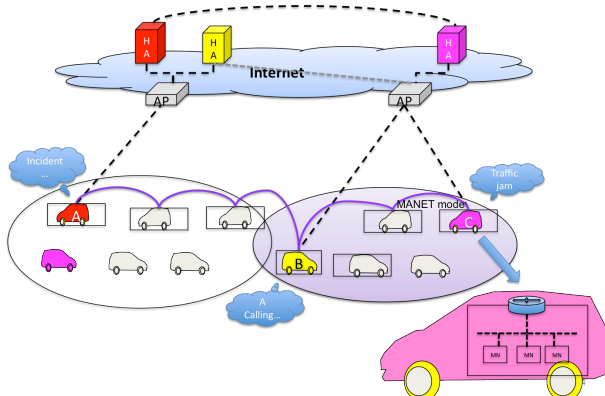


Fig. 1 In-vehicle Mobile Gateway based MANEMO system

In order to decide the path to forward packets for mobile networks, some path selection methods for the in-vehicle mobile gateway have been proposed. In 1), MANEMO gives priority to the MANET links without any multi-path selection. In 2), routing decision is mentioned with preference information and three parameters, available bandwidth, round trip time, and hop count. However, though reducing the packet loss rate is necessary in real-time vehicular network, it has not been considered in the existing system to make the switching decision. The system introduced in 3) was built with Multiple Routing Tables by using Route Policy Database (RPDB). It is based only on the flow characteristics and does not considering the fluctuating wireless path qualities. The MANET functions in 1), 2), and 3) are established by version 1 of the proactive Optimized Link State Routing (OLSR) protocol. Besides, to optimize NEMO network performance, the policy mentioned in 6) establishes the route discovery from the mobile router to its home agent by using the reactive Ad-hoc On Demand Vector (AODV) protocol. The bottleneck link problem was not considered in this system.

### 3. eMANEMO Method

To achieve the high performance for the real time V2V communication network, this paper proposes eMANEMO - a flexible multi-path selection method for the two-function in-vehicle mobile gateway systems. The key idea of eMANEMO

is based on the periodical multi-path information checking and the path cost evaluation based on quality metrics for the MANEMO path switching decision.

#### 3.1 Path Quality Metrics

When both of MANET and NEMO paths are available, eMANEMO starts to calculate the path cost periodically. In order to estimate the quality of each path, we choose three following parameters for the path cost calculation: available bandwidth, delay, and error rate.

- **Available Bandwidth (B)**

Unlike connections between routers in wired networks, the link qualities in mobile network always change. It seems impossible to use the interface bandwidth specification to estimate the quality of the link. In order to choose usable routes, routers should dynamically calculate the available bandwidth to make the switching decision.

- **Delay (D)**

Delay is an important performance metric of network system. In addition to determine the path cost, delay is used as a parameter in our calculation formula. It specifies how long it takes for a bit of data to travel across the network environment from the mobile router to another.

- **Error Rate (E)**

In high-speed mobile networks, packet retransmission causes wastes of system resources. Since reducing the error rate is extremely important in the real time V2V communications, it should be considered in the relationship with the available bandwidth and delay to estimate the cost for the path switching decision.

Packet pair technique is proposed to estimate the link quality parameters with a low network system overhead. A number of probe packets are sent to measure all of available bandwidth, delay and error rate at once.

$$B = \frac{L}{\Delta_{out}} \quad (1)$$

$$D_{(t)} = (1 - \alpha) \times D_{(t-1)} + \alpha \times D_{sample} \quad (2)$$

$$E = \frac{N_{lost\_pkt}}{N_{total}} \times 100 \quad (3)$$

The available bandwidth B is estimated by the division of the sending packet

size  $L$  and the time out spacing of packet pairs  $\Delta_{out}$ . Delay  $D$  is the estimated round trip time of packets. And error rate  $E$  is calculated by the rate of packet losses occur.

