Performance Evaluation of Vehicle-mounted Mobile Relay in Next Generation Cellular Networks

Keunhang Heo[1], Hyunsik Kang[2], Un-Chul Moon[3] and JungRyun Lee[4]
School of Computer Science and Engineering, ChungAng University,Seoul, Korea
[1,2][e-mail: {hkh0517, hyunsik }@wm.cau.ac.kr]
[3,4][e-mail: {ucmoon, jrlee}@cau.ac.kr]
*Corresponding author: JungRyun Lee

Received January 18, 2011; revised April 2, 2011; accepted May 24, 2011; published May 31, 2011

Abstract

Compared to nomadic and fixed relay stations, vehicle-mounted mobile relay stations show different characteristics caused by the time-variant topology, due to their mobility. Especially, a relay mounted in a vehicle is differentiated from nomadic or fixed relay by the restricted distance between the relay and associated mobile station and the variable density of relay deployment in a cell. In this paper, we identify the characteristics of vehicle-mounted mobile relay stations and provide some parameters that highly influence the performance of vehicle-mounted relay. Through simulation, we measure the effect of relay density, zone ratio, relay transmission power, and frame transmission mode on the performance of vehicle-mounted relay. The results show that the performance of vehicle-mounted relay is highly susceptible to the above vehicle-mounted relay-specific parameters.

Keywords: Mobile relay, cellular network, interference, mobile office.

This research was supported by the KCC(Korea Communications Commission), Korea, under the R&D program supervised by the KCA(Korea Communications Agency) (KCA-2011-09913-04002) and Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by Korea government Ministry of Knowledge Economy (20104010100570)

DOI: 10.3837/tiis.2011.05.001

1. Introduction

Recently, due to the increase in the number of mobile stations (MSs) equipped with communication technology, we entered the era of ubiquitous computing. Meanwhile, mobile communication technology, such as LTE/LTE-Advanced or WiBRO Evolution, has reached the stage of commercialization. These next generation communication technologies make it possible for MSs to break away from their spatial limitation and for the user to use high quality communication services *on the move*. As a result, the demand for ubiquitous communication services in the various vehicles is expected to dramatically increase, and as a result, vehicles will be equipped with an infotainment space that can make use of communication networks providing information, entertainment, and internet or act as a mobile office.

The telematics service is an example of vehicle-mounted communication systems. Since most telematics services are built on the basis of wireless cellular technologies, the performance of the current telematics system is equal to or less than that of wireless cellular network users. So, telematics service users experience the deterioration of QoS when they are located on the cell edge area or on the move. On the other hand, we can expect more enhanced cell edge capabilities by using a vehicle-mounted relay station (RS) in that smart and multiple antenna technologies can be more easily applied to vehicles than MSs, which is not feasible to MSs because of their limited space. In fact, studies on vehicle-mounted MIMO and RF technologies have been recently performed [1][2]. In this paper, our research is focused on the performance of in-vehicle users being relayed by vehicle-mounted RS.

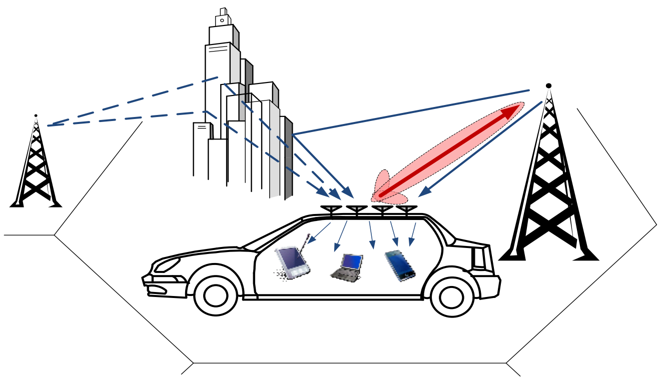

Fig. 1. Concept of Mobile Office Using Vehicle-mounted Mobile Relay Station

In a survey paper related to relays [3], the need for vehicle-mounted mobile relays is mentioned and an efficient resource allocation scheme is proposed for nomadic relay stations. In [4], a general overview of multi-hop relaying and an analysis of system performance is given. In [5], a performance analysis is given depending on the concurrency between the direct path and relay path. Also, an efficient path selection scheme is proposed for MSs in the cell. In [6], the performance variation caused by the location of relay station is emphasized. In [7], the authors introduced inter-relay interference and showed the simulation results using different frequency reuse factors (FRFs) in order to analyze the effect on the inter-relay interference. In addition, a path selection scheme is proposed that is superior to the one in [5].

Although a considerable amount of research has been conducted on relays, all of these studies assume that nomadic or fixed relays are employed. A comparison between nomadic and fixed relay stations shows that mobile or vehicle-mounted mobile relay stations have specific characteristics caused by the time-variant topology due to their mobility. In addition, the distance between the mobile relay and associated MS is restricted by the vehicle size and is relatively very short compared to fixed or nomadic relays. Hence, RS-MS link status in vehicle-mounted mobile relay is supposed to be more stable than that in nomadic or fixed relays. Instead, we need to pay attention to indigenous characteristic of vehicle-mounted mobile relay system such as frequent changes of inter-RS interferences caused by mobility of RSs. For this reason, the existing research results cannot be directly applied to vehicle-mounted mobile relay stations. In this paper, we identify the characteristics of vehicle-mounted mobile relay stations and derive the system parameters that influence the performance of in-vehicle users. And we analyze the system performance as a function of these system parameters.

