Novel DFT-based Channel Estimation Scheme for Sidehaul System

Hun Choe, Sangmi Moon and Intae Hwang
Dept. of Electronics and Computer Engineering, Chonnam National University
300 Yongbongdong Bukgu Gwangju, 500-757, Republic of Korea

Keywords: 2-D MMSE, DFT-based Channel Estimation, DMRS, MIMO, SC-FDMA, Sidehaul System.

Abstract: Recently, 3rd Generation Partnership Project (3GPP) has developed sidehaul system to cope with the explosively increasing mobile data traffic. The sidehaul system is based on single carrier-frequency division multiple access (SC-FMDA) due to its low peak-to-average power ratio (PAPR). Also, demodulation reference signal (DMRS) is designed to support multiple input multiple output (MIMO). In this paper, we propose the DFT-based channel estimation scheme for sidehaul system. The proposed scheme uses the 2-dimensional minimum mean square error (2-D MMSE) interpolation scheme for the user moving at a high speed. Simulation results show that the proposed channel estimation scheme can improve normalized mean square error (NMSE), error rate and throughput of conventional system.

1 INTRODUCTION

Explosive demands for mobile data communication are driving changes in the way mobile operators respond to the challenging requirements of higher capacity and improved quality of user experience (QoE). Currently, the 3rd Generation Partnership Project (3GPP) has developed small cells by increasing the node deployment density in macrocells to handle increased capacity requirements ((http://www. qualcomm.com/media/ documents / files / 1000x-more-smallcells-web-.pdf; Hamalainen, 2012; Nakamura, 2012).

This approach, nevertheless, has a fundamental problem in that the cost of operation and installation increases with the number of small cells deployed. Especially, the fixed small cell is inefficient in environments where the maximum local traffic changes by the hour owing to the increase in the floating population.

To solve this problem, we need to develop a moving small cell that can be connected to the macro base station through a wireless backhaul system, and is movable by the user. Nevertheless, there is a limit to the network capacity that can be increased only by wireless backhaul technologies. As the network capacity is limited by the wireless backhaul system that connects the macro base station, a sidehaul system between moving small cells is required to enable a moving small cell to communicate.

In moving small-cell environments, inter-cell interference increases. Studies have been carried out to solve the interference problem by adopting a transmission method to reduce the interference at the base station, a cooperation technique between cells (Myung et al., 2006; 3GPP, TS 36.211, 2013), and a high-performance reception algorithm that handles the interference at the receiver. In the former case, each user equipment (UE) has to feed back the channel information for the interference information to be processed. In view of the possible inaccuracy of the feedback information as well as the feedback overhead due to the increase of the number of antennas, there are restrictions on this interference processing method that requires feedback. Meanwhile, another interference processing method at the receiver has recently attracted the attention in 3GPP as the method does not require feedback.

Network-assisted interference cancellation and suppression (NAICS) is the technology used to reduce the adverse effect of interference by using interference cancellation receivers and interference suppression receivers. In terms of improvement of the capacity and interference cancellation, several receiver algorithms based on the minimum mean-square error (MMSE) have been proposed for multi-

Choe H., Moon S. and Hwang I..
Novel DFT-based Channel Estimation Scheme for Sidehaul System.
DOI: 10.5220/0005232001950201
In *Proceedings of the 5th International Conference on Pervasive and Embedded Computing and Communication Systems* (PECCS-2015), pages 195-201
ISBN: 978-989-758-084-0

cell environments. 3GPP Release 12 selects NAICS as the study item (SI) and discusses the improvement in performance, the type of support information, and the overhead with network support (Zaka *et al.*, 2009).

In this paper, we first describe the conventional receiver used to reduce the inter-cell interference and propose a hybrid receiver that integrates the interference rejection combining (IRC) technique with successive interference cancellation (SIC). The paper is organized as follows. We present the overview of the sidehaul system in Section 2. Section 3 describes the conventional receivers. In section 4, we propose the novel hybrid receiver for achieving full successive cancellation (FSC). Section 5 presents the performance analysis of the proposed scheme through simulations. Finally, the conclusion drawn is given in section 6.

