Cascade Handover Scheme in High-Speed Transport (HST) using mmWave-based Mobile Hotspot Network

Woogoo Park, Heesang Chung, and Ilgyu Kim
Mobile Wireless Backhaul Research Section
Electronics and Telecommunications Research Institute (ETRI)
Daejeon, Korea
{wgpark, hschung, igkim}@etri.re.kr

***Abstract*—Capacity and coverage improvements in mobile communication networks have evolved to accommodate increased use of broadband data. One way to enable the use of broadband data is to utilize the mmWave band. The mmWave-based mobile backhaul solution is very useful for providing broadband data traffic for mobile service providers, including carriers. However, when moving at high speed like a high-speed train, a proper handover algorithm is required in a mobile backhaul system in order to overcome the high handover shortage or delay experienced at these frequencies. Fast and efficient handover reliance on these high-speed moves has a significant impact on the control layer procedure. In this paper, we design a cascade handover method and evaluate the throughput of handover data in a Mobile Hotspot Network (MHN) using a spectrum band over 6 GHz.**

Keywords-throughput; handover; backhaul; mobile hotspot network; above 6 GHz.

I. INTRODUCTION

Mobile data traffic has grown 4,000 times over the past decade and global mobile data traffic is growing 30.6 exa-bytes per month by 2020 [1]. As more than 50 billion connected devices are expected to be launched, including 1.5 billion cars worldwide, mobile communication networks have become an important factor in meeting the needs of specific vertical industries and dramatically increasing the number of devices [2]. Cellular-type small cells below 6GHz are not the same in terms of user and system requirements to meet the need for a significant increase in data traffic when considering ultra-dense network solutions. Especially when moving at high speed, very different requirements are required. Small backhaul in urban areas is an effective solution for inter-cell interworking. However, the problem caused by mobility in high-speed is still under investigation in the mmWave-based backhaul network [3], [4]. Especially, it can provide low cost and small architecture, such as mmWave backhaul, channel feasibility, use of large scale MIMO, measurement of mmWave propagation, and combination of multi beam antenna for outdoor mmWave mobile communication [5]-[7]. MmWave-based technology has evolved over the last few decades and has contributed to reducing the number of cells required. Backhaul and fronthaul networks for 5G transport are also presented in the Xhaul architecture, which allows for flexible and reconfigurable all network elements.

For high-speed transport (HST), such as subways and trains, some results with high data rates of up to 350 km/h have been presented [9]-[10]. At 60 km/h at 60 GHz, the Doppler spread is over 3 kHz and is several hundred microseconds faster than today's cellular systems. Also, high shadowing conditions can overcome beam conditions, but channel conditions force mmWave beam blocking due to large changes in path loss in mobile environments [3]. We design and implement a cascade handover scheme, which enables faster and more efficient handover. Through this simulation, we tried to confirm the relationship between packet generation and handover at high speed. We propose this method and evaluate the performance of the method according to data throughput. The rest of this paper is mentioned as follows. Section II introduces related work and Section III outlines the MHN system. Section IV presents the proposed cascade handover scheme including window. Then, procedures and performance evaluations for synchronization and handover execution are described in Sections V and VI. The conclusion is in Section VII.

II. RELATED WORK

To provide broadband access, such as virtual reality and augmented reality services for users in these HSTs, it is imperative to overcome the challenges of poor channel conditions and large numbers of simultaneous handovers. As the number of small cell layout increases in 5G, fast handover is required at cell edge [8], [11]. Reference [11] shows two improvements in handover performance in LTE systems. One is to prevent radio link failure in the handover, which provides the reliability of the transmission of the handover procedure while the user equipment is under poor radio channel conditions. The other is to define an early handover preparation through an Early Handover Preparation with Ping-Pong Avoidance (EHOPPPA) handover to ensure reliable transmission of the handover procedure in good radio channel conditions. In order to apply this in HST, we face some problems, such as mmWave-based beam processing and high mobility. Thus, an mmWave-based Distributed Antenna System (DAS) for mobile communication systems is introduced and can transmit data up to 1 Gbps at distances of up to 1 km using the 27 GHz spectrum band [12]. In addition, having a network of moving connected terminal devices can support faster and higher functionality.