### 3.2 Switching Decision

As mentioned in the previous section, current studies have shown that switching from the NEMO path to the MANET link is a useful way to reduce the latency of network systems, providing high throughput routes to vehicles bypass the home agents. However, if the distance between the vehicles are not close enough to make the stability of MANET link higher than the NEMO link, the inefficient switching will occur. Therefore, when MANET links become up, there is a need to measure and calculate the cost of paths to decide which is the best one for transferring data.

In order to achieve the highest performance of V2V communication, the path cost is calculated in inverse proportion to the available bandwidth, and direct proportion to the delay and error rate of path. The best path will be the one which provides the lowest cost for the data transfer.

Here is the formula that we use to calculate path costs:

$$C = f(B, D, E) = \frac{w_b}{B} + w_d \times D + w_e \times E \quad (4)$$

$B$ ,  $D$ ,  $E$  represent the value of bandwidth, delay, and error rate respectively;  $w_b, w_d, w_e$  are weight vectors of parameters.

$$f(n) = \begin{cases} \text{MANET, if } C_{manet} < C_{nemo} \\ \text{NEMO, if } C_{manet} \geq C_{nemo} \end{cases} \quad (5)$$

If the cost of the OLSR path becomes smaller than the NEMO's, the OLSR path is chosen for the data transmission. On the contrary, if the cost of the MANET link becomes greater than the NEMO paths cost, the NEMO path will be chosen. eMANEMO system assumes that the Internet default gateway is set on the NEMO route if NEMO link is available.

## 4. eMANEMO System Design and Implementation

In this system, each mobile router acts as a mobile gateway of the in-vehicle attached network. Figure 1 shows the design of eMANEMO system.

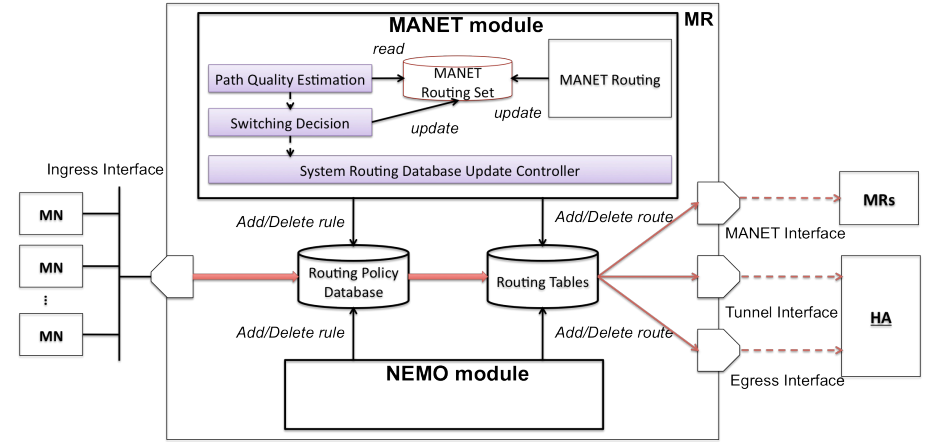


Fig. 2 Overview of eMANEMO system

There are two main modules in eMANEMO system, the NEMO module and MANET module. These modules work in parallel to periodically update the system routing database. The NEMO module provides routes to the home agent of the mobile routers. The MANET module provides the shortcut routes to the other mobile routers via the ad-hoc connections. In order to serve a fast routing performance the route to all destinations within the mobile ad-hoc network should be known and maintained before use in data transmission.

The MANET module is divided into four submodules: the MANET routing submodule, the path quality estimation submodule, the switching decision submodule, and the system routing database update controller submodule. In addition to the ad-hoc routing information, the MANET routing submodule also exchanges the NEMO interface address. Thus, the MRs can reach all of the destination networks via two ways, MANET and NEMO.

The path quality estimation submodule periodically checks the routing database. If the ad-hoc link becomes up, the system establishes the path quality estimation and calculate the multi-path costs. Based on the results of path cost computing, the switching decision submodule decides the best one to use in data transfer. After that, the system routing database update controller submodule

updates routing information to the system database.

The mobile router has three output interfaces: the tunnel interface, the egress interface and the ad-hoc interface. Packets from mobile nodes which came through the ingress interface will be processed by the mobile router, and then the router will forward the packets to the correct interface to the destination.

