Overlaid HDD System Using Relays

Young Jin Sang, Jin Bae Park, Seong-Lyun Kim and Kwang Soon Kim†
Department of Electrical and Electronic Engineering, Yonsei University
134, Shinchong-dong, Seodaemun-gu, Seoul 120-749, Korea
E-mail: {yjmich, spacey2k}@dcl.yonsei.ac.kr,{slkim,ks.kim}@yonsei.ac.kr
† Corresponding Author

***Abstract*— HDD is a duplexing scheme that combines TDD and FDD, taking the advantages of both systems. In this paper a novel overlaid HDD system concept is proposed. The proposed overlaid HDD system uses both TDD and FDD in both regions via two paired frequency bands. Our design objective is to propose an adequate frame structure for an overlaid HDD system with fixed relay stations to enhance the system throughput, especially for the outer region. The frequency reuse factors for the inner and the outer region are set differently to overcome the interference from other cells. It is shown that in the proposed overlaid HDD system, the throughput of the outer region is increased by 58% in the UL and 20% in the DL at 5% throughput loss of the inner region both in the UL and DL compared to that of the overlaid HDD system without relay stations. Also, the proposed overlaid system has 9% gain in the DL compared to the single-band system with relay stations.**

I. Introduction

Various kinds of duplex schemes have been proposed recently as the candidates for the next generation mobile communication systems [1]. Traditionally frequency division duplexing (FDD) is typically used in modern communication systems. However, downlink traffics increase in proportional to the recent growth of new applications. Thus, time division duplexing (TDD) has been considered as an attractive solution. TDD merges uplink (UL) and downlink (DL) channel into one frequency band for better efficiency, especially when the UL and DL traffics are not symmetric. On the other hand, TDD has some disadvantages such as vulnerability to intercell interference, long round time delay, and guard time between DL and UL. Such drawbacks of TDD can be considered as the advantages of FDD over TDD and vice versa.

In future mobile communication systems, new duplexing schemes are required to take the advantages of both FDD and TDD. One of candidates is a hybrid division duplexing (HDD) system. In [2][3], a straightforward combination of TDD and FDD was proposed using unpaired bands. In the conventional HDD system, the cell is typically divided into two regions; the inner region using TDD and the outer region using FDD. By combining two duplexing schemes, it was shown that the interference at CTS (cross time slot), in which some cells are active in the DL while other cells are active in the UL, can be reduced.

On the other hand, relay-based multihop communications have been widely investigated for future mobile communication systems [4][5]. By adopting relay stations in existing systems, the throughput of the outer region and the cell coverage can be improved. The IEEE 802.16j system is an example of relay-based systems using orthogonal frequency division multiple access (OFDMA) scheme [6]. It is well known that an OFDMA system does not suffer from intracell interference due to the orthogonality among subcarriers. However, such a single-band OFDMA system with relay stations suffers from intercarrier interference (ICI) generated by other users in the same cell when the propagation delay to other relay stations or to a base station from a mobile station exceeds the cyclic prefix (CP) lengths of an OFDMA symbol [7][8]. Such ICI generated by other users in each cell spreads in the entire band and may degrade the system performance significantly. Thus, a new duplex scheme appropriate for a relay-based system is required.

In this paper, we propose a novel overlaid HDD system. A cell is divided into two regions as in the conventional HDD system. However, unlike the conventional HDD system, the proposed overlaid HDD system uses two paired frequency bands and the users in the outer region select the mobile station in the inner region as a relay station to enhance the throughput of users in the outer region. Mobile stations, relay stations, and a base station can use either TDD or FDD in both regions via two paired frequency band. The frequency reuse factor of the inner and the outer regions are set differently, depending on the interference from other cells, which enables the system to manage the interference more efficiently. Thus, the proposed overlaid HDD system is a quite suitable to adopt relay stations. In a single-band system, the ICI caused if the base station and the relay stations simultaneously send their signals in a same band to different mobile stations. However, in the proposed overlaid system, the base station and the relay station does interfere the mobile stations in the inner region and the outer region. A frame structure suitable for the overlaid HDD system is proposed and the cell throughput of the proposed overlaid HDD system will be obtained and compared with those of other systems.