The rest of this paper is organized as follows. In section 2, the system parameters affecting the characteristics of vehicle-mounted mobile relay stations are defined. Section 3 describes the system model. Section 4 presents the simulation environment and performance evaluation methods used in this study. Section 5 explains the simulation results, and we conclude this paper in Section 6.

2. System Parameters of Vehicle-mounted Mobile Relay Stations

In this session, we enumerate and explain some system parameters that affect the system performance of vehicle-mounted mobile relay stations in the context of OFDMA/TDD based IEEE 802.16m [9].

2.1. RS Density

The vehicle-mounted mobile relay has different characteristics from that of fixed or nomadic relays because of its time-variant topology. According to the results obtained so far, the number of fixed or nomadic relay stations in a cell should be properly controlled in order to maximize the cell capacity. However, in the case that vehicle-mounted mobile relays are employed in a cell, the number of these relays is usually uncontrollable, so its network topology cannot be managed either. When a number of vehicles are gathered in a confined location due to external reasons such as traffic jam or waiting at a red light, the capacity of RS is affected by interference from neighbor relays. Therefore, the density of the RSs is one of the important parameters influencing the capacity of the cell where vehicle-mounted relays are employed. In this paper, we define RS density as the number of RSs per square meter (RS/m^2) and used it to quantify the density of the vehicle-mounted relays.

2.2. Zone Ratio

While the channel status between the vehicle-mounted mobile relay and base station changes frequently because of its high mobility, the channel status between the RS and MS is quite stable. (Notice that the distance from relay to the users inside vehicle is limited to the size of the vehicle.) It implies that the throughput bottle-neck phenomenon between the BS and MS in a vehicle does not arise from the RS-MS link, but from the BS-RS link. Therefore, increasing the length of BS-RS transmission zone can improve the cell capacity. On the other hand, if the BS-RS transmission zone is too long, then there is not enough bandwidth to transmit data between the RS and MS, which again acts as a bottleneck between the BS and MS. This gives rise to the necessity of studying the appropriate ratio between the lengths of BS-RS and RS-MS transmission zones.

In each frame, the downlink region is divided into T_{BS} and T_{RS}, where T_{BS} and T_{RS} mean the lengths of BS-RS and RS-MS transmission zones, respectively. We define BR_zone_ratio as the occupation ratio of the BS-RS transmission zone to that of all resources. The RM_zone_ratio is similarly defined as the occupation ratio of RS-MS transmission zone to that of all of resources. So, the BR_zone_ratio and RM_zone_ratio are described simply as follows.

$$BR\_zone\_ratio = \frac{T_{BS}}{T_{BS} + T_{RS}} \tag{1}$$

$$RM\_zone\_ratio = \frac{T_{RS}}{T_{BS} + T_{RS}} \tag{2}$$

2.3. RS Transmission power

The transmission power of vehicle-mounted mobile relay should be high enough to guarantee the QoS of the user inside the car. On the other hand, considering the mobility of a vehicle-mounted relay, high RS transmission power may increase the inter-relay interference that causes poor performance in cell capacity. So, it is necessary to analyze the influence of the transmission power of the vehicle-mounted relay on interference in the BS-RS and RS-MS links and the service quality of the user inside the car.

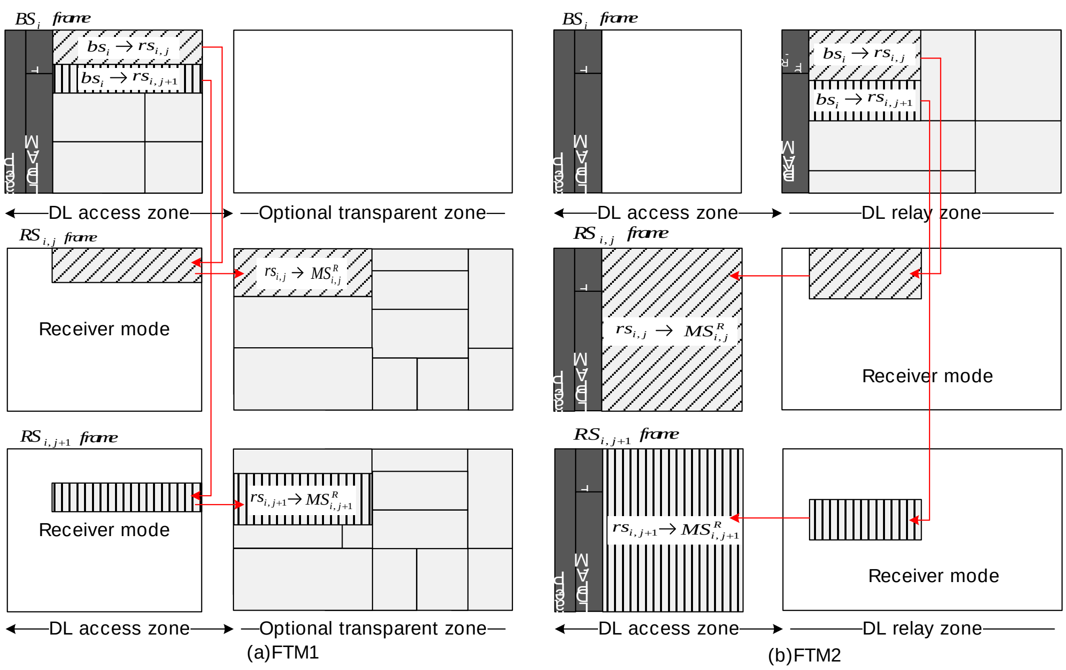

Fig. 2. Schematic illustration of transparent **(a)** and nontransparent modes **(b)**. Symbols used are described in **Table 1**.

