Novel Hybrid Receiver for Interference Cancellation and Suppression in Sidehaul System

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Abstract: Recently, the 3rd Generation Partnership Project (3GPP) has developed a sidehaul system to cope with the explosively increasing mobile data traffic. Nevertheless, numerous challenging technical problems that need to be overcome remain. One of the major problems is interference management between small cells. In this paper, we propose a novel hybrid receiver for full successive cancellation (FSC) to reduce the interference from neighboring cells in the sidehaul system. The proposed receiver can cancel and suppress interference by integrating the interference rejection combining (IRC) technique with successive interference cancellation (SIC). We perform a simulation based on the 20-MHz bandwidth of the 3GPP LTE-Advanced technology. Simulation results show that the proposed receiver can achieve a lower error rate and a higher throughput compared to conventional receivers.

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 (Samsung, 94-99; Sawahashi *et al.,* 2010.), 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

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receiver algorithms based on the minimum mean-square error (MMSE) have been proposed for multi-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 (3GPP TR 36.866 , 2014).

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 OVERVIEW OF A SIDEHAUL SYSTEM

2.1 Structure of Transmitter and Receiver in a Sidehaul System

We design the structure of the transmitter and the receiver used in the sidehaul system based on the uplink of LTE-Advanced (3GPP, TS 36.211 , 2013). Single carrier-frequency division multiple access (SC-FDMA) has drawn great attention as an attractive alternative to OFDMA, especially in the uplink communications where a lower peak-to-average power ratio (PAPR) greatly benefits the mobile terminal in terms of transmit power efficiency and reduced cost of the power amplifier. Therefore, SC-FDMA has been adopted as the access scheme in the sidehaul system.

As depicted in Figure 1, the baseband signal representing the physical sidehaul shared channel (PSSCH) is defined in terms of the following steps:

- Channel Coding
- Scrambling
- Modulation of scrambled bits to generate complex-valued symbols
- Mapping of complex-valued modulation symbols onto one or several transmission layers
- Transform precoding to generate complex-valued symbols
- Precoding of 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 SC-FDMA signal out through the wireless channel.

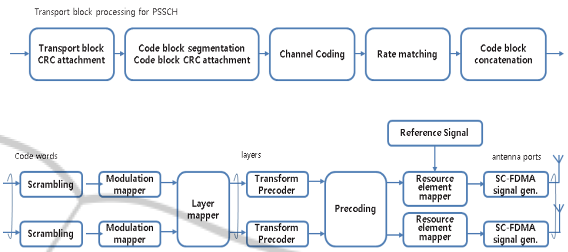

Figure 1: Block diagram of transmitter in sidehaul system.

In the receiver, the received signal is usually distorted by the channel characteristics. In order to recover the transmitted signal, the channel is estimated using a reference signal and compensated in the receiver. Figure 2 shows the structure of the receiver in the sidehaul system.

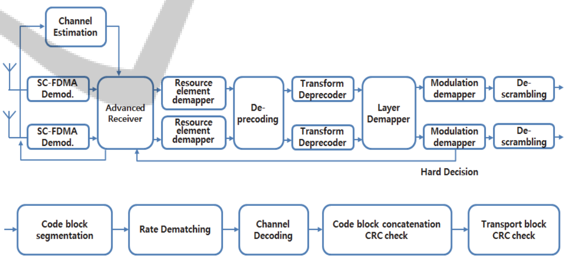

Figure 2: Block diagram of receiver in sidehaul system.

2.2 Structure of Resource Allocation in a Sidehaul System

A physical resource block (PRB) is the minimal unit used for resource allocation in a 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; the values of the block parameters N_{symb}^{UL} and N_{sc}^{RB} are listed in Table 1.

A PRB consists of $N_{symb}^{UL} \times N_{sc}^{RB}$ resource elements (REs), corresponding to one slot in the time domain and 180 kHz in the frequency domain.

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

In the sidehaul system, PSSCH is the channel

Table 1: Resource block parameters.

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

used for sidehaul data transmission, and the demodulation reference signal (DMRS) is the reference signal. 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, whereas in the time domain, DMRS will occupy the fourth SC-FDMA symbol in each slot with a normal cyclic prefix (CP), as shown in Figure 3. In the case of extended CP, DMRS will occupy the third SC-FDMA symbol in each slot.

