

Iterative Receiver Algorithm for Millimeter Wave Mobile Hotspot Network System

Dae-Soon Cho[†], Il-Kyu Kim[†]

[†]Electronics and Telecommunication Research Institute {dscho@etri.re.kr}

Abstract—The need of high speed data rate services at mobile group vehicles moving at high speed has been on the increase. ETRI (Electronics and Telecommunications Research Institute) has been designing and developing a new moving wireless backhaul system, Mobile Hotspot Network (MHN) system, which can support over 1Gbps data rate services for mobile group vehicles running at high speed up to 500km/h such as KTX (Korea Train Express) express train. In this paper, the methods to adopt the iterative receiver algorithm are introduced to improve MHN system performance. One of the main characteristics of MHN system is to apply multi-flow structure, which may cause interferences between two data stream, therefore, this can degrade system performance. However, due to multi-flow characteristic, we can apply the iterative receiver algorithm. In this paper, we showed the possibility to improve system performance by applying iterative receiver algorithm. Currently, we have developed the MHN test-bed system and had a goal to demonstrate the real time performance of the MHN system in the outdoor environment by Feb., 2016. Outdoor demonstration will be shown at line 8 subway in Seoul, Korea.

Keywords— MHN, Iterative Receiver, Multi-flow, Millimeter Wave.

I. INTRODUCTION

The exponential growth of wireless data services driven by mobile internet and smart devices such as smart phone and tablets has made start the investigation of the 5G systems. The new 5G [1-2] mobile networks are expected to be deployed around 2020. It is anticipated that the volume of mobile traffic in 2020 will increase 1000 times more than that of the current traffic. In order to meet this exponential growth, improvements in air interface capacity and allocation of new spectrum are important. Therefore, there has been a recent interest in exploiting mmWave [3-6] frequencies for outdoors, especially for wireless mobile broadband communication system, for multi-Gbps communication over several hundreds of meters [6]. The current close-to-capacity system designs in current 3G and 4G cellular standards, such as LTE-A [7-8], make it extremely difficult to meet the ever increasing demands of higher data rate communication with limited spectrum below 3GHz. However, cellular mobile communication in higher frequencies of mmWave spectrum can potentially provide GHz of bandwidth, enabling multi-Gbps communication.

Currently, most of the wireless and mobile communication systems such as LTE and LTE-A systems are optimized at low speed environment. Recently, high data rate transmission at high speed is

deeply required. To realize this, spectral efficiency should be high at high speed. A study on 5G is currently ongoing in the world, and most of the companies and institutes are considering use of millimeter band for achieving Giga bps data rate. ETRI has developed a system that can support high data rate transmission on high speed and group vehicles such as subway, KTX and express bus. We are considering using millimeter wave band, and have a target of supporting up to 2.5Gbps at 400km/h speed.

In this paper, we introduce a new system (MHN) [9-12] that can support Giga bps data rate in wireless mobile environment with millimeter wave band, which is especially focused on the high speed moving group vehicles. Moreover, we described the methods to adopt the iterative receiver algorithm to improve MHN system performance.

This paper is organized as follows. In the next section, we briefly introduce the MHN system which has been developed at ETRI. In section 3, we introduce the method to adopt the iterative receiver algorithm to MHN system. Finally, a summary of this article is given.

II. MHN SYSTEM

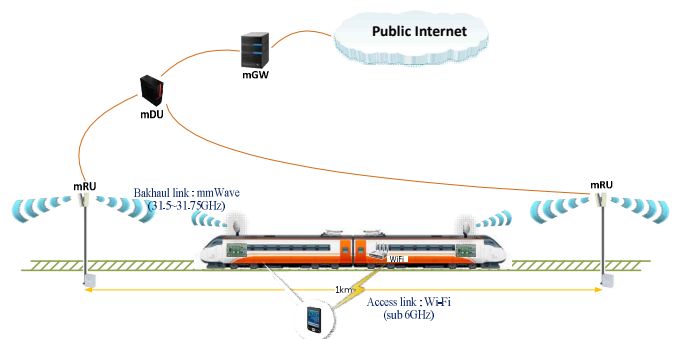


Figure 1. MHN system scenario for subway

MHN is a two-hierarchy system. The first is a wireless mobile backhaul link between a train and a base station using millimeter wave band, in which Gbps rate data are transmitted. The other is an access link inside a train using (Giga) Wi-Fi and/or LTE-A Femto, in which data are supported to the passengers in a compartment. That means general subscribers can use high speed Wi-Fi services with their own smart phones.