2.4. Frame Transmission Mode

Relay supports two kinds of frame transmission mode (FTM), transparent mode and nontransparent mode [9]. **Fig. 2** describes the operational procedures of transparent and nontransparent modes. Notice that there is no inter-RS interference (interference among RS-MS links) for transparent mode. It is known that transparent and nontransparent modes are useful to overcome the problem of coverage holes and to extend the cell coverage, respectively [10]. However, this result assumes fixed or nomadic relay deployment, so it is not applicable to the study of vehicle-mounted mobile relay. Therefore, we evaluate the performances of each frame transmission mode in the context of vehicle-mounted mobile relay. Hereafter, we refer the transparent and nontransparent modes as FTM1 and FTM2, respectively, in the rest of the paper.

3. System Model

3.1. Network Definition

We define some network parameters used for evaluating the performance of vehicle-mounted mobile relay system as follows.

Table. 1. Network Parameters

SYMBOL	EXPLANATION
d_{A-B}	Distance between A and B.
M	The number of RS associated with each RS.
O	The number of MS associated with each BS.
bs_i	*i*-th BS ($1 \le i \le 18$).
$rs_{i,j}$	*j*-th RS associated with *i*-th BS ($1 \le j \le M$).
$ms_{i,j}^R$	The MS associated with *j*-th RS of *i*-th BS via relay link.
$ms_{i,l}^D$	*l*-th MS directly associated with *i*-th BS (no relay link) ($1 \le l \le O$).
pow_{Tx}^A	Transmission power of entity *A* (*A* can be a RS or an MS).
p_A^{sig}	Received signal power of entity *A*.
$p_A^{\text{int}-servR}$	Received interference power of entity *A* from RS located in serving BS.
$p_A^{\text{int}-nbrR}$	Received interference power of entity *A* from RS located in neighbor BS.
$p_A^{\text{int}-D}$	Received interference power of entity *A* from BSs.
$p_A^{\text{int}-R}$	Total inter-relay interference of entity *A*.
SIR_A	*SIR* of entities *A*.
$d\_BR_{i,j}$	The amount of data sent to *j*-th RS from *i*-th BS.
$d\_RM_{i,j}$	The amount of data sent to MS from *j*-th RS in *i*-th BS
$d\_BM_{i,j}^R$	The amount of data sent to MS through *j*-th RS in *i*-th BS
$d\_BM_{i,j}^D$	The amount of data sent to *j*-th MS from *i*-th BS via direct link.

d_B_i	Total throughput of i-th BS.

3.2. Networks Assumption

In this paper, we make some assumptions to properly focus on the performance evaluation of vehicle-mounted mobile relay systems.

i) There is no inter-RS handover; that is to say, the user inside a car does not move its air connection to the neighbor RS.

ii) There is only one MS associated to each RS.

iii) The transmission power of vehicle-mounted mobile relay is uniformly distributed across whole frequency bands.

3.3. SIR Calculation and MCS level Selection

There are two interference scenarios that may cause QoS deterioration to the user inside a vehicle. One is the interference between BS-MS link and RS-MS links in FTM1, and the other is interference among the RS-MS links in FTM2. We apply a network structure with 19 cells and the simple path-loss model defined in [15].

The signal and interference power of $rs_{i,j}$ are calculated as follows.

$$p^{sig}_{rs_{i,j}} = 10^{pow^{BS}_{Tx} - (130.19+37*\log(d_{bs_i - rs_{i,j}}))} \tag{3}$$

$$p^{\text{int}}_{rs_{i,j}} = \sum_{p=0,\, p\neq i}^{18} 10^{\left(pow^{BS}_{Tx} - (130.19+37*\log(d_{bs_p - rs_{i,j}}))\right)/10} \tag{4}$$

$$SIR_{rs_{i,j}} = 10\log\left(\frac{p^{sig}_{rs_{i,j}}}{p^{\text{inter}}_{rs_{i,j}}}\right) \tag{5}$$

The signal power of $ms^R_{i,j}$ connected to $rs_{i,j}$ is given by

$$p^{sig}_{ms^R_{i,j}} = 10^{(pow^{RS}_{Tx} - (130.19+37*\log(d_{rs_{i,j} - ms^R_{i,j}})))/10}. \tag{6}$$

In the case of FTM2, there are two sources of interference affecting $ms^R_{i,j}$. When the BSs transmit data to the MSs connected to the direct path, the RS-MS link can suffer from interference, which is calculated as follow.