2 STRUCTURE OF TRANSMITTER AND RECEIVER IN SIDEHAUL SYSTEM

We design the structure of transmitter and receiver in sidehaul system based on uplink of LTE-Advanced (3GPP, TS 36.211, 2013). As depicted in Figure 1, the baseband signal representing the physical sidehaul shared channel (PSSCH) is defined in terms of the following steps:

- Scrambling
- Modulation of scrambled bits to generate complex-valued symbols
- Mapping of the complex-valued modulation symbols onto one or several transmission layers
- Transform precoding to generate complex-valued symbols
- Precoding of the complex-valued symbols
- Mapping of precoded complex-valued symbols to resource elements
- Generation of complex-valued time-domain SC-FDMA signal for each antenna port

After generating the PSSCH, the transmitter sends them out through the wireless channel. The received signal is usually distorted by the channel characteristic. In order to recover the transmitted signal, the channel is estimated using the reference signal and compensated in receiver.

SC-FDMA has drawn great attention as an attractive alternative to OFDMA, especially in the uplink communications where lower PAPR greatly benefits the mobile terminal in terms of transmit power efficiency and reduced cost of the power amplifier. Therefore, it has been adapted as the access scheme in sidehaul system.

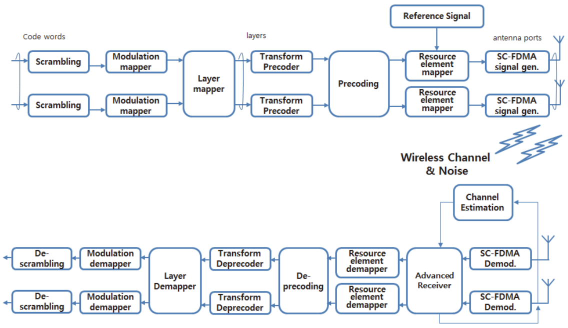

Figure 1: Block diagram of transmitter and receiver in sidehaul system.

A physical resource block (PRB) is the minimal unit for resource allocation in sidehaul system. A PRB is defined as N_symb^UL consecutive SC-FDMA symbols in the time domain and N_sc^RB consecutive subcarriers in the frequency domain, where N_symb^UL and N_sc^RB are given by Table 1.

A PRB consists of N_symb^UL×N_sc^RB resource elements, corresponding to one slot in the time domain and 180 kHz in the frequency domain.

Table 1: Resource Block Parameters.

Configuration	N_{sc}^{RB}	N_{symb}^{UL}
Normal cyclic prefix	12	7
Extended cyclic prefix	12	6

Each radio frame is 10ms long and consists of 20 slots of length 0.5ms. A subframe is defined as two consecutive slots where subframe i consists of slots 2i and 2i+1.

3 SIDEHAUL REFERENCE SIGNAL DESIGN

PSSCH is the channel for sideaul data transmission, and DMRS is reference to acquire the channel estimation values used in the PSSCH data detection. Different DMRS sequences are needed to support the MIMO system. In this section, we describe the DMRS structure.

3.1 DMRS Design

DMRS sequence is generated using the constant amplitude zero auto correlation (CAZAC) sequence to separate the signal of each terminal with code division multiplex (CDM) [5]. A DMRS sequence is defined by a cyclic shift (CS) α of a base sequence according to

$$r_{u,v}^{(\alpha)}(n) = e^{j\alpha n}\bar{r}_{u,v}(n), \quad 0 \le n < M_{\mathrm{sc}}^{\mathrm{RS}} \tag{1}$$

where is the length of DMRS sequence, m is the PRB number and is the subcarrier number within each PRB. Multiple DMRS sequence can be derived from a single base sequence through different values of α.