Since the advent of new technologies for mobile communications for HST, multiple base stations have been designed for low interference and low handover times. For this purpose, MHN is a mobile backhaul based on mmWave, and several base stations are installed at intervals of 1km next to the railway for users who boarded in HST, and trains pass through MHN's mRUs along the railways in turn. The focus of this paper is on the subway of the city and in the HST placement in rural areas and is designed to have a cell radius that is wider than the current small cell size for city radius and small cell placement, i.e., a radius of 500 m. The coverage of this arrangement is such that the spacing between the two mRUs is less than 1 km due to the mmWave characteristics such as propagation loss, shadowing (e.g., humidity, rain fades and blockage) and Doppler spread [12].

The LTE physical layer is designed to support high throughput data delivery of 350 km/h and even 500 km/h in rural areas than 3G systems. However, the situation of HST can still suffer from LTE networks. First, the wireless channel status changes greatly in HST environment. Second, handover between cells is often apt to occur in terms of speed. To solve this problem, LTE-based cell array technique was introduced in [10]. While cell arrays may be effectively active on the approaching LTE cell, there are some difficulties in supporting seamless handover that does not interfere with the multimedia stream. LTE-based solutions are limited in meeting Gbps multimedia services. The handover decision procedure in LTE network between two eNBs is typically initiated by the eNBs without communicating with the MME. The decision of the home eNB that moves the UE to the target eNB is based on a measurement report for the UE, such as a Channel Quality Indicator (CQI), the target eNB is ready to prepare radio resources before confirming the handover. As soon as a handover is completed, the target eNB indicates the home eNB to release its resources.

III. MOBILE HOTSPOT NETWORK

Since MHN typically spans geographical areas, it is not economically feasible to build specific networks for users who are always in the HST. Therefore, a mobile wireless backhaul network that can be accessed even during high-speed movement between Wi-Fi and the network is needed so that users can connect to the network via Wi-Fi installed in the HST without changing the specifications of the terminal. In the MHN, the 27 GHz band was designed and used to provide mobile wireless backhaul to the HST. An mmWave backhaul data traffic is converted to Wi-Fi data traffic inside the HST. In Figure 1, the MHN architecture based on mmWave communication for HST is introduced. The overall architecture consists of multiple mobile radio units (mRU), multiple mobile vehicular equipment (mVE), and mobile digital devices (mDU) connected to the mobile gateway (mGW). Each mDU communicates with multiple mRUs over fiber optics and is responsible for baseband signal processing. Each mRU function is an important part of the RF transmission at the base station with unique cell identity. Beamforming can support multiple independent wireless links between mRU and mVE. One mDU and several mRUs belong to mNBs. The handover procedure is established between the home mNB and the target mNB via the M2 interface. Other Packet Data Unit (PDU) streams can be transmitted between mRU and mVE. The multi-antenna installation of mVE is designed to reduce handover latency by maintaining multiple connections to the mRU over the M-Uu interface. MVE is a relay that is connected to the mobile router using the T1 interface and the mobile router is connected to the Wi-Fi AP using the T2 interface. Passengers on board can easily access Wi-Fi via their mobile handsets. This architecture also greatly improves spectral efficiency by allowing mRUs to simultaneously use the same radio resources. The mRU in the mNB can communicate with the mVEs before and after the HST using a beam like the mmWave-based base station [12].