$$p^{\text{int}-D}_{ms^R_{i,j}} = \sum_{p=0}^{18} 10^{(pow^{BS_p}_{Tx} - (130.19+37*\log(d_{bs_p - ms^R_{i,j}})))/10} \tag{7}$$

Also, we must consider the inter-relay interference from inside and outside of the cell.

$$p^{\text{int}-servR}_{ms^R_{i,j}} = \sum_{p=0,\, p\neq j}^{M} 10^{(pow^{RS}_{Tx} - (130.19+37*\log(d_{rs_{i,p} - ms^R_{i,j}})))/10} \tag{8-a}$$

$$p^{\text{int}-nbrR}_{ms^R_{i,j}} = \sum_{p=0,\, p\neq i}^{18} \sum_{q=0}^{M} 10^{(pow^{RS}_{Tx} - (130.19+37*\log(d_{rs_{p,q} - ms^R_{i,j}})))/10} \tag{8-b}$$

The total inter-relay interference of $ms_{i,j}$ is given by

$$p^{\text{int}-R}_{ms^R_{i,j}} = p^{\text{int}-servR}_{ms^R_{i,j}} + p^{\text{int}-nbrR}_{ms^R_{i,j}}. \tag{8}$$

In this case, SIR between RS and MS is calculated as

$$SIR_{ms_{i,j}^R} = 10\log\left(\frac{p_{ms_{i,j}^R}^{sig}}{p_{ms_{i,j}^R}^{inter-D} + p_{ms_{i,j}^R}^{inter-R}}\right). \tag{9}$$

The signals of $ms_{i,l}^D$ coming from the serving BS are expressed as

$$p_{ms_{i,l}^D}^{sig} = 10^{(pow_{Tx}^{BS} - (130.19 + 37*\log(d_{BS_i - ms_{i,l}^D})))/10}. \tag{10}$$

The interference power from the neighbor BSs is given by

$$p_{ms_{i,l}^D}^{int-D} = \sum_{p=0, p\neq i}^{18} 10^{(pow_{Tx}^{BS} - (130.19 + 37*\log(d_{bs_p - ms_{i,l}^D})))/10}. \tag{11}$$

Also, the interference power caused by each relay is expressed as

$$p_{ms_{i,l}^D}^{int-R} = \sum_{p=0}^{18}\sum_{q=0}^{M} 10^{(pow_{Tx}^{RS} - (130.19 + 37*\log(d_{rs_{p,q} - ms_{i,l}^D})))/10}. \tag{12}$$

So, SIR between the BS and direct path MS link is described by

$$SIR_{ms_{i,l}^D} = 10\log\left(\frac{p_{ms_{i,l}^D}^{sig}}{p_{ms_{i,l}^D}^{int-D} + p_{ms_{i,l}^D}^{int-R}}\right). \tag{13}$$

SIR is calculated using the same formula as that shown above, and the selection of MCS level is based on **Table 2** [7].

Table 2. MCS Level Table

MCS Level	1	2	3	4	5	6	7	8	9	10
Modulation	QPSK					16 QAM,			64 QAM	
Coding rate	1/12	1/6	1/3	1/2	2/3	1/2	2/3	3/4	2/3	5/6
SIR(dB)	-3.35	-1.65	0.5	2.5	4.5	7.35	10.2	11.5	15.05	18.9

3.4. Throughput Calculation

The throughput is calculated by considering the proportion of the frame occupied by a specific MCS level. When M RSs exist and the MCS level of the connection between $rs_{i,j}$ and bs_i is p, the capacity of this link is calculated as follows.

$$d\_BR_{i,j} = MCSdata_p \times \frac{1}{M \times BR\_zone\_ratio}. \tag{14}$$

Similarly, when an MS is connected to $rs_{i,j}$ and the MCS level of the connection between $rs_{i,j}$ and the MS is r, the capacity of this link is given by

$$d\_RM_{i,j} = MCSdata_r \times \frac{1}{RM\_zone\_ratio}. \tag{15}$$

Also, the data rate of the $ms_{i,l}^D$ connected to bs_i with s-th MCS level is given by equation (16).

$$d\_BM_{i,l}^D = MCSdata_s \times \frac{1}{O \times RM\_zone\_ratio}. \tag{16}$$

If the BS-RS link status is poor, then a bottleneck phenomenon may occur, even though the RS-MS link status is very good. So, the amount of data that the MS receives is expressed by

$$d\_BM_{i,j}^{R} = \min(d\_RS_{i,j}, d\_RM_{i,j}). \quad (17)$$

As a result, the total throughput of i-th cell is given by

$$d\_B_i = \sum_{p=0}^{M} d\_BM_{i,p}^{R} + \sum_{q=o}^{O} d\_BM_{i,l}^{D}. \quad (18)$$