The definition of the base sequence depends on the sequence length. For , the base sequence is given by.

$$\bar{r}_{u,v}(n) = x_q(n \bmod N_{\mathrm{ZC}}^{\mathrm{RS}}), \quad 0 \le n < M_{\mathrm{sc}}^{\mathrm{RS}} \tag{2}$$

where the q^{th} root Zadoff-Chu sequence is defined by

$$x_q(m) = e^{-j\frac{\pi q m(m+1)}{N_{\mathrm{ZC}}^{\mathrm{RS}}}}, \quad 0 \le m \le N_{\mathrm{ZC}}^{\mathrm{RS}} - 1 \tag{3}$$

with q given by

$$\begin{aligned} q &= \lfloor \bar{q} + 1/2 \rfloor + v \cdot (-1)^{\lfloor 2\bar{q} \rfloor} \\ \bar{q} &= N_{\mathrm{ZC}}^{\mathrm{RS}} \cdot (u+1)/31 \end{aligned} \tag{4}$$

The length $N_{\mathrm{ZC}}^{\mathrm{RS}}$ of the Zadoff-Chu sequence is given by the largest prime number such that $N_{\mathrm{ZC}}^{\mathrm{RS}} < M_{\mathrm{sc}}^{\mathrm{RS}}$. For , $M_{sc}^{RS} < 3N_{sc}^{RB}$ base sequence is defined as computer generated constant amplitude zero autocorrelation (CG-CAZAC) sequence and is given by

$$\bar{r}_{u,v}(n) = e^{j\varphi(n)\pi/4}, \quad 0 \le n \le M_{\mathrm{sc}}^{\mathrm{RS}} - 1 \tag{5}$$

where the value of $\varphi(n)$ is given in (3GPP, TS 36.211, 2013).

In order to reduce the inter-cell interference (ICI), there are two kinds of hopping defined for the DMRS. First, group hopping is the method to obtain an effect of randomizing of ICI by changing the group index in slot unit. The sequence-group number u in slot n_{s} is defined by a group hopping pattern $f_{\mathrm{gh}}(n_{\mathrm{s}})$ and a sequence-shift pattern according to

$$u = \left(f_{\mathrm{gh}}(n_{\mathrm{s}}) + f_{\mathrm{ss}}\right) \bmod 30 \tag{6}$$

There are 17 different hopping patterns and 30 different sequence-shift patterns. The hopping pattern is generated based on 17 random hopping patterns. Thus group hopping pattern for 504 cell ID is represented with combination of patterns. Secondly, sequence hopping only applies for reference-signals of length $M_{\mathrm{sc}}^{\mathrm{RS}} \ge 6N_{\mathrm{sc}}^{\mathrm{RB}}$. Hopping takes place between two base sequence indexes within the base sequences group as slot unit in sub-frame. For reference-signals of length $M_{\mathrm{sc}}^{\mathrm{RS}} < 6N_{\mathrm{sc}}^{\mathrm{RB}}$, the base sequence number v within the base sequence group is given by $v = 0$. For reference-signals of length $M_{\mathrm{sc}}^{\mathrm{RS}} \ge 6N_{\mathrm{sc}}^{\mathrm{RB}}$, the base sequence number v within the base sequence group in slot n_{s} is defined by

$$v = \begin{cases} c(n_{\mathrm{s}}) & \text{if group hopping is disabled and sequence hopping is enabled} \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

where $c(i)$ is the pseudo-random sequence.

In order to support MIMO transmission in sidehaul system, DMRS between the antennas are orthogonal by using the CAZAC sequence with different cyclic shift value each antenna. The PSSCH demodulation reference signal sequence $r_{PSSCH}^{(i)}(\cdot)$ associated with transmit antenna, $i = 0, 1, \cdots, N_{\mathrm{tx}} - 1$, is defined by

$$r_{PSSCH}^{(i)}(n) = e^{j\alpha_i n}\bar{r}_{u,v}(n), \qquad n = 0, \cdots, M_{sc}^{RS} - 1 \tag{8}$$

where cyclic shift α_i in a slot n_{s} is given as $\alpha_i = 2\pi n_{cs,i}/12$ with

$$n_{cs,i} = \left(n_{cs,0} + \frac{12}{N_{\mathrm{tx}}} \cdot i\right) mod 12 \tag{9}$$

Therefore, it is possible to separate the channel by orthogonal DMRS between the antennas.