II. System Model

A. Conventional HDD system [2][3]

In the conventional HDD System, two unpaired frequency bands exist. The main (wider) band uses TDD mode and the optional (narrower) band is for FDD UL. Using the two frequency bands, TDD and FDD schemes can coexist in a cell. The cell area is divided into two regions as shown in Fig.1: mobile stations in the inner region send UL data through the

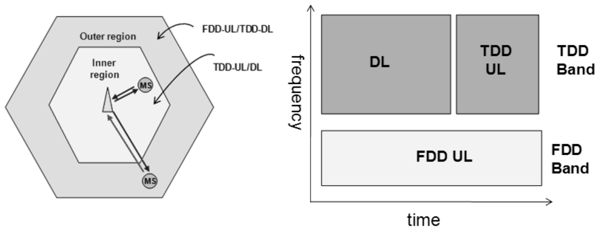

Fig. 1. Conventional HDD system.

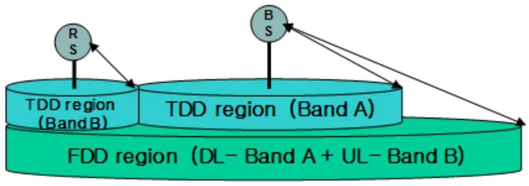

Fig. 2. Overlaid HDD system.

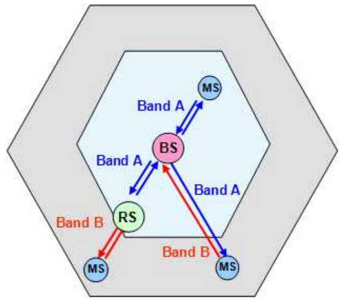

Fig. 3. Frequency usage of proposed overlaid HDD system.

TDD band while those in the outer region send UL data in the FDD band. The FDD band is narrower than the TDD band. The DL traffic is sent through the TDD band only both in the inner and the outer regions. The base station selects which band mobile stations should send UL data through based on the location, the mobility, and the receive (RX) power level of each user. The conventional HDD system straightforwardly combines TDD and FDD to solve the disadvantages of TDD in UL to improve the cell coverage and to obtain flexible DL/UL asymmetry in each cell.

B. Proposed Overlaid HDDsystem

A new concept of HDD system, called overlaid HDD, is described in this section. In the overlaid HDD system, there exist two paired frequency band: band A and band B. The mobile stations in the inner regions are selected as the relay station to support UL transmission and DL reception of mobile stations in the outer region. Fig. 2 shows the duplexing scheme of the proposed overlaid HDD system. The TDD scheme via band A is used in the transmission between a base station and mobile stations in the inner region and the FDD scheme is used for mobile stations in the outer region. The transmission between relay stations and mobile stations works in TDD mode via band B. To the base station, a relay station is considered as a mobile station. Thus, the relay stations communicate in TDD mode with the base station via band A. Fig. 3 shows the frequency band used for the transmission betweeen each pair of nodes. If there are remaining channels in the band B, mobile stations in the inner region can use the channels. The overlaid HDD system adopts the concept of reuse partitioning [9][10] to overcome interference from other cells. Using the reuse partitioning scheme, the frequency reuse factors of band A and band B can be set differently. Here, the frequency reuse factor is defined as the fraction of subchannels used in a cell. The transmission in the inner region is much less influenced from the intercell interference than the outer region. Thus, the frequency reuse factor of the inner region (K_1) can be close to or equal to 1. In order to prevent mobile stations in the outer region from falling into outage due to intercell interference, the frequency reuse factor of the outer region (K_2) should be smaller than 1. The frequency reuse factor K_1 or K_2 for the each transmission can be determined by measuring interference level and the interference level can be measured from the received power level of unused subchannels in each cell.

C. Multihop transmissions

In the proposed HDD system, we make use of the multihop transmission to enhance the throughput of the mobile stations in the outer region. In the multihop transmission, a mobile station in the outer region selects a mobile station in the inner region as a relay station which gives the higher rate than the direct transmission. The mobile station in the outer region selects a mobile station as a relay station for the UL transmission and the DL transmission, independently. The throughput of the mobile station which uses relay station is defined as the minimum of the throughput of the first link between that of the second link. The first link denotes the link between the mobile station in the outer region and the relay station. The second link denotes the link between the relay station and the base station. The mobile station in the outer region selects a mobile station in the inner region as a relay station that give twice higher throughput than the direct transmission because using relay stations requires twice the time slots of the direct transmission. On DL transmission, the same criteria can be used for the selection of the relay station.