The system was implemented on GNU/Linux platform with programming language C/C++. UMIP, USAGI-patched Mobile IPv6(Nautilus6 working group) for Linux, was used to set up the NEMO module. The MANET module was implemented as a modification of nOLSRv2 daemon of Niigata University group.

## 5. Experimental Results

In this section, we describe the evaluation of eMANEMO in the indoor experiments and the operation verification in the real field test.

### 5.1 Overview of Test Environment Setup

Figure 3 shows the setup of the demonstration system. Home agents connected to the Internet via a router of the Internet Research Laboratory by their Ethernet interfaces. In this evaluation, the home link was not in use, so the dummy interfaces were configured and set up in the home agents for the home link advertisements.

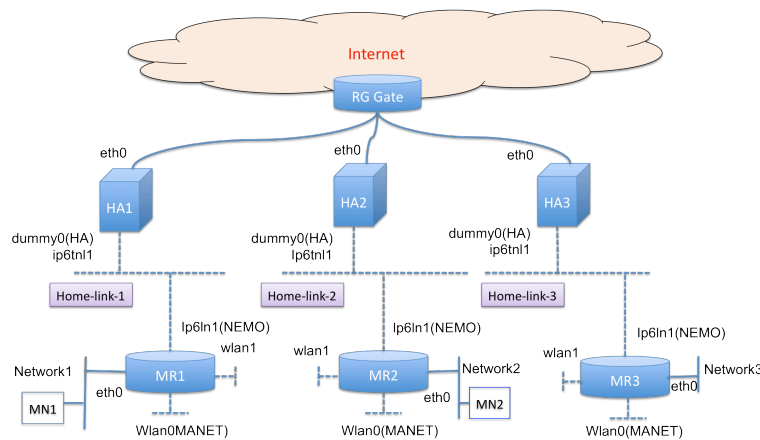


Fig. 3 Demonstration System Setup

Evaluation tests use three home agents(HAs), three mobile routers(MRs) and two mobile network nodes(MNNs). MRs provide the global internet connectivities to the ingress mobile network through their Ethernet interfaces. They registered the care of addresses on the wireless network interfaces, connected to the access point of the laboratory. Then, they sent binding updates to the HAs to create network tunnels to the home agents by the NEMO interface(*wlan1*). All the packets from the mobile network nodes and binding update messages would be first forwarded to their home agents, then be sent to the destinations through these tunnels. The mobile routers are able to connect to others through the MANET interfaces - *wlan0* interfaces. Then the packets would be directly forwarded to the destination mobile network via MANETs.

Table 1 Nodes Information

Nodes	CPU	Wireless Devices
MRs	Intel Core i5-520M 2.4GHz	(wlan0)Intel Centrino IEEE 802.11abgn (wlan1)AtermWL54AG IEEE 802.11abgn
HA1	Intel Core 2 Duo 2.4 GHz	
HA2	Intel Core 2 Duo 1.86 GHz	
HA3	Intel Pentium 1.70 GHz	
MN1	Intel Core 2 Duo 2.4GHz	
MN2	Intel Core i5-520M 2.4GHz	

The hardware specification of nodes is shown in Table 1. All of these are installed the network mobility supported Linux Ubuntu 10.04 Kernel 2.6.27.

In the indoor experiments, the efficiency of eMANEMO system was evaluated in various network situations. TC and Ipv6tables tools were used to emulate the increase and decrease of the distance between vehicles.(Figure 4)

Below are the measurements and the comparisons that will be done:

- The measurement of throughput, round trip time, packet loss rate of the traffic between MNNs.
- The comparison of the throughput, round trip time, and packet loss rate measurement results with the two-function gateway MANEMO system(without the path cost based routing decision), and stand alone NEMO system.
- Measure the convergence time. Since mobile routers are independently establishing the path quality estimation and the switching decision, the switching