4. Simulation Design

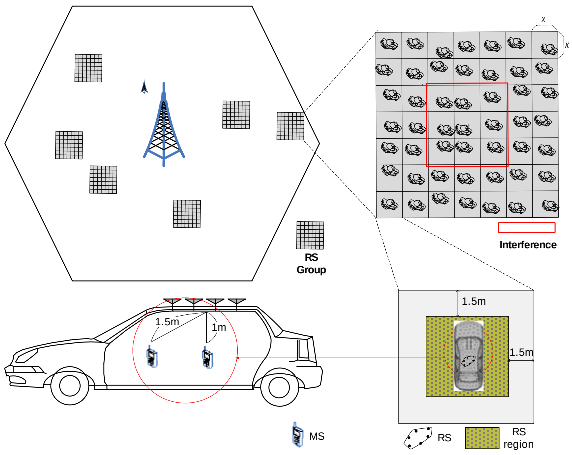

Fig. 3. Schematic illustration of the simulation method

Table 3. Simulation Parameter Setup

Parameter	Description
Cell structure	19 cell, 2-tier
Site to site distance	1.5km
Antennas	SISO
Carrier frequency	2.5GHz
Path loss	130.19+37.6*log10(d)
BS transmit power	46dBm
Traffic Model	Full buffered
RS transmission power	5~24dBm

As a simulation model, we consider OFDMA/Time Division Duplex (TDD) macro cellular systems. Parameters used in simulation runs are summarized in **Table** 3.

Considering the vehicle size, we assume that the MS is randomly located over a distance of more than 1*m* and less than 1.5*m* from the relay in a vehicle. The RS block is defined as the region where a vehicle can be located. The RS block is a square whose side is *x m* long. Notice that the RS density varies with the value of *x*. The relay is randomly located in this RS block, but the minimum distrance (1.5m) from the four sides of the RS block is guaranteed assuming the relay is located in the center of the vehicle. The RS group consists of 7x7 RS blocks. To measure average performance of vehicle-mounted mobile relay, RS groups are set to be located randomly in a cell and do not overlap with each other in each simulation trial. A schematic illustration of the network simulation scenario is given in Fig. 3. The Monte Carlo method with more than 10,000 trials is used for the simulation runs.

5. Results

5.1. Effect of the BS-MS connection on the RS-MS link under FTM2

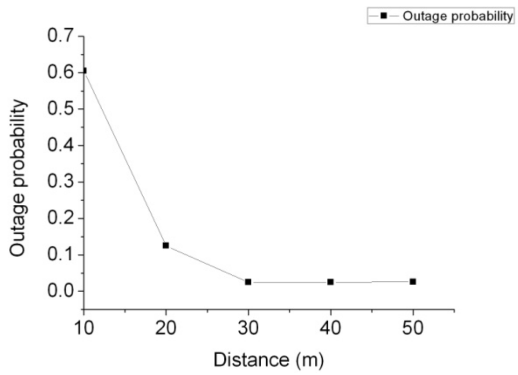

Fig. 4. Outage probability of RS-MS link according to the distance from BS (RS density: 0.10, RS transmission power: 11dBm)

In the case of FTM2, the RS-MS links may suffer from interference originating from the BS transmission power. We measure the outage probability of the MSs directly connected to the relays as a function of distance from the BS to the RS group.

Fig. 4 shows that the outage probability of the RS-MS connection becomes zero when the distance between BS and the RS group is longer than 30*m*. This is because the signal strength between the RS and MS in the vehicle is quite strong due to shorter distance between the RS and MS. So, we can say that the BS-MS connections have little effect on the RS-MS links. This phenomenon originating from the short distance between RS and MS characterizes the performance of vehicle-mounted mobile relay systems.

5.2. Effect of RS-MS connections on BS-MS link under FTM2

In the case of FTM 2, the greater the number of RS groups/RSs located in the cell, the greater the interference on an MS that is directly connected to the BS. We measure the MCS level distribution of the MS connected to the BS (**Fig. 5-(a)**) and the throughput of BS-MS link (**Fig. 5-(b)**) as a function of the number of RS groups. The result shows that the outage probability (MCS level 0) of the BS-MS links increases (thus, the throughput of BS-MS link increases) as the number of RS groups increases.

5.3. BS-MS link quality vs. RS Transmission Power

We measure the effect of RS transmission power on the BS-MS link. As the RS transmission power increases, interference that the BS-MS link experiences increases. As shown in **Fig. 6**, the performance of MCS level distribution (**Fig. 6-(a)**) and BS-MS link throughput (**Fig.

6-(b)) decrease. The result shows that the BS-MS link suffers from performance degradation due to the RSs/RS groups.

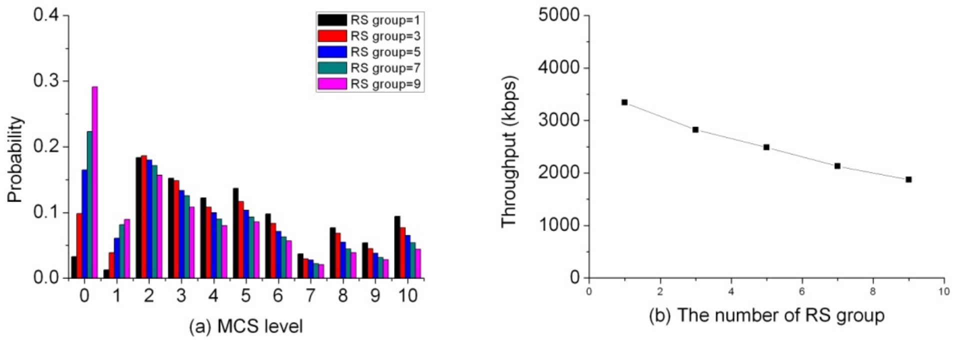

Fig. 5. MCS level distribution **(a)** of RS and throughput **(b)** of BS-MS link as a function of the number of RS groups (RS density per group: 0.10, BR zone ratio=0.5, RS transmission power: 11dBm)