3.2 Mapping of DMRS

In sidehaul system, the DMRS for PSSCH in the frequency domain will be mapped to the same set of PRB used for the corresponding PSSCH transmission with the same length expressed by the number of subcarriers, while in the time domain DMRS will occupy the 4th SC-FDMA symbol in each slot with normal cyclic prefix (CP), as shown in Figure 2. In case of extended CP, DMRS will occupy the 3rd SC-FDMA symbol in each slot.

In this mapping, SC-FDMA symbols with DMRS at all are transmitted periodically for channel estimation. Using these DMRS, a time-domain interpolation is performed to estimate the channel along the time axis. Since DMRS are inserted into all subcarriers of DMRS with a period in time, this arrangement is suitable for frequency-selective channels. For the fast-fading channels, however, it might incur too much overhead to track the channel variation by reducing the DMRS period. Therefore, we will propose the channel estimation scheme for the time-varying channel in the next section.

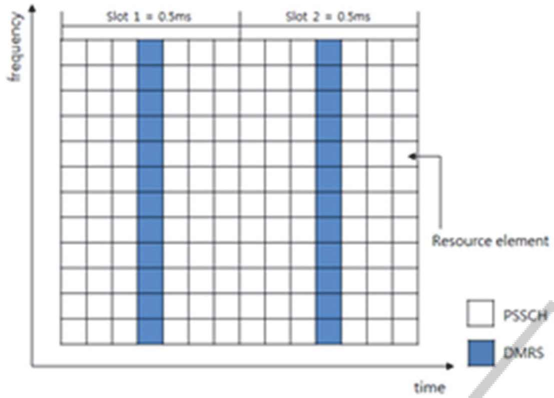

Figure 2: Mapping of DMRS.

4 NOVEL DFT-BASED CHANNEL ESTIMATION SCHEME

In this section, we describe the DFT-based channel estimation scheme and propose the 2-dimensional minimum mean square error (2-D MMSE) to compensate the effect of ICI in the time varying channels.

4.1 Novel DFT-based Channel Estimation

The received signal by the jth receive antenna in the kth subcarrier and the lth SC-FDMA symbol, $Y_j(k,l)$, is expressed as follows

$$Y_j(k,l) = \sum_{i=0}^{N_{\mathrm{tx}}-1} H_{j,i}(k,l) X_{j,i}(k,l) + N_i(k,l) \quad (10)$$

where $H_i(k,l)$ represents $N_{\mathrm{rx}} \times N_{\mathrm{tx}}$ channel matrix of the kth subcarrier and the lth SC-FDMA symbol, $X_i(k,l)$ represents N_{tx}-dimensional transmit signal vector of the kth subcarrier and the lth SC-FDMA symbol, and $N(k,l)$ is the N_{rx}-dimensional additive white gaussian noise (AWGN) vector.

Based on Figure 2, we can see that $X_i(k,3) = X_i(k,10) = r_i(k)$, since group hopping and sequence hopping are not assumed here, which are the DMRS. The channel estimation is based on $Y_i(k,3)$ and $Y_i(k,10)$.

The steps for DFT-based channel estimation are as follows:

1) Multiply Y(k,3) with the conjugate of r_0 (k), i.e.,

$$\widetilde{H}(k,3) = Y(k,3) r_0(k)^* \quad (11)$$

2) Perform N-point IFFT over H̃(k,3) to get the time domain channel, i.e.,

$$\tilde{h}(n,3) = \frac{1}{\sqrt{2}} \sum_{k=0}^{N-1} \widetilde{H}(k,3) e^{j2\pi kn/N} \quad (12)$$

where $0 \le n \le N-1$.

3) Perform the windowing for channel impulse response (CIR) using window function, i,e.,

$$\tilde{h}_w(n,3) = \begin{cases} \tilde{h}(n,3), & N - N_{win}^{neg} \le n < N_{win}^{pos} \\ 0, & otheriwse \end{cases} \quad (13)$$

where window parameter N_{win}^{neg} and N_{win}^{pos} are the number sample of positive region and negative region of window function, respectively. And that are set considering the delay spread and size of channel.