According to the MHN system development schedule, we have a target to completely install a test-bed system and demonstrate 1Gbps data throughput of the system in line 8 subway in Seoul, Korea, in Feb, 2016. We have a main target of Gbps data transmission and over 99% handover success rate. We completed physical layer and higher layer specification

works [11-14]. Standardization process is now ongoing in IEEE. Major characteristic of these specifications is to support over 500km/h with 20~40GHz frequency band and we designed 250us TTI, which means 1/4 of LTE specifications.

eNB (eNodeB) of the MHN system is composed of mDU (MHN Digital Unit) and mRU (MHN Radio Unit). UE (User Equipment) of the MHN system is defined as mTE (MHN Terminal Equipment), which is installed at both sides of a train or a subway. The distance between mRU is about 1km. Two antennas of one mTE are configured with both sides, back and forth. Operating scenario of the MHN system is shown in figure 1.

TABLE I. NUMEROLOGY OF OFDM FOR MHN

CP	0.125			
System bandwidth (MHz)	125	250	500	1,000
Sampling rate (MHz)	184.32	368.64	737.28	1474.56
Subcarrier spacing (kHz)	180			
Number of subcarrier (total)	694	1,388	2,777	5,555
Number of subcarrier (except guard band)	624	1,249	2,499	4,999
OFDM symbol length (FFT size)	1,024	2,048	4,096	8,192
OFDM symbol duration (us)	5.56			
CP length	128	256	512	1,024
CP length (First OFDM symbol)	128	256	512	1,024
CP duration (us)	0.69			
CP duration (First OFDM symbol) (us)	0.69			
Slot duration (us)	250			
Number of slot per millisecond	4			
Number of sample per millisecond	184,320	368,640	737,280	1,474,560
Number of sample per slot	46,080	92,160	184,320	368,640
Number of OFDM symbols per slot	40			

MHN system support both TDD (Time Division Duplex) mode and FDD (Frequency Division Duplex) mode. We are considering the main duplex mode as TDD. This is because of the allocation of frequency band. MHN system requires very wide band minimum 125MHz to 500MHz. FDD needs pair bands for downlink band and uplink band. Therefore, it is not easy to secure wide frequency band. On the other hand, in TDD, we can use downlink and uplink transmission in one band simultaneously. 1 radio frame is consisted of 10ms, 1 frame has 40 slots (TTIs). In frequency domain, 1 resource block (RB) is 12 subcarriers. Maximum 50 RBs are supported. System bandwidth is scalable. A basic bandwidth is 125MHz, can be configured to up to 4 x 125MHz (500MHz) with maximum 4 carrier aggregations. Pilot patterns are placed considering high speed environment. These parameters are listed in table I.

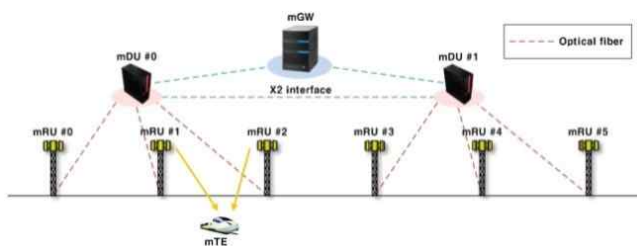


Figure 2. Multi-flow Technique based on DAS

Main characteristic is to adopt multi-flow concept, as shown in figure 2, which can double throughput with the same bandwidth. Subcarrier space is 180kHz. 1024 FFT is used. 1

TTI is 250us and 1 TTI has 40 OFDM symbols. Downlink control channels can be assigned at first 4 OFDM symbols at every TTI.