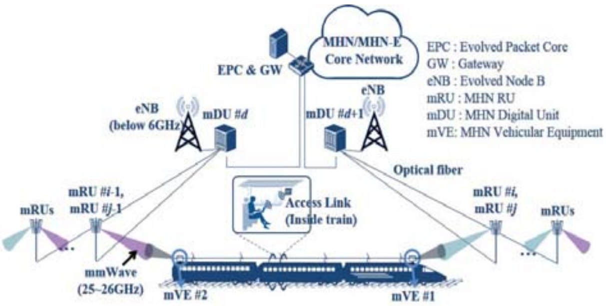
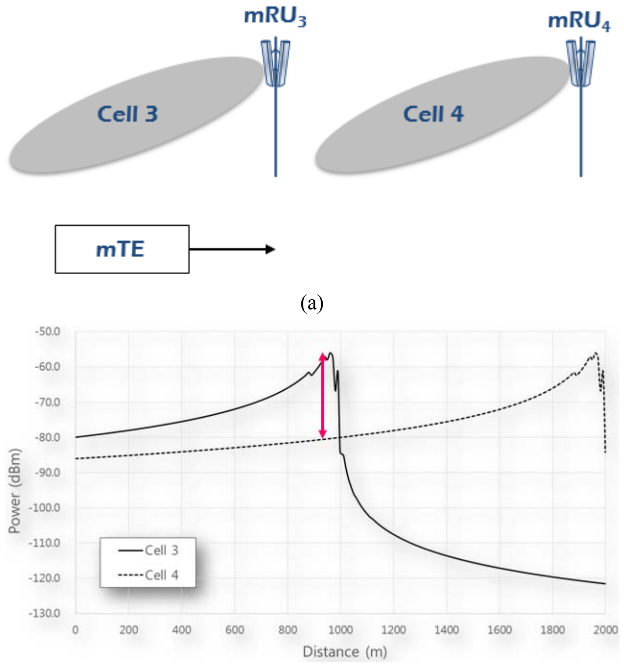


Figure 1. MHN Architecture.

IV. HANDOVER SCHEME WITH WINDOW

The MHN handover scheme has a synchronized channel structure and a cell search algorithm that can reliably process neighbor cell search when the interference of the home channel is 25 dB or more. The MHN proposed a cell search algorithm in which the offset and the reserved region are located at positions of synchronized channel symbols according to cell ID [12]. In this paper, we propose a handover method for fast movement between mVE and mRU. The handover procedure of cell 3 must be triggered at the maximum power of the assumed mRU_3 before entering the next cell 4 in the target mRU_4 due to the sudden drop of the received power at the cell edge of cell 3. From the viewpoint of high-speed movement, the faster the handover time, the lower the data transmission rate. Further, if the handover time is too late, the received power of the target mRU_4 received by the mVE is too low, which may cause a handover failure as shown in Figure 2. In [12], it provides an LTE-based solution that can support high throughput and continuous multimedia services for HST users, in order to ensure that wireless channel conditions change rapidly and connections are not interrupted frequently for fast handovers.



(a)

(b)

Figure 2. Cell search and time scheme for fast handover in MHN [13]. (a) Concept and (b) Scheme.

The solution uses a "cell array" that can organize continuous cells along the railway in cooperation with the femtocell service through Wi-Fi communication that collects traffic demand within a train [10]. The cascade handover method uses the window based on the moving speed of the HST, and the size of the window is determined by the HST's speed. As the moving speed increases, the size of the window increases. When the speed decreases, the size of the window decreases. Equation (1) determines the size of the *W* window based on the moving speed and shows how to calculate the window size through each moving speed (= *velocity*):

$$W_{size} = \left| 2^{(\log_{10} velocity)-1} + \frac{1}{2} \right| \qquad (1)$$

where W_{size} represents the window size being shipped. The *velocity* indicates the moving speed in km/h. From the point of view of the handover between the two mRUs, the corresponding window size was calculated using the moving speed received from the HST.

