논문 2008-45TC-10-1

제로 포싱 (zero-forcing) 빔 형성과 반직교 기반 사용자 선정을 이용한 클러스터 (cluster) 기반 셀 협력 전송 방식의 성능에 대한 연구

(On the Performance of Zero-Forcing Beamforming with Semi-orthogonal User Selection in Clustered Cell Coordinated Transmission)

양 장 훈*, 장 승 훈*, 김 동 구*

(Janghoon Yang, Seunghun Jang, and Dong Ku Kim)

요 약

본 논문에서는 반직교 기반 사용자 선정과 제로 포싱(zero-forcing) 빔 형성에 기반한 간단하면서도 효율적인 세 셀 단위 셀 협력 전송 방법을 제안한다. 육각 셀룰라 시스템 모델에서 각 셀마다 두 그룹의 사용자를 갖는 와이너. (Wyner) 채널 모델에 대해서, 제안한 제로-포싱 협력 전송 방식의 합 전송율의 상계치는 송신 안테나 수와 사용자수의 이중 로거리듬(logarithm)에 비례함을 보인다. 모의 실험 결과는 제안된 협력 전송 방식의 효율성을 확증하며, 사용자 수에 따른 합 전송율은 상계치와 거의 같음을 확인할 수 있다.

Abstract

In this paper, a simple and efficient three cell based clustered-cell coordination is proposed with well known zero-forcing beamforming (ZF-BF) with a semi-orthogonal user selection (SUS) as transmission and scheduling scheme. For a modified Wyner''s channel model with two classes of user groups for a hexagonal cellular system, the upper bound of asymptotic sum rate scaling of ZF-BF in a proposed coordination is shown to be proportional to the number of transmit antennas and double logarithms of the number of users. The numerical results verify the efficiency of the proposed cell coordination. It is also numerically shown that ZF-BF with the SUS in CCCT actually achieves the upper bound of asymptotic sum rate sum rate scaling.

Keywords: Zero-forcing, sum rate, cell coordination, MIMO

I. INTRODUCTION

Increasing demand on the high data rate over the wireless channel has brought about numerous works on the multi-input multi-output (MIMO) system. Despite of the promising enormous gain provided by MIMO system, however, its performance is often significantly degraded by interference in multi-cell environment[1]. This problem is very striking in cellular network where the channel reuse is close to one to increase the capacity by installing more base stations (BSs) where the large data traffic is required.

To overcome this problem, more articulated cell

---

* 정회원, 연세대학교 전기전자공학과 이동통신 연구실
(Department of Electrical and Electronic Engineering of Yonsei University, Mobile Communication Lab)

※ The material in this paper was presented in part at the JCCI 2008

접수일자: 2008년7월16일, 수정완료일: 2008년10월16일

coordinations have been considered recently. Two pioneering works[2~3] on multi-cell processing attracted the significant attention to this field. Through more theoretical approach,[2] proved the significant gain by coordinated transmission. whereas [3] numerically showed gain of the coordinated transmission and proposed a BS selection as a simple form of coordination to avoid the BS synchronization problem. Sum rate bounds of joint multi-cell processing for Rayleigh downlink symmetric Wyner's type channels was derived in asymptotic user regime, showing that the sum rate scales with double logarithms of the number of users per cell as in a single cell environment[4]. The zero forcing(ZF) beamforming(BF) in a circular Wyner's array system model was shown to be optimal in sum rate scaling[5]. For a more general multi-cell channel model which considers both the path loss and the log-normal distributed shadowing, it was shown that multiuser diversity in a coordinated cellular MIMO time division multiple access(TDMA) system grows proportional to the square root of the number of users and the number of coordinating BSs[6]. As the introduction of MIMO offers the significant improvement of capacity in a single cell environment, the considerable capacity improvement is also achieved by increasing number of transmit and receive antennas for coherently coordinate transmission (CCT) in cellular networks[7~8].

There are also other works which focus on a cell coordination without joint encoding over multiple BSs due to the practical realization and physical limitation of the backhaul capacity and processing power at the centralized processor. A framework for joint power allocation and user scheduling in multi-cell network in the view of the ad-hoc network was presented[9]. A limited cooperation to resource allocation of the power and bandwidth was proved to achieve the sum rate growth of double logarithm of the number of users for symmetric channel while single logarithm of the number of users for non-symmetric channel[10]. More practical cell coordination of opportunistic downlink beamforming with joint selection of the user, beam, and BS is shown to achieve the significant sum rate improvement over the noncoodination system with limited feedback of the signal to interference plus noise ratios (SINRs)[11]. Denser BS installments with proper power control and user selection outperformed the network MIMO with ZF-BF in an idealized two dimensional hexagonal cellular array[12].