III. ITERATIVE RECEIVER ALGORITHM FOR MOBILE HOTSPOT NETWORK SYSTEM

MHN system scenario is shown in figure 1, which is mainly focused to the communications of high speed mobile group vehicles and designed to work at LOS environment. MHN system basically uses two antennas, back and forth, and has the structure that each antenna transmits and receives the separate data stream. Therefore, MHN system is designed to support the multi-flow structure as shown in figure 2. Each antenna is to receive the separate data stream from each mRU. However, in case of low SINR (Signal to Interference and Noise Ratio), when the vehicle is placed at the middle of two mRUs, the opposite side of signals can be received and each signal can occur interference and the system performance will degrade. In this case, we need to improve the performance.

We introduce the method to adopt the iterative receive algorithm to MHN system to improve the receiving performance. In general, we can apply iterative receive algorithm when multi code-words are transmitted.

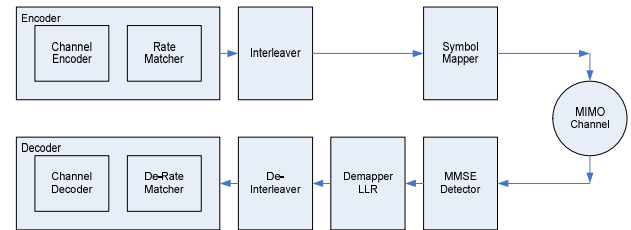


Figure 3. Decoding Procedure of Communication System

Wireless communication systems are generally consisted of encoder and modulator at transmitter and demodulator and decoder at receiver as shown in figure 3. In a MIMO transceiver system which supports spatial multiplexing mode and has multi code-words, after first demodulation and decoding operations, the second demodulation and decoding algorithm are performed iteratively with interference cancellation to improve the performance of receiver.

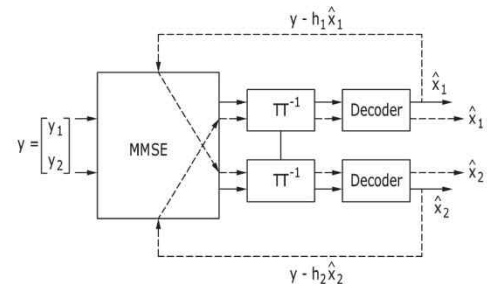


Figure 4. PIC Structure

Figure 4 shows the structure of parallel interference cancellation (PIC). Using the decoded data from 1st iteration, encoding and modulation will be performed like at transmitter. By doing this, we can regenerate the transmitted symbol data

without interference at each code-word. Next, interferences will be eliminated from received signals of first iteration, which will be applied at each code-word. When IR is applied, the procedure is the same as that of the first iteration. Symbols are detected at detector, which are used at computing LLR values and these values are input to channel decoder. Performance will be better by demodulating and decoding with the symbols that interferences are removed.

As described earlier, in order to apply IR algorithm, multi code-words are necessary, in MHN system, one code-word is used. Therefore, IR concept is fundamentally not applicable to MHN system. To improve performance, it is necessary to adopt IR algorithm to MHN system. To do this, in this paper, we propose the method to adopt multi code-words algorithm to MHN system.

In case of figure 5, ideal case is that the signal of mRU #2 is received at ant #1 and the signal of mRU #3 is received at ant #2. However, the signal of mRU #3 can be received at ant #1 and vice versa. In this case, we must know the DCI (Downlink Control format Indicator) information of the signal of mRU #3 at ant #1 in order to demodulate the signal of mRU #3 at ant #1 and vice versa. In this case, as modems of ant #1 and #2 are placed at the same moving vehicle, decoded DCI information of ant #2 can be transmitted to the modem of ant #1. Similarly, the opposite case can be possible. Decoded DCI information of ant #1 can be transmitted to the modem of ant #2. Currently, as each modem can receive two data streams from ant #1 and #2, we can adopt iterative receive algorithm.