TABLE I. WINDOW SIZE WITH RESPECT TO MOVING SPEED OF TRANSPORT

velocity (km / hour)	**window size (W_{size})**	**moving distance (m / sec)**	**moving speed between mRUs (sec / 1 km)**
100	2	27.8	36
500	3	138.9	7.2
750	4	208.3	4.8

Table I shows the results of a simple method of calculating the window size according to each HST mode with different moving speeds (e.g., the speed of the subway is 100 km/h, about 500 km/h for HST and about 750 km/h for future HST). This minimizes interrupt times for handover and cell search times (e.g., mVE and target mRU should find best handover timing). Therefore, depending on the speed characteristics of the HST over 500 km/h, which is a condition experienced by the system, the connection to be sustained is affected by the long downtime that can be very intermittent between mRUs.

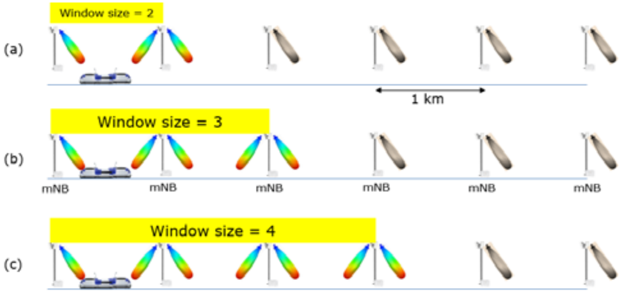


Figure 3. Assigned cases for window size. (a) Velocity is 100 km/hour as shown in subway. (b) Velocity is about 500 km/hour as shown in HST. (c) Velocity is about 750 km/hour for future HST.

V. CASCADE HANDOVER PROCEDURE

We use neighboring cell search and handover structure in the region where the power of the home cell is very large. In our procedure, a cascade handover concept and technique with window is used as shown in Figure 3. The window considers the special features of the mRU to determine the moving speed, coverage and radio resource management. The handover scheme aims at selecting and transmitting the target mRU without interruption. The shorter the duration of the unnecessary handover procedure, the more efficiently the handover mechanism will be implemented. Also, as shown in Figure 2-(b), the home mRU decides to handover the UE moving to the target mRU when the signal strength is high. To use this technique, the mRU must be synchronized within the calculated window size before performing the handover procedure. An improved handover procedure is shown in Figure 4.

A. Synchronization for handover preparation

Synchronization between home mRU and target mRU has been introduced to minimize handover interruption time due to high speed. If the home mRU in source mNB is mRU_0 and mRU_0 is followed by target mRU_1, mRU_2, ... mRU_n, then the target mRU_1 to mRU_n are the neighbor cells to be handed over. First, we calculate the window size according to the speed of movement by HST, as in (1). In addition, a synchronous channel structure / cell search algorithm is required to stably perform neighbor cell search even when the interference of the home cell is higher than 25 dB. In this paper, we introduce a synchronization procedure between mRUs on the assumption that the synchronous channel structure and the cell search algorithm are operating.