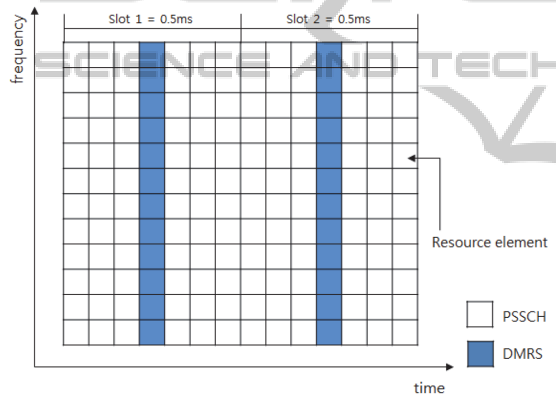

Figure 3: Mapping of demodulation reference signal (DMRS).

3 CONVENTIONAL RECEIVER

In this section, we describe conventional receivers based on techniques such as MMSE, IRC, SIC, and maximum likelihood (ML). For a sidehaul system, the received signal at an RE can be expressed as:

$$\boldsymbol{x} = \boldsymbol{H}\,\boldsymbol{s} + \sum_{i=1}^{p} \boldsymbol{H}_i \boldsymbol{s}_i + \boldsymbol{n}, \quad (1)$$

where $\boldsymbol{s}$ and $\boldsymbol{H}$ are the desired signal targeted to the UE and its corresponding propagation channel respectively, and $\boldsymbol{s}_i$ and $\boldsymbol{H}_i$ ($i = 1,2,\dots,p$) are p interfering signals and their corresponding channels; $\boldsymbol{n}$ is an additive white noise vector. It can be assumed that the signals transmitted from different sources and different MIMO layers are mutually independent of each other and have unit power. Thus we have $\boldsymbol{R}_s = E\{\boldsymbol{s}\,\boldsymbol{s}^H\} = \boldsymbol{I}$, $\boldsymbol{R}_{si} = E\{\boldsymbol{s}_i \boldsymbol{s}_i^H\} = \boldsymbol{I}$, and $E\{\boldsymbol{s}\,\boldsymbol{s}_i^H\} = E\{\boldsymbol{s}_i \boldsymbol{s}_j^H\} = \boldsymbol{0},\ i,j = 1 \dots p, i \neq j$. Note that the actual transmission power and the precoding matrix are factored in the channel matrix.

3.1 MMSE Receiver

The MMSE receiver treats interference as white noise. Along with the channel matrix for the desired signal, only interference-plus-noise power σ_{I+n}^2 needs to be estimated by the MMSE receiver. The MMSE receiver can be expressed as

$$\hat{\boldsymbol{s}} = \boldsymbol{H}^H (\boldsymbol{H}\boldsymbol{H}^H + \sigma_{I+n}^2 \boldsymbol{I})^{-1} \boldsymbol{x}. \quad (2)$$

3.2 IRC Receiver

The MMSE-IRC receiver is expected to outperform the MMSE receiver in strong interference scenarios. The MMSE-IRC receiver can be expressed as

$$\hat{\boldsymbol{s}} = \boldsymbol{H}^H (\boldsymbol{H}\boldsymbol{H}^H + \boldsymbol{R}_{I+n})^{-1} \boldsymbol{x}. \quad (3)$$

where $\boldsymbol{R}_{I+n}$ is the interference and noise covariance matrix. As the DMRS sequence of the serving cell is known at the receiver, the interference and noise covariance matrix can be estimated as

$$\boldsymbol{R}_{I+n} = E[\tilde{\boldsymbol{x}}(k,l)\tilde{\boldsymbol{x}}^{\boldsymbol{H}}(k,l)], \quad (4)$$

where $\tilde{x}(k,l)$ is expressed as

$$\tilde{\boldsymbol{x}}(k,l) = \boldsymbol{x}(k,l) - \hat{\boldsymbol{H}}(k,l)\boldsymbol{r}(k,l). \quad (5)$$

Here, $r(k,l)$ is the DMRS sequence of the serving cell.

3.3 SIC Receiver

There are two types of SIC receivers. In the first type, only symbol demodulation is involved in the SIC process; in the other, forward error correction FEC decoding is involved. It can be expected that if FEC decoding is involved in the SIC process, the performance will be better compared to the receiver that uses only symbol demodulation. It has to be noted that FEC decoding requires detailed coding information and resource allocation information of the interference signal to be available to the UE receiver. This requires considerable system coordination and signaling overheads. In this study, the SIC receiver that uses only symbol demodulation is employed.