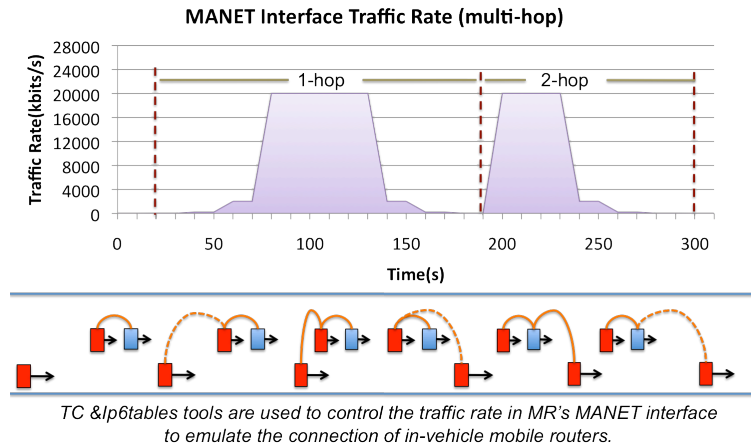


Fig. 4 Emulation of vehicles' movement and ad-hoc connection state

times of each mobile router in the same link are different. The measurement and comparison of mobile routers' switching time will verify the convergence time of eMANEMO system.

The operation of eMANEMO system will also be verified in the field test.

## 5.2 Results

### 5.2.1 Evaluation 1: One-hop Ad-hoc Connection

Figure 5 shows the throughput comparison among NEMO, the MANEMO system without the path cost based routing decision and eMANEMO system.

From  $t = 0$  to  $t = 19$ s, the traffic rate of MANET interface of MR1 was configured as disconnected. Therefore, all of three systems used the NEMO route for their data transfer. When  $t = 20$ s, the MANET interface of MR1 was brought up. The MANEMO system without the multi-path selection immediately added the available routes to the routing table, and it caused the decrease of link throughput and the increase of the delay. Setting the traffic rate of the MANET interface to 20kbits/s has made the RTT increase of 5,738 milliseconds (approximately 5.7 seconds) with 7 packet losses. Different from that, after receiving the routing information from its MANET neighbor, eMANEMO calculated and compared the path costs to the destination (MANET and NEMO) and decided whether to

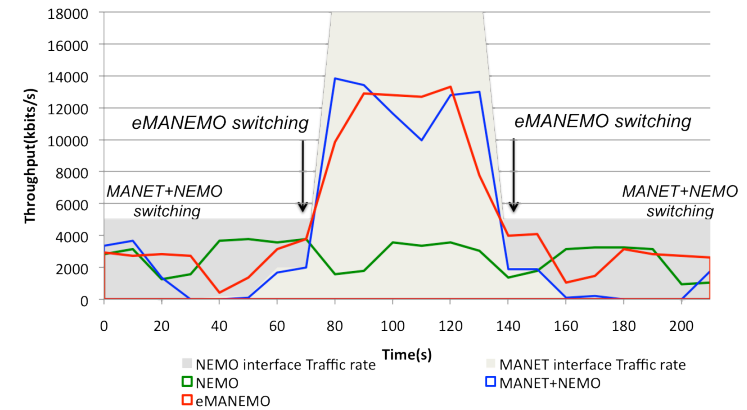


Fig. 5 Throughput between MNNs in case 1-hop ad-hoc connection is available

use this route for data transmission or not. Thus, the router continued to use the NEMO route instead of adding the MANET to the routing table.

At  $t = 40$ s, the traffic rate was increased to 200kbits/s, and then to 2,000kbits/s at  $t = 60$ s. The delay of MANET link was reduced to 2.6s. However, the throughput of the MANET link was still lower than the NEMO link.