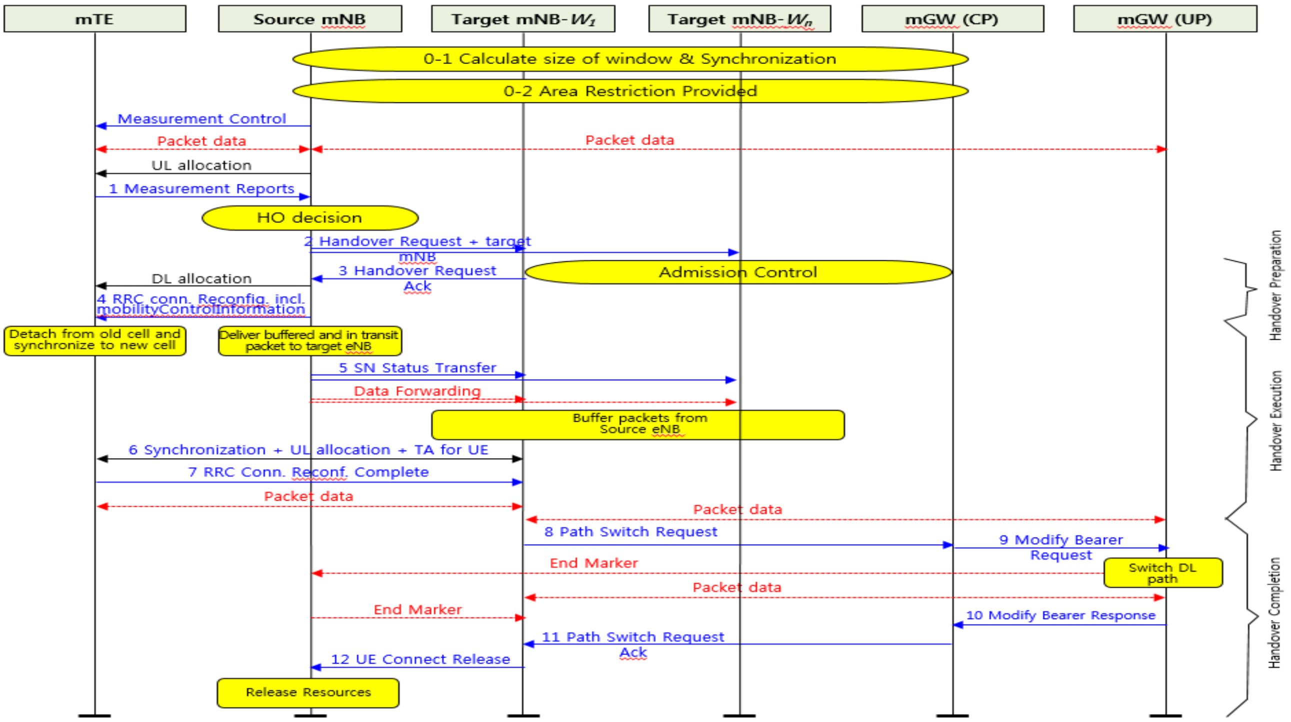


Figure 4. Handover procedure using window between mVE and mNBs.

The home mRU then sends a handover ready message to each target mRU corresponding to the window size calculated as the handover preparation information. Note that the mRU belongs to the mDU, and because the mDU and mRU belong to the mNB, the message is received by the mDU in the mNB. If window size is 3, it is assumed that the moving speed of the HST between the home mRU and the target mRU is about 500 km/h. In case of synchronization for handover between home mRU and target mRU, improvement of Radio Resource Control (RRC) message and application of window use are performed in terms of time and location.

$$\text{target mRUs at Home mRU}_{(=\text{mRU}_0)} \rightarrow \{\text{mRU}_1,\ \text{mRU}_2,\ \text{mRU}_3\} \tag{2}$$

$$\text{target mRUs at Home mRU}_{(=\text{mRU1})} \rightarrow \{\text{mRU}_2,\ \text{mRU}_3,\ \text{mRU}_4\} \tag{3}$$

$$\vdots$$

$$\text{target mRUs at Home mRU}(=\text{mRU}_{n\text{-}3}) \rightarrow \{\text{mRU}_{n\text{-}2},\ \text{mRU}_{n\text{-}1},\ \text{mRU}_n\} \tag{4}$$

Equation (2) to (4) list the sequence of target mRUs according to the change of the home mRU when the window size according to the HST speed is determined. The overall value for this can be explained by the following (5). The mRU not participating in the handover is in the sleep mode in order to block the power consumption, and the value "0" in (5) means the mRU corresponding to the sleep mode. For efficient operation of the sleep mode, inter-mRU synchronization by the RRC in the mDU is most important.

$$A_{i,j} = \begin{vmatrix} a_h & a_{t,1} & a_{t,2} & a_{t,3} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & a_h & a_{t,1} & a_{t,2} & a_{t,3} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_h & a_{t,1} & a_{t,2} & a_{t,3} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_h & a_{t,1} & a_{t,2} & a_{t,3} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_h & a_{t,1} & a_{t,2} & a_{t,3} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_h & a_{t,1} & a_{t,2} & a_{t,3} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a_h & a_{t,1} & a_{t,2} & a_{t,3} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_h & a_{t,1} & a_{t,2} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_h & a_{t,1} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_h \end{vmatrix} \tag{5}$$

where $A_{i,j}$ represents status of mRUs associated with time (i), j is location of each mRU. a_h is home mRU and $a_{t,(1,2,3)}$ is target mNBs. $A_{i,j}$ is calculated according to the conditions of the following equation.