III. FRAME STRUCTURE FOR THE OVERLAID HDD

A. Frame structure

Fig. 4 shows the proposed frame structure for the overlaid HDD system with adaptive transmission and multihop transmission in cellular systems. Here, MS_o and MS_i denote the mobile stations in the outer region and in the inner region, respectively. Also, RS denotes the relay station and BS denotes the base station. Each subframe at band A or band B is allocated for either UL or DL transmission according to various situations. A subframe is composed of a number of OFDMA symbols in the time domain and a number of subchannels in the frequency domain. The mobile stations

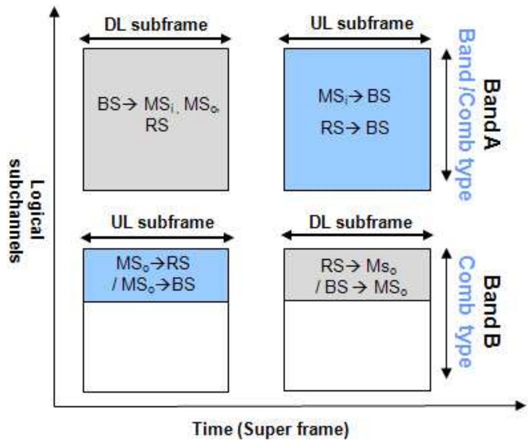

Fig. 4. Proposed frame structure for proposed overlaid HDD system.

TABLE I
SIMULATION PARAMETERS.

Parameters	Value
Number of subchannels	32 x 2 - dual band 64 - single band
FFT sizes	1024 x 2 - dual band 2048 - single band
Number of subchannels	32 x 2 - dual band 64 - single band
Fading channels	Pathloss exponents = 4 Veh A channel model
User distribution	100 users uniformly distributed
Cell radius	5 km
Inner region radius	2.5 km
Average RX SNR from cell edge	3dB
CP length	16.67 μs (1/4 of symbol length)

in the inner region uses the band-type subchannels which are composed of adjacent subcarriers. The mobile stations in outer region uses the comb-type subchannels in which the subcarriers are distributed over entire frequency band. In the proposed overlaid HDD system, mobile stations in the outer region use the FDD. Thus, the band A is used for downlink transmission of mobile stations both in the outer region and the inner region, which implies that the band A has both types of subchannels, comb-type subchannel and band-type subchannel. In downlink perspective, the existence of the inner and outer subchannels in the same band does not induce the ICI problem because the base station is the only transmitter. The band B has only comb-type subchannels because the band B is used by mobile stations in the outer region, only.

B. Comparison to conventional systems

In the conventional HDD system, the intercell interference is controlled by cooperative scheduling of users with neighbor cells [3]. To reduce the intercell interference, the scheduling of

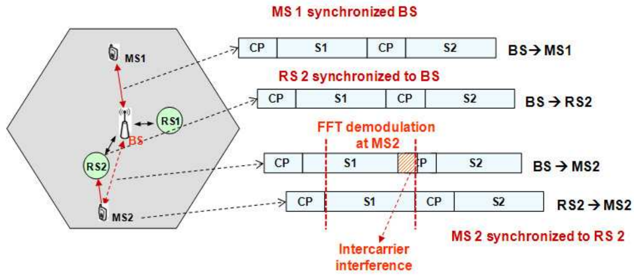

Fig. 5. Example of intercarrier interference.

users are conducted based on the location of mobile stations in the cell. However, the scheduling process in the conventional HDD system requires a cooperation among neighboring cells. In the proposed overlaid HDD system, the concept of reuse partitioning is adopted. The proposed overlaid HDD system has two paired bands with different frequency reuse factors in the two regions. The frequency reuse factor of the outer region is below 1 to guarantee the minimum SINR to mobile stations in the outer region without cooperative scheduling between neighboring cells.

In addition to the reuse partitioning, the proposed overlaid HDD system allows the mobile stations in the inner region to relay the traffic of outer region to enhance the throughput of the mobile stations in the outer region. OFDMA multihop relays has been already adopted in various systems, such as IEEE 802.16j [6]. However, a single-band OFDMA system has some disadvantages when multiple sources such as base station, relays and mobiles transmit simultaneously in a same band although they use different subchannels. As shown in Fig. 5, the base station transmit to a mobile (MS1) in the inner region and the relay (RS2). In this situation, the MS1 and the RS2 are synchronized to the received signal from the base station. When the RS2 tries to relay the signal to the MS2, the transmission timing is delayed compared to that of the base station according to the propagation delay between the base station and the RS2. Since the MS2 has to be synchronized to the RS2, the ICI may occur at the MS2 when the base station and the RS2 transmit their data simultaneously in a same band. In the proposed overlaid HDD system, the mobile stations in the outer region does not suffer from such ICI because mobile stations in the inner region and the outer region use different frequency bands. From this perspective, the proposed overlaid HDD system is quite robust to the ICI problem compared to single-band systems when relay stations are adopted.