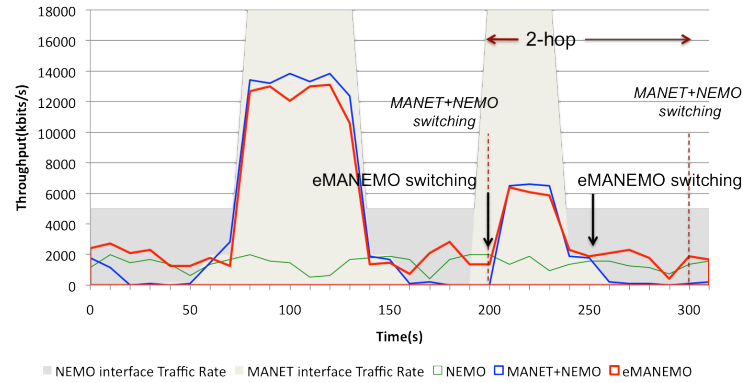
After 23s, at  $t = 83$ s, when the traffic rate was increased to 10 times, the cost of the MANET route became lower than the NEMO one. MR1 added the MANET route to the system routing database. One second later, MR2 switched its connection from NEMO to MANET. The throughput on the link between each end point was increased from 3,775kbits/s to 9,857 kbits/s, and then to the maximum value 13,317 kbits/s. The RTT was decreased from 75.6s to 20.2s after switching.

At  $t = 140$ s, the traffic rate of MANET interface was limited to 2,000kbit/s again. The MANET link bandwidth decreased to nearly 2,000kbits/s, and the RTT was increased from 19.4s to 45s. Since the cost of the MANET path has become higher than the NEMO, eMANEMO stopped investigating MANET route and smoothly switched back to the stable NEMO.

### 5.2.2 Evaluation 2: Multi-hop Ad-hoc Connection

Figure 6 presents the performance of the system in the comparison with other

methods when the MANET connectivities of the MRs were changed from 1-hop ad-hoc connections to 2-hop ad-hoc connections. In this evaluation, from  $t = 0$  to  $t = 200$ ms, the performance of the network link between MNNs was the same with the case two mobile routers are near to their home agents. At time  $t = 200$ s, the MANET link between MR1 and MR2 changed from 1-hop to 2-hops connection. Because the quality of 2-hop ad-hoc path was set highly, eMANEMO switching from the NEMO path to the MANET path after receiving the routing information from neighbors. At  $t = 260$ s, while the MANEMO system without path cost execution continued utilizing the worse MANET link, eMANEMO switched back to the NEMO link to prevent the increase of the network system overload.



**Fig. 6** Throughput between MNNs in case multihop ad-hoc connection is available

Despite of the network overhead, which was caused by the path quality estimation, has made the maximum throughput of eMANEMO lower than the traditional MANEMO system, the average values of parameters in multi-hop ad-hoc connection (Table 2) have proved that eMANEMO had entirely improved the performance for V2V data transmission.

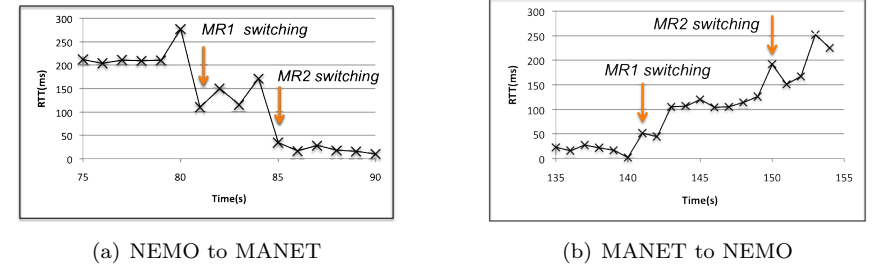
### 5.2.3 Evaluation 3: Convergence Time

Figure 7 shows the convergence time results. Experimental results showed that convergence time was always in the range between 0 to the path quality estimation interval. The default value of the interval was 7 seconds. There was

**Table 2** Average value of parameters in case multi-hop ad-hoc connection is available

Method	Throughput	Round Trip Time	Packet Loss Rate
NEMO	2080 kbits/s	119 ms	5.31 % (17/320)
MANET+NEMO	3325 kbits/s	918 ms	10.62 % (34/320)
eMANEMO	3784 kbits/s	75 ms	8.75 % (28/320)

no packet loss occurred in almost all switching events.