$$A_{i,j} = \begin{cases} 1, & \text{if } A_{i,j} \in a_h \text{ and } A_{i,j} \in a_{1..W_{Size}}; \\ 0, & \text{otherwise,} \end{cases} \tag{6}$$

where window size can be considered as $0 < W_{size} \leq j$. There is the number of mRU and velocity for HST. For the considered simulation practical environment, we select the velocity for train is below 750 Km/h and the number of stations is more than 3 respectfully.

B. Handover preparation in home mRU in mNB

As soon as the handover decision is complete, the home mRU of the mNB sends a "handover request" message containing target mRU IDs to target mRUs equal to the window size for admission control when dynamic resource allocation by the scheduler is activated. MRU compares its mRU ID with the target mRU ID sent from the home mRU. An mRU with a different ID does not send a “handover request confirmation” message to the home mRU. In this way, the moving speed of the HST is stably maintained even when the moving speed changes between 0 km/h and the maximum speed.

C. Handover execution in home mRU in mNB

For handover performance, in order to ensure smooth mobility between the home mRU and the target mRU in the mNB, the home mRU and all target mRUs within the window size need to share the optimal resource allocation. The home mRU sends resource allocation information to the target mRUs for fast handover execution. When the handover procedure is complete, the role of the home mRU is taken by the target mRU and the window move is moved to the next mRU. This approach is done so that the neighboring target mRUs of the home mRU are pre-assigned with the logical network entities by the control entity of the peer mRUs to the users accessing the Wi-Fi via the mVE in the HST. In particular, cooperating peer mRUs can centralize the architecture associated with the handover procedure that controls the data service of the target mRU, thereby contributing to a reduction in seamless service and handover interruption time.

D. Sleep mode for less power consumption in mRU

Due to the characteristics of subways and trains, the ratio of the total running area to the whole area is very limited depending on the moving speed and position of the train. The train passes the waiting status for a certain period of time and then the next train passes. Therefore, since the base stations located between the train and the next train continue to consume electric power, the electric power is cut off after the train has passed and the entrance of the train is received from the neighboring home RU in the vicinity of the RRC message in advance, which will contribute to power saving. The data delivery in home mRUs is typically done using a point-to-multi point approach, which is deployed in a dense arrangement. This scheme ensures a high data rate between the mVE and the mRU and at the same time minimizes intra-system interference that may occur between different cells of the MHN. Therefore, mRUs that do not participate in the handover procedure are put into sleep mode without power consumption. The home mRU enters the sleep mode as soon as it receives the "handover complete" message. In particular, if the mDU to which the home mRU belongs is different from the mDU to which the target mRU belongs, the base station handover must occur. At this time, the entire mNB (its mDU and mRUs) serving as the base station transits to the sleep mode.

VI. PERFORMANCE EVALUATION

A simulation based on a MHN in the mmWave range assumes that the train will run on a straight rail. The simulation model presented in this paper is evaluated on trains as an on-off model, and the possibility of access interception has a great influence on fast handover and scheduler design. Because the test cannot be performed in a real environment like a train running at a speed of 500 km/h, this simulation has replaced train speed by adjusting the interval of packets occurring between two mRUs. The design of on-off model for the application level depends on exactly how the access is described at the link level. In probabilistic modeling, each on-off source can be characterized by a two-state Markov chain with a Poisson ratio. Under this assumption, the analysis of the IP traffic model between mNB and mVE is mainly performed using the on-off model. The data streams exchanged between the mRU and the mVE can be described by an on-off model, which indicates that the processing time of each "on" model represents the generation of one data stream at a constant rate of 500 Mbps and the processing period of each "off" model is indicated the inactivity period between adjacent data streams. The configuration and flow of the on-off model for evaluating the handover procedure is shown in Figure 5.