The flow chart of the SIC receiver is depicted in Figure 4.

The SIC receiver can be expressed as

$$\hat{\boldsymbol{s}} = \boldsymbol{H}^H (\boldsymbol{H}\boldsymbol{H}^H + \sigma_n^2 \boldsymbol{I})^{-1} \left(\boldsymbol{x} - \sum_{i=1}^{p} \boldsymbol{H}_i \tilde{\boldsymbol{s}}_i\right), \quad (6)$$

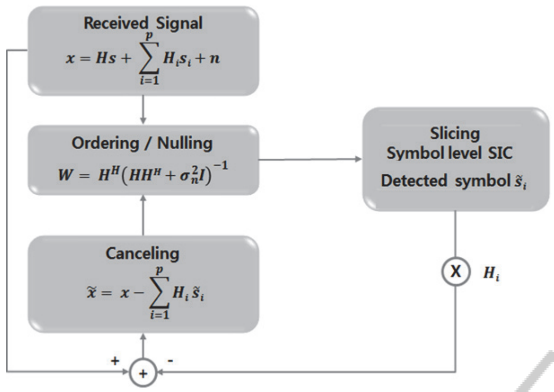

Figure 4: Flow chart of SIC receiver.

where $\tilde{\boldsymbol{s}}_i$ is the quantized estimation of the interference signal $\boldsymbol{s}_i$.

The receiver needs to know the modulation order of the interference signal and the channel matrix of the interferers as well. The SIC receiver requires system assistance to receive the interference modulation order information and means to estimate the interference channel metrics.

3.4 ML Receiver

ML receivers provide an optimal performance compared to other receiver structures. SIC receivers can be viewed as sub-optimal realizations of ML receivers. SIC receivers have less computational complexity with some performance degradation compared to ML receivers. The ML receiver, similar to the SIC receiver, requires information of the modulation order and channel metrics of interference signals. The ML receiver can be expressed as

$$\{\hat{\boldsymbol{s}}, \hat{\boldsymbol{s}}_1, \hat{\boldsymbol{s}}_2, \dots, \hat{\boldsymbol{s}}_p\} = \arg \min_{s, s_1, s_2, \dots, s_p \in \boldsymbol{\Omega}} \left\| \boldsymbol{x} - \boldsymbol{H}\,\boldsymbol{s} - \sum_{i=1}^{p} \boldsymbol{H}_i \boldsymbol{s}_i \right\| \quad (7)$$

where $\boldsymbol{\Omega}$ is the set of constellation points of the modulations used for the desired signal and the interference signal. In the actual implementation of an ML receiver, the estimate of the interference signal $\hat{\boldsymbol{s}}_1, \hat{\boldsymbol{s}}_2, \dots, \hat{\boldsymbol{s}}_p$ can be discarded.

4 PROPOSED RECEIVER

In this section, we propose the novel hybrid FSC receiver that combines IRC with SIC. The flow chart of the proposed FSC receiver is depicted in Figure 5.

According to the steps shown in Figure 5, the signal-to-interference ratio (SIR) of the received signal is calculated. If the interference signal is greater than the desired signal, SIR < 0, and the interference signal is estimated by IRC and the estimated interference signal $\tilde{s}_i$ is expressed as

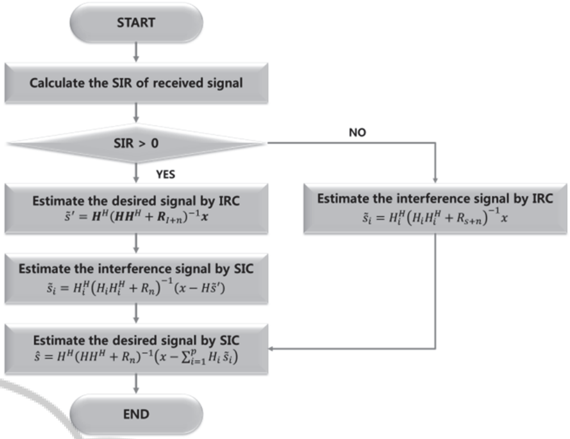

Figure 5: Flow chart of FSC receiver.

$$\tilde{\boldsymbol{s}}_i = \boldsymbol{H}_i^H \left(\boldsymbol{H}_i \boldsymbol{H}_i^H + \boldsymbol{R}_{s+n} \right)^{-1} \boldsymbol{x}, \quad (8)$$

where R_{s+n} is the desired signal and noise covariance matrix. Finally, the desired signal is estimated by SIC and this estimated desired signal $\hat{s}$ is expressed as

$$\hat{\boldsymbol{s}} = \boldsymbol{H}^H (\boldsymbol{H}\boldsymbol{H}^H + \boldsymbol{R}_n)^{-1} \left(\boldsymbol{x} - \sum_{i=1}^{p} \boldsymbol{H}_i \tilde{\boldsymbol{s}}_i \right), \quad (9)$$

where R_n is the noise covariance matrix.