IV. Performance Evaluation

A. Simulation parameters and environments

In this section, we compare the performance of the proposed system in the UL and the DL to that of the single-band system with relay stations and that of the overlaid HDD system without relay stations. For the simulation, we consider $20MHz$ bandwidth. We uses two $10MHz$ with 1024-point FFT for the proposed overlaid system and the conventional HDD systems and a single $20MHz$ band with 2048-point

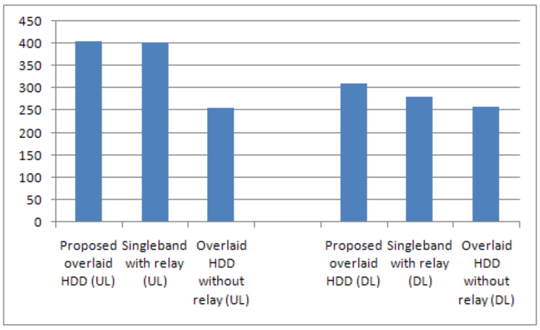

Fig. 6. Throughput of the outer region.

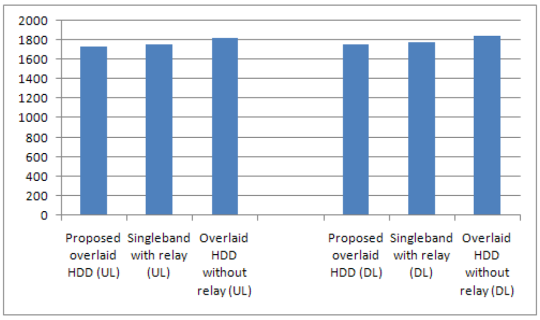

Fig. 7. Throughput of the inner region.

FFT for a single-band system. Each band has 36 subchannels. A subchannel is comprised of 24 subcarriers. In each cell, 100 users are distributed uniformly. The path-loss exponent is set to 4 and the ITU-R vehicular A channel model is used. Also, we assume that if a mobile station transmits with full power at a cell edge, the average received SNR at the base station is 3dB. As the mobile station moves to the base station, the average received SNR increases. Table I summarizes the simulation parameters.

Band-type subchannels are used in the inner region and comb-type subchannels are used in the outer region to average the intercell interferences. The frequency reuse factors of the inner and the outer regions are set to 1 and 1/3, respectively. The mobile stations in the inner region and the outer region are selected randomly.

The capacity of each subchannel is assumed to be the sum of capacities ($log_2(1+SNR)$) of composing subcarriers. This assumption is not appropriate to predict the exact value of the actual throughput using practical modulation and coding. However, it is enough to compare different systems, which in the main focus of this paper.

B. Simulation results

The performance of the proposed overlaid system is compared with that of the overlaid HDD system without relay station and that of the single-band system with relay stations. Fig. 7 shows the performance enhancement in the outer region by adopting relay stations. The same frequency reuse partitioning scheme has been used for the proposed overlaid HDD system, the single-band system with relay station, and the overlaid HDD system without relay station. Adopting the proposed scheme, the throughput of the outer region is increased by 58% in the UL and 20% in the DL compared to the system without relay stations. From Fig. 6, the throughput of the inner region is decreased 5% both in the UL and the DL which is relatively small compared to enhancement in the outer region. As shown in Fig. 7, the performance of the proposed system is increased by 1% and 9% compared to that of the single-band system in UL and DL, respectively. The improvement from the overlaid HDD is weak in UL, because we assumed that all mobiles are synchronized to their destinations. Therefore, all mobile stations transmitting to a specific destination adjust their transmission time so that the received signals at the destination are synchronized. Thus, the ICI caused from the propagation delay difference exceeding the CP length is quite well attenuated in the UL. However in the DL, the transmission timings of the base station and the relay stations are different, which causes received signal timing difference greater than the CP length in some mobiles without enough attenuation. Thus, the performance improvement of the proposed system is quite considerable in the DL transmission.