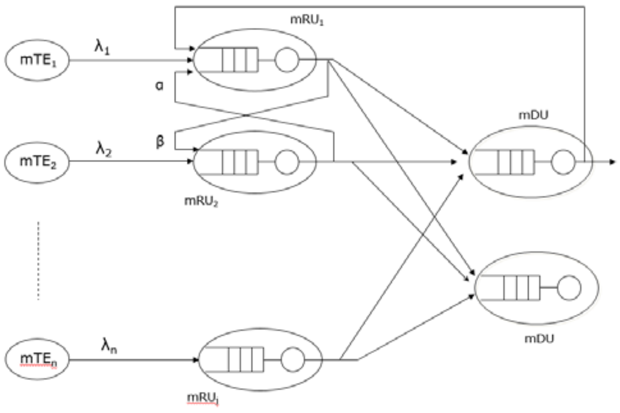


Figure 5. On-off Model to generate packets for handover

This model shows the operational status of the mVE, which provides a different set of performance than the 3GPP common User Equipment (UE). MVE converts the data received from multiple UEs into a packet stream through Wi-Fi which is an access point (AP) operating in the HST, and transmits the data stream to mRU. When the transmitted packet stream arrives at the mRU, the mRU may select it based on the exponential distribution. In probabilistic modeling, individual on and off modes can be characterized by a two-state Markov chain with a Poisson's rate, λ. The sojourn times of the two states can be exponentially distributed by the exponents α and β. This means that the model is related to the next interaction. ① mRUs receiving the users' data streams from the mVE send the data stream to the connected mDU. ② the gateway is connected not only to the home mDU, but also to the target mDU, which is the neighbor mDU of the home mDU to control the data stream. Each data stream is distributed within the mNBs in the home and target mDU. The distribution between mVE and mRU means the capacity of mRU and handover triggering, and the distribution between mRU and mDU includes handover at the cell boundary. mDU orchestrates those interactions and make sure of keeping session connection without interruption.

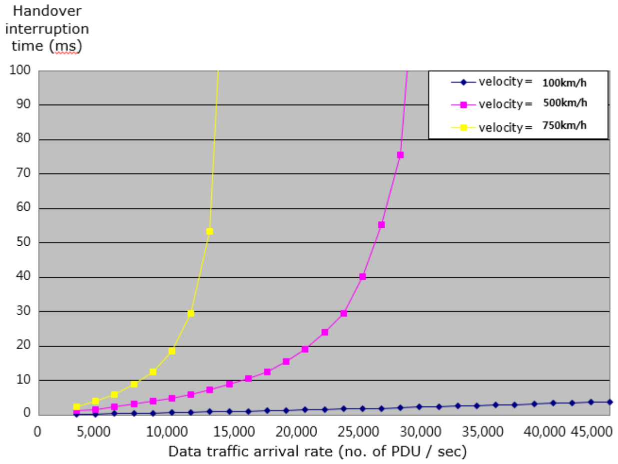


Figure 6. Handover interruption time according to traffic arrival rate.

In Figure 6, it can be shown that the handover downtime increases from 100km/h to 750km/h according to the data traffic arrival rate, when the window size requiring minimum handover interruption time is expected. The data traffic arrival rate is generated by PDUs that occur per second. When HST is operating at 500 km/h or less, the handover interruption time is maintained steadily according to the traffic, but the performance is drastically degraded as the traffic gradually increases at 750 km/h. This means that if the HST speed exceeds 500kh/h, the data traffic arrival interval is less than 1msec, or the data arrival rate is more than 12,500, the proposed handover method cannot provide proper window size. Therefore, we need another approach for handover that depends on window size. For example, as the HST operates at a speed of 750 km/h, the cell radius between the two mRUs must be at least 500 m to solve the performance degradation.