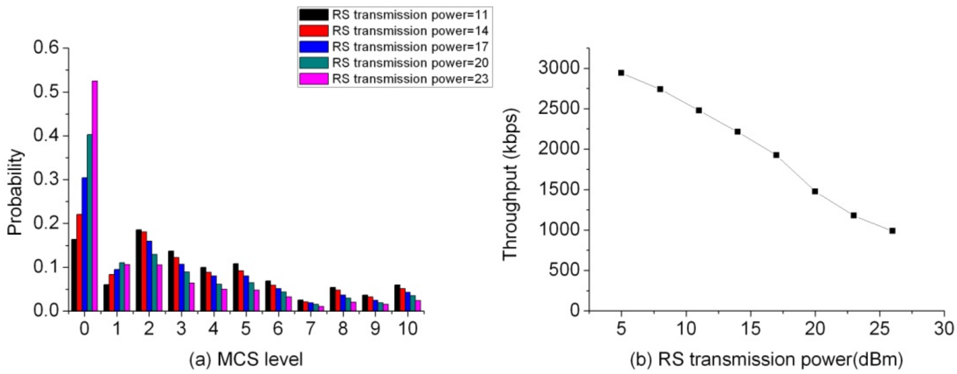

Fig. 6. MCS level distribution **(a)** and throughput **(b)** of BS-MS link as a function of RS transmission power. (RS density: 0.10, RS group: 5, Location of RS group: random, BR zone ratio=0.5)

5.4. RS-MS link quality vs. RS transmission power

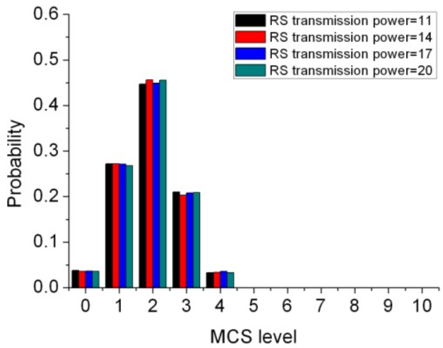

Fig. 7. MCS level distribution of RS-MS link as a function of RS Transmission Power (RS density: 0.10, RS group: 5, Location of RS group: random, BR zone ratio=0.5)

We measure the distribution of the MCS level of the RS-MS link according to the RS transmission power. Unlike Subsection 5.3, there is no significant change in the MCS level of

RS-MS link as the RS transmission power varies. This is because the received signal strength of an MS in a vehicle increases although the neighbor RS increases its transmission power.

On the other hand, the result in Subsection 5.3 shows that a high transmission power of RS affects the quality of the BS-MS link. Combining it with the result in **Fig. 7**, we can say that it should be avoided to keep the RS transmission power high since a low RS transmission power can mitigate the interference from the RS-MS connections to the BS-MS connections. If we do so, then the overall system performance in the case of low RS transmission power will be higher than that of high RS transmission power.

5.5. RS density vs. cell throughput

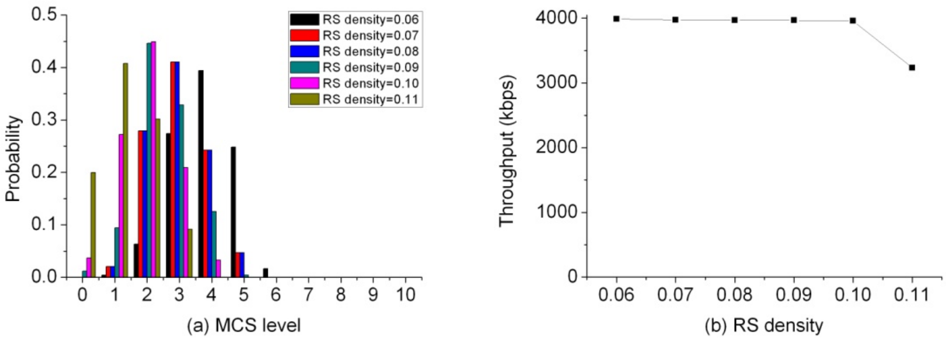

Fig. 8. MCS level distribution **(a)** and throughput **(b)** of RS-MS links according to RS density (RS group: 5, Location of RS group: random, BR zone ratio=0.5, RS transmission power: 11dBm)

The MCS level distribution in **Fig. 8-(a)** shows that the quality of RS-MS connections becomes worse as the RS density increases. As RS density increases, RS-MS link quality becomes worse due to inter-RS interference where there is no effect on BS-RS link. That is, BS-RS link are much likely to be a bottle-neck when data are transmitted from BS to MS via RS. That's why the performance degradation of RS-MS link does not happen until RS density reaches 0.10. However, when RS density is greater than 0.10, interference among RSs is too high for RS to transmit all data received from BS alghouth there is enough resource available (whole DL access zone of RS). That explains the reason why RS-MS link throughput starts to decrease when RS density is greater than 0.10. Please notice that value of MCS level 0 dramatically increases when RS density becomes 0.11.