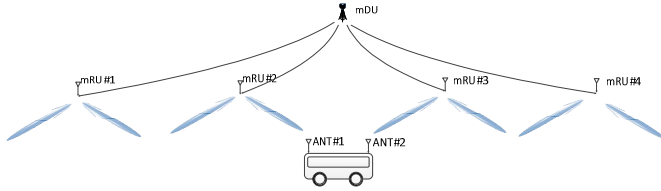


Figure 5. Multi-flow for MHN

One of the most popular detectors is MMSE detector and the principle of this detector is described as below.

Let the transmitted complex-valued symbol is $\mathbf{x}$, following equation is established, where $\mathbf{w}$ is independent identically distributed additive white Gaussian noise with zero mean and variance σ^2 .

$$\mathbf{y} = \mathbf{H} \cdot \mathbf{x} + \mathbf{w} \quad (1)$$

Linear transform $\hat{\mathbf{G}}$ to minimize the mean-squared estimation error of transmitted symbols is given as

$$\hat{\mathbf{x}} = \hat{\mathbf{G}} \cdot \mathbf{y} \text{ and } \hat{\mathbf{G}} = \arg \min_{\hat{\mathbf{G}}} \left[\|\hat{\mathbf{x}} - \mathbf{x}\|^2 \right] \quad (2)$$

Next, Eq. (3) is formed by a necessary condition for transform.

$$\begin{aligned} \frac{\partial}{\partial \hat{\mathbf{G}}} \mathbb{E} \left[\|\mathbf{G}\mathbf{y} - \mathbf{x}\|^2 \right] \Big|_{\hat{\mathbf{G}}} &= 0 \\ \Rightarrow \mathbb{E} \left[\left(\hat{\mathbf{G}}\mathbf{y} - \mathbf{x} \right) \cdot \mathbf{y}^* \right] &= 0 \end{aligned} \quad (3a)$$

$$\begin{aligned} \Rightarrow \hat{\mathbf{G}} \cdot \mathbb{E} \left[\mathbf{y}\mathbf{y}^* \right] &= \mathbb{E} \left[\mathbf{x}\mathbf{y}^* \right] \\ \Rightarrow \hat{\mathbf{G}} \cdot (\mathbf{H}\mathbf{H}^* + \sigma^2 \mathbf{I}) &= \mathbf{H}^* \end{aligned} \quad (3b)$$

As channel state matrix $\mathbf{H}$ has a full-column rank, MMSE weight matrix $\hat{\mathbf{G}}$ can be calculated by MMSE weight matrix.

$$\hat{\mathbf{G}} = (\mathbf{H}^* \cdot \mathbf{H} + \sigma^2 \mathbf{I})^{-1} \cdot \mathbf{H}^* \quad (4)$$

In Eq. (4), operand $\mathbf{A} = \mathbf{H}^* \cdot \mathbf{H} + \sigma^2 \mathbf{I}$ can be decomposed as three matrices product $\mathbf{L} \cdot \mathbf{D} \cdot \mathbf{L}^*$ with Cholesky decomposition by modified Gaussian elimination. LDU decomposition for Hermitian matrix is computed by following equations.

$$\begin{aligned} d_i &= a_{ii} - \sum_{k < i} |l_{ik}|^2 d_k \\ l_{ij} &= \left(a_{ij} - \sum_{k < j} l_{jk}^* l_{ik} d_k \right) / d_j, \text{ for } i < j \end{aligned} \quad (5)$$

MMSE weight matrix $\hat{\mathbf{G}}$ can be computed by the solution of the following simultaneous equation.

$$\mathbf{L} \cdot \mathbf{D} \cdot \mathbf{L}^* \cdot \hat{\mathbf{G}} = \mathbf{H}^* \quad (6)$$

Let $\mathbf{B} = \mathbf{L}^* \cdot \hat{\mathbf{G}}$, we can solve the elements of MMSE weight matrix sequentially by following equation.