4) Separate the time domain channel for different data stream, i.e., calculate

$$\hat{h}_i(n,3) = \tilde{h}_w\left(\left(n + \frac{n_{cs,i}N}{12}\right) mod(N), 3\right) \quad (14)$$

5) Do N-point FFT of $\hat{h}_i(n,3)$ to get the frequency domain channel response of each data stream, i.e.,

$$\widehat{H}_{i,DFT}(k,3) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \hat{h}_i(n,3) e^{-j2\pi kn/N} \quad (15)$$

Find the channel frequency response by performing the above process for the rest of $Y(k,10)$

4.2 Interpolation Scheme

To estimate the channel for data signal, the reference signal subcarriers must be interpolated. Since channel frequency responses from DFT-based channel estimation are separated into 7 SC-FDMA symbols.

4.2.1 Linear Interpolation

Linear interpolation is the simplest method for interpolation. We calculate the linear equation using channel frequency response that is obtained from the DFT-based channel estimation [6].

$$\widehat{H}_{i,Linear}(k,l) = \widehat{H}_{i,DFT}(k,3) + \frac{m}{6}\left(\widehat{H}_{i,DFT}(k,10) - \widehat{H}_{i,DFT}(k,3)\right), \quad m = 0,1,\cdots,M-1 \quad (16)$$

Where $M = 7$ is the spacing between DMRS.

4.2.2 2-D MMSE Interpolation

Linear interpolation scheme may be applicable only when the channel characteristic does not change within an SC-FDMA symbol period. However, the channel for the terminals that move fast may vary with time within an SC-FDMA symbol period, in which longer SC-FDMA symbol period has a more severe effect on the channel estimation performance. The time-varying channel may destroy the orthogonality among subcarriers at the receiver, resulting in ICI. Due to the effect of ICI, it cannot be compensated by the conventional interpolation scheme.

In order to deal with the effect of ICI in the time-varying channels, we propose the 2-D MMSE interpolation that performs the interpolation in both frequency and time domain. The following algorithm summarizes how to get the estimates $\hat{H}_{2-D\,MMSE}$.

First, we update the channel estimation about SC-FDMA symbol including the DMRS signal in frequency domain.

$$\hat{H}^f_{2-D\,MMSE} = R^f_{hp}\left[R^f_{pp} + \frac{1}{SNR} I_p\right]^{-1} \hat{H}^f_{DFT} \qquad (17)$$

where $\hat{H}^f_{DFT}$ is expressed in (15).

Then we apply the MMSE in time domain and estimate the channel impulse response for the entire SC-FDMA symbols.

$$\hat{H}^t_{2-D\,MMSE} = R^t_{hp}\left[R^t_{pp} + \frac{1}{SNR} I_p\right]^{-1} \hat{H}^f_{2-D\,MMSE} \qquad (18)$$

where R_{hp} is the cross-correlation matrix between the true channel H and temporary channel estimate $\hat{H}$ and R_{pp} autocorrelation matrix of temporary channel estimate $\hat{H}$

5 SIMULATION RESULTS AND PERFORMANCE ANALYSIS

In this section, we will present the simulation results for proposed channel estimation scheme and analysis the performance. The simulation results are based on the link level Monte Carlo simulations.

Table 2 shows the general simulation parameters and defines the simulated environment. Table 3, shows the power delay profile (PDP) of extended typical urban (ETU) channel. The simulation parameters are based on 3GPP LTE-Advanced system 20 MHz Bandwidth. And time variant frequency selective channel is modeled according E-UTRA ETU channel with maximum Doppler frequency (f_d) of 300Hz (3GPP TS 36.101, 2013). Also in channel estimation, window parameters are set $N_{win}^{neg} = 16$ and $N_{win}^{pos} = 160$ considering the delay spread and size of ETU channel.

Table 2: Simulation parameters.