5.6. RS-MS link throughput according to BR zone ratio and distance between RS and BS

Fig. 9 shows the RS-MS link throughput as functions of both the RM zone ratio and distance between the BS and RS under FTM 1 (**Fig. 9-(a)**) and 2 (**Fig. 9-(b)**), respectively. As defined in subsection 2.2, the BR zone ratio means the ratio of the amount of resources allocated to BS-RS link to total resources. Under FTM1, considering the short distance (thus, good link quality) between RS and MS, it is desirable to prolong the length of the BS-RS zone in order to enhance the overall system throughput. However, too short a BS-RS zone length causes shortage of absolutely needed resources, so the overall system throughput decreases. This explains the reason why there is a certain zone ratio value that maximizes the RS-MS link throughput under FTM1. Generally, when the amount of data processed in the BS-RS link is the same as that processed in the RS-MS link, performance is maximized under FTM1.

In the case of FTM2, the same logic can be applied to determine the throughput-optimized ratio between BS-RS and RS-MS zones. However, while the RS under FTM1 can use only a part of RS-MS resource, RS can fully utilize the whole RS-MS resource under FTM2. So, the amount of BS-RS resource to get the same throughput to the RS-MS link under FTM2 is much greater than that under FTM1. The results in **Fig. 10** show that both RS-MS and cell throughputs increase as the BR zone ratio increases by up to 0.8. It means that the throughput-optimized BR zone ratio under FTM2 is larger than 0.8, but we do not express this point in the figure since such a ratio is an impractical value.

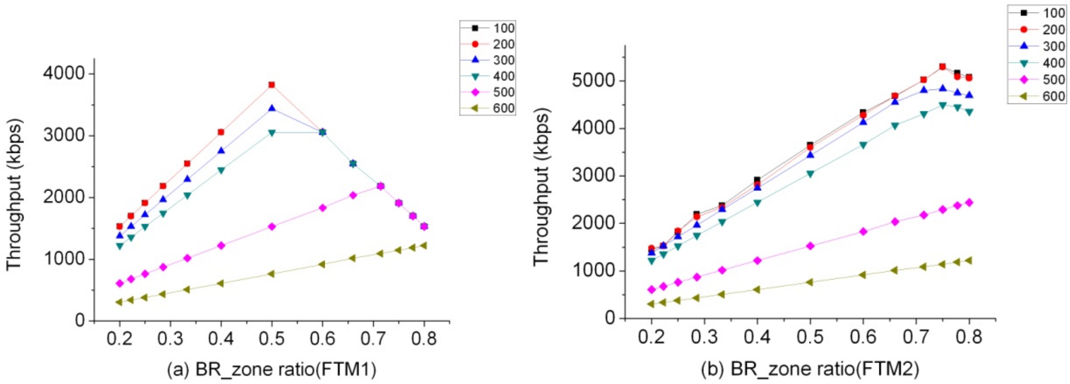

Fig. 9. RS-MS link throughput due to FTM1 **(a)** and FTM2 **(b)** as functions of BR zone ratio and distance between RS and BS (RS density: 0.1, RS group: 1, Location of RS group: 100, 200, 300, 400, 500, 600, BR zone ratio=0.2~0.8, RS transmission power: 11dBm)

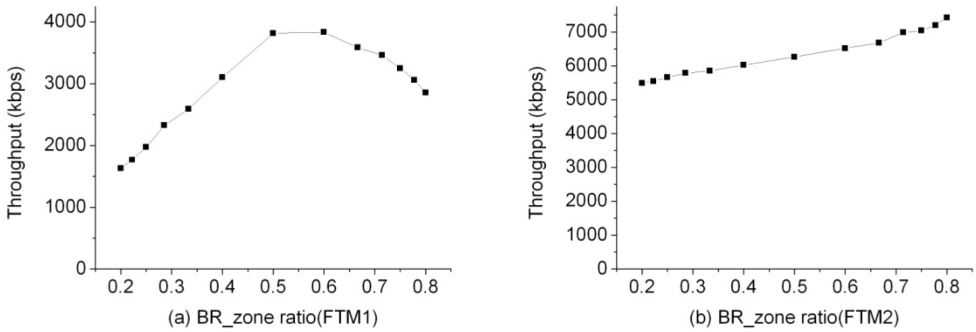

Fig. 10. Cell throughput according to BR zone ratio (RS density: 0.1, RS group: 5, Location of RS group: random, BR zone ratio=0.2~0.8, RS transmission power: 11dBm)

6. Conclusion

In this paper, a vehicle-mounted mobile relay in a next generation communication system is introduced. The distinctive figures of vehicle-mounted mobile relay compared to fixed or nomadic relays are summarized as i) short distance (thus, good link quality) between relay and the associated MS and ii) the possibility of high density of relay deployment. Considering the above two points, we suggest RS density, zone ratio, and RS transmission power as key metrics in evaluating the performance of a vehicle-mounted mobile relay system. For performance evaluation, we measure the inter-effect of RS-MS and BS-MS connections, effect of RS transmission power on both BS-MS and RS-MS connections, and effect of RS density and zone ratio on cell throughput. We believe that the work of this paper can serve as preliminary research of vehicle-mounted relay systems.