$$\begin{aligned} b_{ij} &= \left(h_{ji}^* - \sum_{k < i} l_{ik}^* d_k b_{kj} \right) / d_i \\ \hat{g}_{ij} &= b_{ij} - \sum_{k > i} l_{ki}^* \hat{g}_{kj} \end{aligned} \quad (7)$$

Output signals are the function of both estimated symbols and noise variances, and these are determined by following equations.

$$Sym = \hat{\mathbf{x}} / \mathbf{c}_v \quad (8)$$

$$Snr = \mathbf{c}_v / (1 - \mathbf{c}_v) \quad (9)$$

Column vector $\mathbf{c}$ is calculated by Eq. (10).

$$\mathbf{c} = \text{diag} \left(\left[\mathbf{I} + \sigma^2 (\mathbf{H}^* \cdot \mathbf{H})^{-1} \right]^{-1} \right) = \text{diag} (\hat{\mathbf{G}} \cdot \mathbf{H}) \quad (10)$$

Another case of iterative algorithm can be adopted in figure 5. Ideal case is that the signal of mRU #2 is received at ant #1 and the signal of mRU #3 is received at ant #2. However, the signal of mRU #1 also can be received at ant #1. Similarly, the signal of mRU #4 also can be received at ant #2. In this case, we can adopt the iterative receiver algorithm if we know the DCI information of the signal of mRU #1 at ant #1 to improve the system performance. To do this, DCI information of mRU #1 is simultaneously transmitted at mRU #2. Furthermore, DCI information of mRU #4 is simultaneously transmitted at mRU #3. In this manner, sequential DCI information of next mRU and previous mRU are transmitted. As the path is fixed and we can predict the exact mRU number in MHN system, this

method is applicable in MHN system, which can make MHN system adopt iterative receiver algorithm and improve system performance.

IV. SIMULATIONS

Figure 6 and figure 7 show the performances of the data channel in MHN system, which are focused at high speed circumstances.

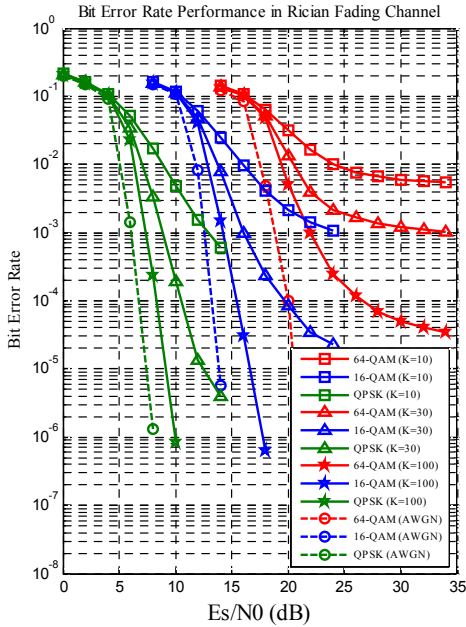


Figure 6. BER ($v=200\text{km/h}$, $R_c=0.8$)

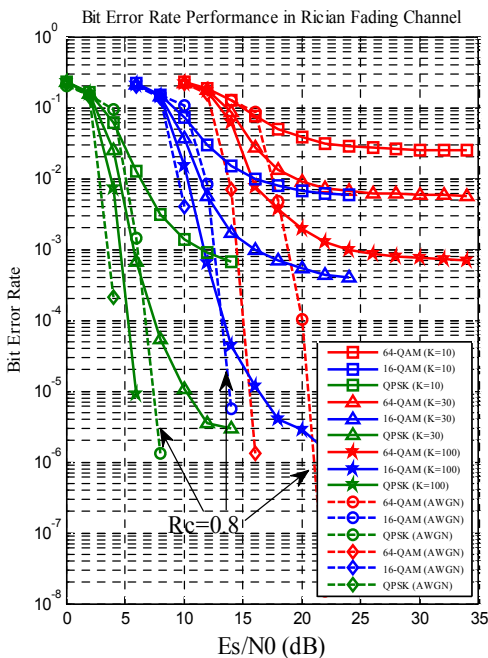


Figure 7. BER ($v=400\text{km/h}$, $R_c=0.6$)