Parameter	Value
Carrier frequency	2 GHz
Bandwidth	20 MHz
Sample frequency	30.72 MHz
Subframe duration	1 ms
Subcarrier spacing	15 kHz
FFT size	2048
Occupied subcarriers	1200
No. of subcarriers/PRB	12
Cyclic Prefix (CP)	Normal CP
No. of OFDM symbols/subframe	14 (Normal CP)
Channel Model	ETU, fd = 300Hz
MIMO Configuration	4x4
Channel Estimation	Ideal, 2-D MMSE, Linear
Advanced Receiver	MMSE

Table 3: ETU Channel Model.

Excess tap delay [ns]	Excess tap delay [sample]	Relative power [dB]
0	0	-1.0
50	2	-1.0
120	4	-1.0
200	6	0.0
230	7	0.0
500	15	0.0
1600	49	-3.0
2300	71	-5.0
5000	154	-7.0

Figure 3 shows the normalized mean square error (NMSE) performance according to channel estimation scheme. The proposed 2-D MMSE brings performance improvements with 3 dB SNR as referenced to NMSE 10^{-2} compared to linear interpolation. Because the proposed scheme estimates the channel of SC-FDMA symbol not including the DMRS using the correlation characteristic of the channel except $l = 3$ and $l = 10$. Therefore, proposed scheme can estimate the channel of moving small cells at high speed.

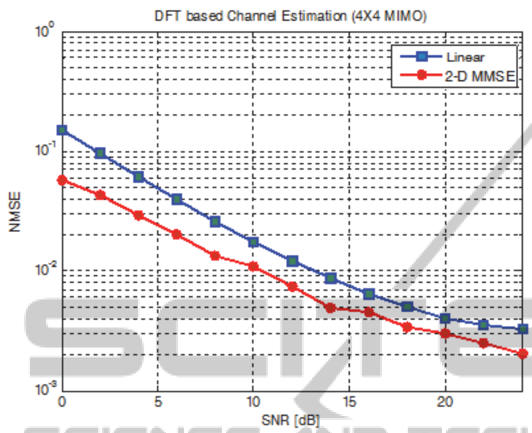

Figure 3: MMSE performance according to channel estimation scheme.

Figure 4 shows the Uncoded bit error rate (BER) according to channel estimation scheme. As referenced to Uncoded BER 10^{-2}, 35 dB, 40 dB, and 50 dB are the minimum required SNR of Ideal, 2-D MMSE and Linear, respectively.

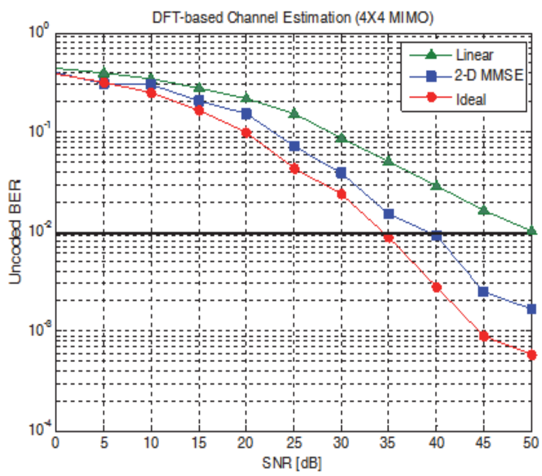

Figure 4: BER performance according to channel estimation scheme.

Figure 5 shows the frame error rate (FER) according to channel estimation scheme. As referenced to FER 10^{-1}, 37 dB, 43 dB, and 55 dB are the minimum required SNR of Ideal, 2-D MMSE and Linear, respectively.

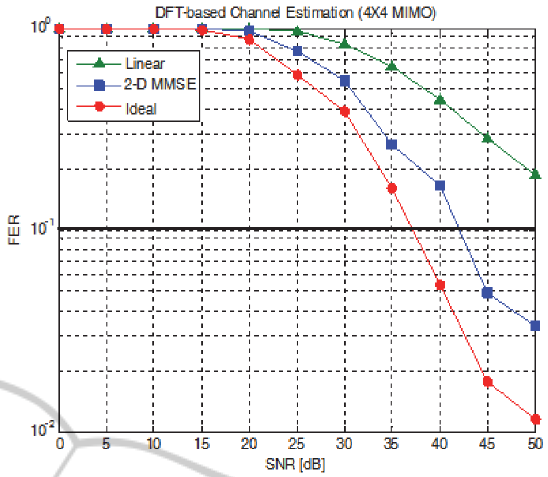

Figure 5: FER performance according to channel estimation scheme.