VII. CONCLUSION

The large bandwidth available at mmWave frequencies can greatly increase the capacity of the fifth generation wireless systems based on wireless backhaul. However, when moving at high speeds, utilizing the optimal handover algorithm in the MHN system to overcome the high handover shortage rate or delay experienced at these frequencies, a suitable handover algorithm is required. In particular, a fast moving mVE ahead of the target mRU will require a decision as to when to initiate a handover, and if this determination is made too fast or too late, a delay or short circuit of the session may occur. In this paper, we propose a method for providing information about target mRUs through a window to determine timing to start a fast and efficient handover. The results show that cascaded handover with windows improves cell search and extends link range to reduce handover interruption time. This procedure provides the user of the HST with an efficient handover scheme from the home mRU to the target mRU in the window according to the rate, and can be performed without collaboration with the evolved packet core (EPC). A prepared message communicates directly with the target mRU and the home mDU to which the home mRU belongs. It also analyzes both the MHN using the 27 GHz range and shows all of the measurement and simulation results to verify the use of the handover method with the MHN window. In addition to supporting high speeds of over 500 km/h, many technical issues remain. We will improve the proposed handover method by extending the simulation environment for further research.

ACKNOWLEDGMENT

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) (No. 2014-0-00282, Development of 5G Mobile Communication Technologies for Hyper-connected smart services).

REFERENCES

[1] Cisco, ‘‘Cisco visual network index: Global mobile traffic forecast update,’’ 2016.

[2] Ericsson, "More than 50 billion connected devices," White Paper. 284 23-3149, February 2011.

[3] S. Rangan, T. S. Rappaport, and E. Erkip “Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges,” Proceedings of the IEEE | vol. 102, no. 3, March 2014, pp. 366-385.

[4] J. Hansryd, “Non-line-of-sight microwave backhaul for small cells,” Ericsson Review, March 2013.

[5] S. Rajagopal, S. Abu-Surra, and M. Malmirchegini, “Channel Feasibility for Outdoor Non-Line-of-Sight mmWave Mobile Communication,” IEEE Vehicular Technology Conference, pp1-6, September 2012.

[6] S. Sun, T. S. Rappaport, R. W. Heath, A. Nix, and S. Rangan “MIMO for Millimeter-Wave Wireless Communications: Beamforming, Spatial Multiplexing, or Both?,” IEEE Com. Magazine, vol. 52, issue 12, pp.110-121, December 2014.

[7] S. Sun, G. R. MacCartney Jr., M. K. Samimi, S. Nie and T. S. Rappaport, “Millimeter Wave Multi-beam Antenna Combining for 5G Cellular Link Improvement in New York City,” IEEE ICC 2014 - Wireless Communications Symposium, pp. 5468-5473, August 2014.

[8] A. De La Oliva, “Xhaul: Towards an Integrated Fronthaul / Backhaul Architecture in 5G Networks,” IEEE Wireless Communications, vol. 22, Issue 5, pp.32-40, October 2015.

[9] K. Guan, “Mobile Channel Characterization in Typical Subway Tunnels at 30 GHz,” IEEE P802.15 Working Group for Wireless Personal Area Networks, September 2015.

[10] O. B. Karimi, J. Liu, and C. Wang, “Seamless wireless connectivity for multimedia services in high speed trains,” IEEE Journal on Selected Areas In Comm., vol. 30, No. 4, pp. 729-739, May 2012.

[11] H. S. Park, Y. S. Choi, B. C. Kim, and J. Y. Lee, “LTE Mobility Enhancements for Evolution into 5G,” ETRI Journal, vol. 37, no. 6, pp. 1065-1076, December 2015.

[12] S. N. Choi, J. H. Kim1, I. G. Kim and D. J. Kim, “Development of Millimeter-Wave Communication Modem for Mobile Wireless Backhaul in Mobile Hotspot Network,” IEIE Transactions on Smart Processing and Computing, vol. 3, no. 4, pp. 212-220, August 2014.