TABLE II. MHN SYSTEM SPECIFICATION

Parameters	Values
System Bandwidth	250 MHz
Carrier frequency	31.5 ~ 31.75 GHz
Tx Power	100mW/250MHz
Multiplexing	OFDM
Modulation	64QAM/16QAM/QPSK
Distance (64QAM)	Straight tunnel(LOS) 1km
	Curved tunnel(NLOS) 500m
Duplex	TDD
Throughput per train	1Gbps
Diversity	Rx (UL), Tx (DL)
Antenna Gain	22dBi
Beam Width (3dB)	horizontal 8°/vertical 8°

V. CONCLUSIONS

In this paper, we introduce the MHN system that can support Giga bps data rate in wireless mobile environment with millimeter wave band, which is especially focused on the high speed moving group vehicles. We proposed the method to adopt the iterative receiver algorithm to MHN system to improve the system performance.

ACKNOWLEDGEMENT

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) (No. R0101-15-244, Development of 5G Mobile Communication Technologies for Hyper-connected smart services)

REFERENCES

- [1] Choong-Hee Lee, Sung-Hyung Lee, Kwang-Chun Go, Sung-Min Oh, Jae Sheung Shin, and Jae-Hyun Kim, Mobile Small Cells for Further Enhanced 5G Heterogeneous Networks, ETRI Journal, vol. 37, no. 5, Oct. 2015, pp. 856-866.
- [2] Hyun-Seo Park, Yong-Seouk Choi, Byung-Chul Kim, and Jae-Yong Lee, LTE Mobility Enhancements for Evolution into 5G, ETRI Journal, vol. 37, no. 6, Dec. 2015, pp. 1065-1076.
- [3] El Ayach, O. ; Rajagopal, S. ; Abu-Surra, S. ; Pi, Z. ; Heath, R., Spatially Sparse Precoding in Millimeter Wave MIMO Systems, Wireless Communications, IEEE Transactions on, 2014, 1-15
- [4] Choi, J., On Coding and Beamforming for Large Antenna Arrays in mm-Wave Systems, Wireless Communications Letters, IEEE, 2014, 1-4
- [5] Kalfas, G. ; Tsiokos, D. ; Pleros, N. ; Verikoukis, C. ; Maier, M., Towards medium transparent MAC protocols for cloud-RAN mm-wave communications over next-generation optical wireless networks, Transparent Optical Networks (ICTON), 2013, 1-4
- [6] White_paper_c11-481360, Cisco Visual Networking Index: Forecast and Methodology, June 2010
- [7] Z. Pi and F. Khan, An introduction to millimeter-wave mobile broadband systems, Communications Magazine, IEEE, vol.49, no.6, pg.101-107, Jun. 2011
- [8] A. Ghosh, R. Ratasuk, B. Mondal, N. Mangalvedhe and T. Thomas, LTE-advanced: next-generation wireless broadband technology [Invited Paper], Wireless Communications, IEEE, vol.17, no.3, pg.10-22, Jun. 2010
- [9] MHN TS.211, Physical Channels and Modulation, ETRI
- [10] MHN TS.212, Multiplexing and channel coding, ETRI
- [11] MHN TS.213, Physical layer procedures, ETRI
- [12] MHN TS.214, Measurements, ETRI



Dae-Soon Cho received Ph.D. in information and communication engineering from KAIST (Korea Advanced Institute of Science and Technology). He is working at ETRI (Electronics and Telecommunications Research Institute) as a principal member of engineering staff. His current research interests are 5G mobile and wireless communications.



Il-Kyu Kim received Ph.D. in information and communication engineering from KAIST (Korea Advanced Institute of Science and Technology). He is working at ETRI (Electronics and Telecommunications Research Institute) as a section leader of Giga telecommunication research section 2. His current research interests are 5G mobile and wireless backhaul communications with millimeter wave.