From the simulation results as shown in figure 4 and 5, the proposed scheme bring the significant error performance gain compared with linear interpolation scheme.

Figure 6 shows the throughput performance according to channel estimation scheme. The theory maximum data rate is 334.31 Mbps considering the DMRS and physical sidehaul control channel (PSCCH). As referenced to SNR 50 dB, it can be seen that Ideal, 2-D MMSE and Linear reach the 330 Mbps, 323 Mbps and 272 Mbps, respectively. Therefore, the proposed scheme brings performance improvements with 12 dB SNR as referenced to 250 Mbps compared to linear interpolation.

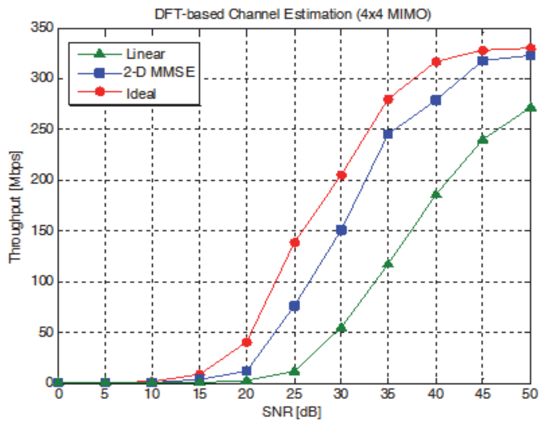

Figure 6: Throughput performance according to channel estimation scheme.

6 CONCLUSIONS

In this paper, we design DMRS to support the MIMO transmission for high speed and capacity data transmission in sidehaul system between moving small cells. Also, we propose the DFT-based channel estimation scheme. The proposed scheme uses the 2-D MMSE interpolation scheme for the user moving at a high speed. Simulation results show that the proposed scheme brings performance improvements with 3 dB SNR as referenced to NMSE 10^{-2} compared to conventional scheme. In case of error rate results, we observe that the proposed scheme clearly outperforms the conventional shcme, with considerable gain of 10 dB and 12 dB as referenced to Uncoded BER 10^{-2} and FER 10^{-1}, respectively. Therefore the proposal in this study is a promising solution for channel estimation in sidehaul system. In our future work, the frame structure could be design to improve the maximum data rate in sidehaul system.

ACKNOWLEDGEMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(NRF-2013R1A1A2007779).

REFERENCES

Qualcomm, "1000x: More Small Cells – Taking HetNets to the Next Level," (http://www.qualcomm.com/media/documents/files/1000x-more-smallcells-web-.pdf).

J. Hamalainen (Ericsson),2012. 2 "Towards Heterogeneous Networks" (http://bnrg.cs.berkeley.edu/~randy/Courses/CS294.S13/13.3.pdf).

T. Nakamura (NTT Docomo), 2012. "Further LTE Enhancements toward Future Radio Access".

H. G. Myung, J. Lim and D. J. Goodman, Sept. 2006. "Single carrier FDMA for uplink wireless transmission," IEEE Veh, Techno. Ma.g., vol. 1, no. 3, pp. 30-38.

3GPP, TS 36.211, Sept. 2013. "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation," V11.4.0.

Klodiana Zaka, Agha Yasir Ali, M. Irfan Anis, Shariq-uz-Zaman, Irfan Usmani and Naveed Ahmed, , Nov. 2009. "Technique for channel estimation in OFDM transmission system using linear interpolation and Euclidean distance algorithm," Asian Himalayas International Conference on Internet (AH-ICI) 2009, pp. 1-5.

3GPP TS 36.101, March 2013. "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception," V11.4.0.