**Fig. 7** Convergence Time

### 5.2.4 Operation Verification in Field Test

The operation of eMANEMO system was verified in the field test around the course of Shonan Fujisawa Campus, Keio University. We set up two access points to provide wireless network for the experiment. (Figure 8)

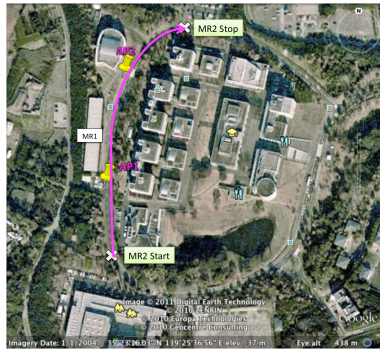
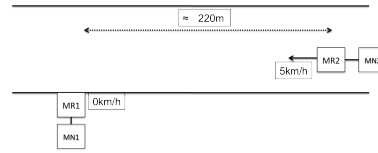
We used two mobile routers, MR1 and MR2, and their attached mobile network nodes, MNN1 and MNN2. MR1 is set to stop at  $v_1 = 0$  km/h. MR2 ran around the course with the speed  $v_2 = 5$  km/h. The distance of two MRs at the start of the evaluation was  $d = 220$  m. (Figure 9)

Figure 10 shows the switching manner of eMANEMO when MR2 were moving close and far to MR1.

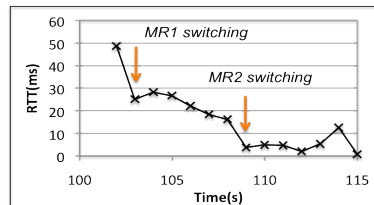
At time  $t = 101$ s, when the cost of the MANET link became lower than the NEMO link, MR1 established the route switching, which made the RTT decrease from 48.1ms to 25.1ms (MR2 were moving close to MR1). 7 seconds after, MR2 also switched from the NEMO to MANET to reduce the RTT from 16.7ms to 3.71ms.

At time  $t = 137$ s, when the cost of the MANET link became higher than the

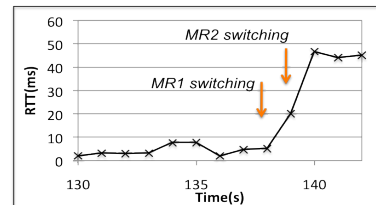


**Fig. 8** Wireless Network Environment Setup**Fig. 9** Movement of MRs

NEMO link(MR2 were moving far to MR1), MR1 established the path switching from MANET to NEMO. One second after, MR2 also made the path switching decision.



(a) NEMO to MANET



(b) MANET to NEMO

**Fig. 10** Switching performance in real field test

### 5.3 Consideration

This section described the testing environment and the evaluation results of the eMANEMO system in different network situations. The accuracy and effectiveness of the path cost based switching decision has been evaluated. It was proved that eMANEMO could help the network system prevent the continuous usage of worse link when multi-path is available, and achieve the high performance for the network system. Experimental results have shown that eMANEMO system can

achieve 7.7% throughput improvement, reduce 85.89% delay and 31.69% packet loss rate. The convergence time for both of MRs during the path switching decision was verified in the range from 0 to the interval of path quality estimation. The operation of eMANEMO was also confirmed in the field test.

In addition, there were some points to be noted during the experiments. First, the adjustment of the size and the number of sending packet pairs is very important in estimating the path qualities. When the number of nodes increases, the path quality estimation processes may cause overhead for the network system. Second, the noise and location of access points sometimes caused inaccurate results. The real field test should be prepared more carefully under consideration of the affect of external factors.

## 6. Conclusion and Future Works

This research proposed eMANEMO multi-path selection method based on the path cost calculation for MANEMO applied to V2V communication network. Experimental results have shown that the path quality based switching execution in eMANEMO helped to prevent inefficient route switching, and achieving the highest performance for the V2V communication network.

In the future, we are focusing on the works as follows. First, improving the accuracy of path quality estimation under consideration for network overhead is required to make more efficient path switching decision. Second, in this system, eMANEMO method was implemented as a part of MANET functionality. We desire a platform that can handle routing information from both of MANET and NEMO modules. Third, in the future, evaluations in real field in consideration of moving speed of vehicles and external factors should be done to ensure the improvement of eMANEMO to current MANEMO systems.

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