If the desired signal is greater than the interference signal, SIR > 0; in this case, the desired signal can be estimated by the following steps.

First, the desired signal is estimated by IRC and $\tilde{s}'$ is expressed as

$$\tilde{s}' = \boldsymbol{H}^H (\boldsymbol{H}\boldsymbol{H}^H + \boldsymbol{R}_{I+n})^{-1} \boldsymbol{x}. \quad (10)$$

The interference signal is then estimated by SIC, and $\tilde{s}_i$ is expressed as

$$\tilde{\boldsymbol{s}}_i = \boldsymbol{H}_i^H \left(\boldsymbol{H}_i \boldsymbol{H}_i^H + \boldsymbol{R}_n \right)^{-1} (\boldsymbol{x} - \boldsymbol{H}\tilde{\boldsymbol{s}}'). \quad (11)$$

In order to cancel the estimated interference in the received signal, the desired signal is estimated by SIC and the estimated desired signal $\hat{s}$ is expressed as (9).

5 SIMULATION RESULTS AND PERFORMANCE ANALYSIS

In this section, we present the link level simulation results to compare the performance of the receivers mentioned in the previous sections. We consider one neighbor cell causing the inter-cell interference in the serving cell. Table 2 shows the general simulation parameters and defines the simulated environment. Table 3 shows the power-delay profile (PDP) of an extended typical urban (ETU) channel. The simulation parameters are based on the 20-MHz bandwidth of 3GPP LTE-Advanced technology. The time-variant frequency-selective channel is modeled as an ETU channel with a maximum Doppler frequency (f_d) of 300 Hz (R4-131291, 2013). In the case of the desired signal, we use the MCS index, and the channel coding parameters are listed in Table 3. Otherwise, the channel coding is not considered in the interference signal because of system complexity. The signal-to-noise ratio (SNR) range is 16 dB–40 dB and SIR is 24 dB.

Table 2: Resource block 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	4 × 4
Channel Estimation	Ideal
Receiver	Conventional Receivers: MMSE, IRC, SIC, and ML Proposed Receiver: FSC

Figure 6 shows the coded bit-error rate (BER) for the different types of receivers. As referenced to a coded BER of 10^{-2}, the minimum required SNR for each type of receiver is given in Table 5. We observe degradation in the MMSE and IRC receivers because of strong interference. On the other hand, the SIC, FSC and ML receivers outperform the MMSE receiver by cancelling the interference

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

Table 4: Channel Coding Parameter: MCS Index 27.

MCS Index	27
CQI Index	14
Modulation	64QAM
Target code rate	0.8525 (5/6)
Information bit payload	637776
Binary channel bits per subframe	75600

signal, and the BER of receivers improves in the following order: SIC, FSC, and ML. The SNR of the proposed FSC receiver required to achieve the coded BER of 10^{-2} differs by about 1 dB compared with that of the ML receiver having ideal performance.

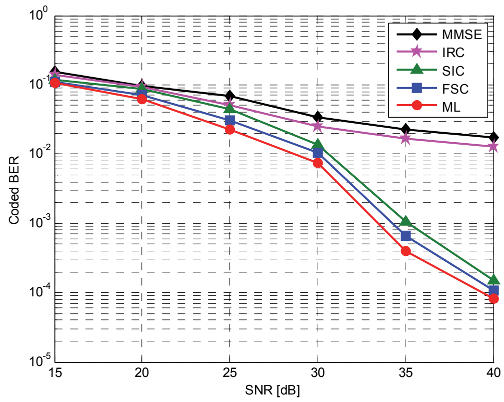

Figure 6: BER performance of different receiver types.

Figure 7 shows the block error rate (BLER) for the different types of receivers compared. As referenced to a BLER of 10^{-1}, the minimum required SNR for each type of receiver is given in Table 6. Compared with the coded BER, the overall error rate is higher. It can be seen that the BLER performance of the receivers is similar to the coded BER performance.