References

[1] P. E. Mogensen, T. Koivisto, K. I. Pedersen, I. Z. Kovács, B. Raaf, K. Pajukoski and M. J. Rinne, “LTE-advanced: the path towards gigabit/s in wireless mobile communications,” in *Proc. of VITAE '09*, pp. 147–151, Denmark, May 2009. Article (CrossRef Link)

[2] 3GPP Technical Report 36.814, “Further Advancements for E-UTRA: Physical Layer Aspects (Release 9),” v2.0.0, March 2010, http://www.3gpp.org. Article (CrossRef Link)

[3] Mohamed Salem, Abdulkareem Adinoyi, Halim Yanikomeroglu and Young-Doo Kim, “Radio Resource Management in OFDMA-based Cellular Networks Enhanced with Fixed and Nomadic Relays,” in *Proc. of WCNC*, pp. 1-6, 2010. Article (CrossRef Link)

[4] R. Pabst, B.H. Walke, D.C. Schultz, P. Herhold, H. Yanikomeroglu, S. Mukherjee, H. Viswanathan, M. Lott, W. Zirwas, M. Dohler, H. Aghvami, D.D. Falconer and G.P. Fettweis, “Relay-based deployment concepts for wireless and mobile broadband radio,” *IEEE Commun. Mag.*, vo. 42, no. 5, pp 80-89, 2005. Article (CrossRef Link)

[5] J. Cho and Z.H.Hass, “On the throughput enhancement of the downstream channel in cellular radio networks through multihop relaying,” *IEEE J. Select. Areas Com.*, vol. 22, no.7, pp. 1206-1219, 2004. Article (CrossRef Link)

[6] V. Genc, S. Murphy and J. Murphy, “Performance Analysis of Transparent Relays in 802.16j MMR Networks,” in *Proc. of WiOpt*, pp. 273-281, 2008. Article (CrossRef Link)

[7] Won-Hyoung Park and Saewoong Bahk, “Resource management policies for fixed relays in cellular networks,” *Computer Communications.*, vol. 32, pp. 703-711, 2009. Article (CrossRef Link)

[8] H. Huining, H. Yanikomeroglu, D.D. Falconer and S. Periyalwar, “Range extension without capacity penalty in cellular networks with digital fixed relays,” in *Proc. of Globevom*, vol. 5, pp. 3053-3057, 2004. Article (CrossRef Link)

[9] IEEE, IEEE Std. 802.16j-2009, “IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Broadband Wireless Access Systems, Amendment 1: Multiple Relay Specification,” Jun. 2009. Article (CrossRef Link)

[10] Vasken Genc, Sean Murphy, Yang Yu and John Murphy, “IEEE 802.16j Relay-Based Wireless Access Networks: An overview,” *IEEE Wireless Communication*, vol. 15, no. 5, pp. 56-63, 2009. Article (CrossRef Link)

[11] Draft IEEE 802.16m Evaluation Methodology Document. IEEE 802.16 Broadband Wireless Access Working Group, 2009. Article (CrossRef Link)

[12] B. Lin, P. Ho, L. Xie and X. Shen, “Optimal Relay Station Placement in IEEE 802.16j Networks,” in *Proc. of IWCMC*, Aug. 2007. Article (CrossRef Link)

[13] IEEE, IEEE Std. 802.16-2009, “IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems,” May 2009. Article (CrossRef Link)

[14] IEEE 802.16 Task Group j, http://www.ieee802.org/16/relay. Article (CrossRef Link)

[15] IEEE 802.16 Task Group m, http://grouper.ieee.org/groups/802/16/tgm/index.html. Article (CrossRef Link)

Keun-Hang Heo received a B.S. degree in electrical engineering from Chung-Ang University, Seoul, Korea, 2009. Since September 2009, he has been pursuing a M.S. degree at the Graduate School of Electrical and Electronics Engineering, Chung-Ang University, Seoul, Korea. His current research interests include radio resource management for Ad-hoc and cellular network and interference mitigation in multi-cell environments.

Hyun-Sik Kang received the B.S degree in electrical engineering from Chung-Ang University, Seoul, Korea, 2010. He is currently working toward his M.S. degree in the same university. His research interests include radio resource allocation, hanover, and QoS for multimedia traffic in wireless networks.

Un-Chul Moon received his B.S., M.S. and Ph.D. degrees from Seoul National University, Korea, in 1991, 1993 and 1996, respectively, all in Electrical Engineering. From 2000, he was with the Woo-Seok University, Korea, and from 2002 with the Chung-Ang University, Korea, where he is currently an Associate Professor of Electrical Engineering. His current research interests are in the areas of power system analysis, computational intelligence and automation.

Jung-Ryun Lee received the B.S. and M.S. degrees, both in mathematics from the Seoul National University, in 1995 and 1997, respectively. He received the Ph.D. degree in electrical and electronics engineering from the Korea Advanced Institute of Science and Technology (KAIST), in 2006. From 1997 to 2005, he was a Chief Research Engineer at LG Electronics, Korea. From 2006 to 2007, he was a full time Lecturer of Electronic Engineering at University of Incheon. Since 2008, he has been an Assistant Professor of Chung-Ang University. His research interests include energy-efficient medium access protocol, resource management and packet scheduling in wireless network. He is a member of IEICE, IEEE and KICS.