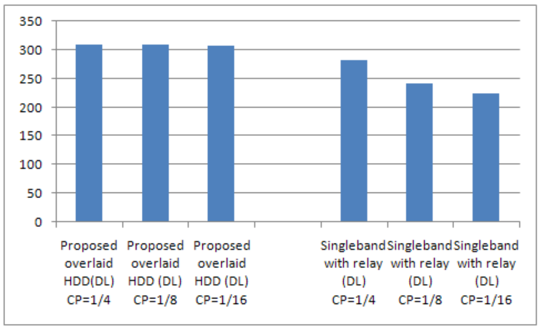

Fig. 8. Downlink throughput with different CP lengths.

Therefore, Fig. 8 shows the performance of the outer region in DL when the CP length changes. The performance difference between the proposed overlaid HDD system and the single-band system gets larger as the CP length decreases. In the case when the CP length equals to 1/8 of the OFDMA symbol duration (the typical value of the CP length), the throughput of the outer region of the single-band system with relay stations is degraded by 27% compared to that of the proposed system. If the CP length equals to 1/16 of the OFDMA symbol duration, the performance of the single-band system with relay stations is degraded by 37 % compared to that of the proposed system. The performance degradation by the ICI at the mobile stations in the outer region caused by the relay stations and the base station becomes more and more critical as the length of CP gets shorter.

V. CONCLUSION

In this paper, we proposed an overlaid HDD system with relay stations and showed that the proposed system is quite adequate to adopt the concept of reuse partitioning and multi-hop transmission for better performance because the proposed system does not suffer from the ICI effect caused from intracell users transmitting to different destinations. The throughput of the outer region of the proposed system is increased by 58% in the UL and 20 % in the DL compared to that of the system without relay stations and is increased by 1% in the UL and 9% in the DL compared to that of the single-band system with relay stations. By using two different frequency bands at different regions, the proposed system can provide robustness to the ICI caused from various sources transmitting to various destinations. The proposed system shows 27% and 37% performance improvement of the outer region in the DL throughput compared to the single-band system with relay stations when the CP length is 1/8 and 1/16 of symbol length, respectively. Thus, the proposed overlaid HDD system is suitable to adopt the relay stations and to manage the intercell interference compared to existing systems. Thus, the proposed overlaid HDD can be considered as a promising solution for future mobile communication systems.

REFERENCES

[1] IST-2003-507581 WINNER D2.5 v1.0, "A duplex arrangements for future broadband radio interfaces," October 2004.

[2] S.B. Yoon and Y.S. Kim, "Wireless communication system for hybrid division duplex," Samsung Elec., Korea Patent, Patent no. 10-0547717, May 2004.

[3] S.B. Yoon and Y.S. Kim, "Hybrid duplex technology: a flexible wireless system enabler for supporting time and frequency division duplex," *Proc. 11th Wireless World Research Forum (WWRF)*, Oslo, Norway, June 2004.

[4] R. Pabst, et al, "Relay-based deployment concepts for wireless and mobile broadband radio", *IEEE Commun. Mag.*, vol. 42, no. 9, pp. 80-89, September. 2004.

[5] M. Gastpar and M. Vetterli, "On the capacity of wireless networks: the relay case", *Proc. IEEE Int. Confer. Comp. Commun. (INFOCOM) 2002*, vol 3, no. 1, pp. 1577-1586, New York, NY, USA, June 2002.

[6] IEEE C802.16-05/013,"Mobile multi-hop relay networking in IEEE 802.16," July 2005.

[7] M. Park, K. Ko, H. Yoo, and D. Hong,"Performance Analysis of OFDMA Uplink Systems with Symbol Timing Misalignment," *IEEE Commun. Letters*, vol. 7, no. 8, pp. 376-378, August 2003.

[8] E. Bala, L. and J. Cimini. Jr "On the uplink sychronization of OFDMA systems," *Proc. IEEE Military Communications Confer. (MILCOM) 2005*, vol. 2, no. 1, pp. 1133-1139, Atlantic city, NJ, USA, October 2005

[9] J. Zander and M. Frodigh, "Capacity allocation and channel assignment in cellular radio systems using reuse partitioning," *Electron. Letters*, vol. 28, no. 5, pp. 438-440, Febrary 1992.

[10] J. Chong and C. Leung, "Performance Analysis of Reuse Partitioning in Cellular Systems," *Proc. IEEE Pacific Rim Conference (PACRIM)*, vol. 1, no. 1, pp. 213-216, Piscataway, NJ, USA, August 1999.

[11] IEEE 802.16e/D5-2004, *Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands*, November, 2004.