Table 5: SNR requirement according to receiver type (Coded BER).

Performance Evaluation (Coded BER < 1%)	SNR
MMSE	42 dB
IRC	41 dB
SIC	31 dB
FSC	30 dB
ML	29 dB

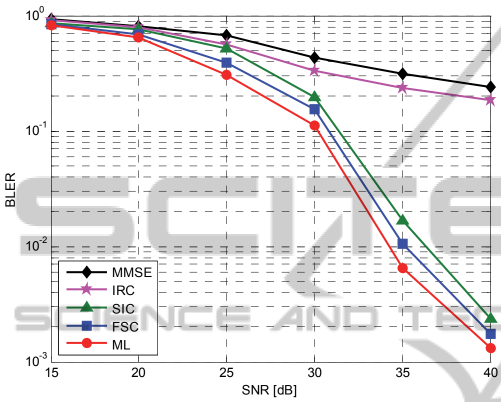

Figure 7: BLER performance of different receiver types.

Table 6: SNR requirement according to receiver type (BLER).

Performance Evaluation (BLER < 10%)	SNR
MMSE	More than 40 dB
IRC	More than 40 dB
SIC	31.5 dB
FSC	30.8 dB
ML	30 dB

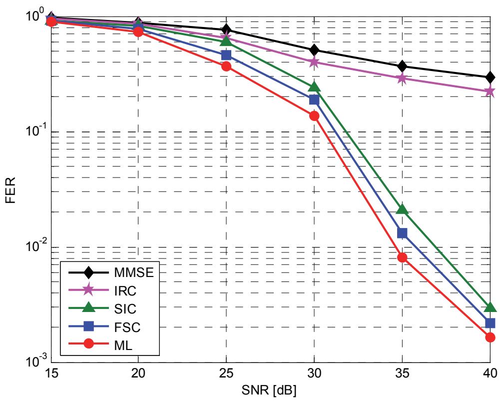

Figure 8: FER performance of different receiver types.

Figure 8 shows the frame error rate (FER) for the different types of receivers. As referenced to an FER of 10^{-1}, the minimum required SNR for the different receivers studied is given in Table 7. It can be seen that achieving the required FER performance requires an SNR that is 1–2 dB higher than that for achieving the BLER performance.

Table 7: SNR requirement according to receiver type (FER).

Performance Evaluation (FER < 10%)	SNR
MMSE	More than 40 dB
IRC	More than 40 dB
SIC	32 dB
FSC	31.2 dB
ML	30.5 dB

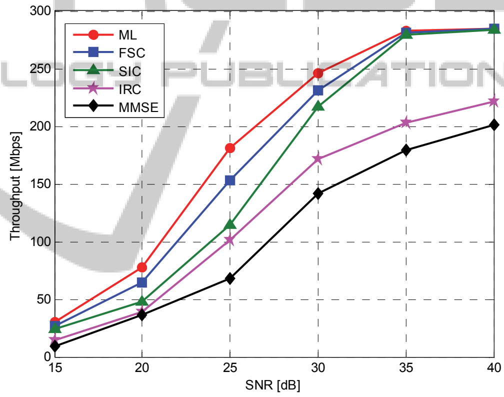

Figure 9: Throughput performance of different receiver types.

Table 8: Throughput according to receiver type.

Max. Data Rate Throughput [Mbps] = 285 Mpbs (theory)	SNR	
	30 dB	40 dB
MMSE	141.37 Mbps	201.34 Mbps
IRC	171.07 Mbps	211.17 Mbps
SIC	216.86 Mbps	284.15 Mbps
FSC	230.78 Mbps	284.38 Mbps
ML	245.71 Mbps	284.53 Mbps

Figure 9 shows the throughput of the different receivers, and the throughput at SNRs of 30 and 40 dB is given in Table 8. When applying the MCS index 27, the theoretical maximum data rate, 285 Mbps, is calculated by considering the reference signal and the control channel. The average throughput of receivers improves in the following order: MMSE, IRC, SIC, FSC, and ML.

6 CONCLUSION

In this paper, we propose the novel hybrid receiver FSC to reduce the interference from neighbor cells in a sidehaul system between moving small cells that is used to improve data rate and capacity. The FSC receiver combining the IRC with SIC satisfactorily suppresses and cancels the interference. Simulation results show that the proposed receiver has a lower error rate and a higher throughput compared to conventional receivers. In our future work, the design of the frame structure would be considered to improve the maximum data rate of the sidehaul system.

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