However, the optimal cell coordination even without joint transmission requires the channel information of all BSs even though it may not have heavy computational complexity for it. To overcome this problem, partial coordinations have been considered as an alternative. A coordination of three sectors with different antenna geometry showed that coordination over colocated antennas performs better than the spatially distributed antennas does in general multi-cell environment[13]. On a simplified Wyner-type network model, partial coordination schemes were proposed and sum rates of several transmission schemes with a partial coordination was derived for non-fading environment for single input single output (SISO) channel. Under common rate constraint, coordination schemes with super-position coding (SPC) was shown to be effective transmission with channel state information (CSI) and even without CSI[14] for a circular Wyner's channel with two classes of users having different geometries. When channel information is outdated significantly, numerical comparison shows that the partial coordination provides the better performance than full coordination[15].

Two major bottlenecks hold up the realization of the cell coordinated transmission practically. First, it is often assumed that backhaul capacity is unlimited, from which feedback transmission delay is treated to be relatively small compared to the rate of the channel change. However, the amount of information exchange depends how many BS are involved in coordination and what kind of information are required. Secondly, the optimal cell coordination requires the huge processing power. Thus, in this paper, we propose a partial cell coordination scheme which offers tradeoff between the complexity and the performance, which we call “clustered cell coordinated transmission (CCCT)”, that combines the cell coordination and coordinated transmission in practical sense.

The main contribution of this paper is to propose a practical solution for cell coordinated transmission and analyze its asymptotic sum rate performance with a joint MIMO processing. The proposed coordination scheme is based on systematic partial coordination which can be easily applicable with small complexity and feedback in generic ideal hexagonal multi-cellular network. The ZF-BF with the SUS was exploited with the proposed cell coordination for its simplicity and performance. The upper bound of the asymptotic sum rate scaling of ZF-BF is shown to be proportional to double logarithm of the number of users. It is also numerically shown that ZF-BF with the SUS under max rate scheduling policy actually achieves this upper bound.

Several critical assumptions are made to make problems simple. All BSs are synchronized to common clocks so that it can be free from excessive interference from timing offset. It is also assumed that the performance degradation due to different propagation delay from different BSs are negligible, which can be the case for orthogonal frequency division multiple access (OFDMA) when the maximum delay is within cyclic prefix interval. Perfect channel state information (CSI) is available to the receiver and the transmitter which is often used for achievable performance characterization. All BSs are assumed to be connected through backhaul with infinite bandwidth and their processing power is infinite so that processing delay may not be considered in this work. No receiver coordination is allowed. Even though some of assumptions are physically unrealizable, it would be reasonable enough to capture characteristics of the achievable performance of the well known ZF-BF with simple coordination.

The paper is organized as follows. In section Ⅱ, a channel model modified from Wyner's is described. In section Ⅲ, a clustered cell coordinated transmission and corresponding effective channels are presented. The upper bound of the asymptotic sum rate scaling of ZF-BF in CCCT is derived in section Ⅳ. In section Ⅴ, the numerical simulation results verify the efficiency of ZF-BF with the SUS in CCCT. Finally, the conclusions are made and some open problems are addressed in section Ⅵ.

Ⅱ. SYSTEM MODEL

We consider a hexagonal multi-cell system with each BS of M transmit antennas and each mobile station (MS) of a single receive antenna. For simplicity of the system model, we adopt the variant of Wyner type channel model where users are classified into two groups of users. i.e. center group and edge group. We assume that users in the center of the cell which we call ‘center user’ are free from other cell interferences, and the users in the edge of the cell we call ‘edge user’ receive interference from only one neighboring BS. Since each cell has overlapping region with six different neighboring cells for hexagonal cellular network, the edge users having different interfering neighbor are differentiated by six different subgroups. Consequently, a cell q consists of total seven subgroups, six edge subgroups $e_{q,n_q(1)},\cdots,e_{q,n_q(6)}$ and one center subgroup c_q where $n_q(i)$ is the interfering BS index of the ith edge subgroup in the cell q. It is also assumed that the numbers of users per subgroup are the same in each cell.

The downlink channel from the BS p to the user k in the subgroup s_k of the cell q can be expressed as

$$\mathrm{h}_{p,q}^{k}=\begin{cases}\beta \mathrm{h}'_{k,p,q}, & s_k=c_q,\ \text{and}\ p=q\\ \mathrm{h}'_{k,p,q}, & s_k=e_{q,n_q(i)},\ \text{and}\ p=q\\ \alpha \mathrm{h}'_{k,p,q}, & s_k=e_{q,n_q(i)},\ \text{and}\ p=n_q(i)\\ 0, & else\end{cases} \tag{1}$$

where $\mathrm{h}'_{k,p,q}\in \mathbb{C}^{M\times 1}$ is a circularly symmetric complex Gaussian channel vector with independently and identically distributed (i.i.d.) elements having zero mean and unit variance, $\beta(\geq 1)$ is center group geometry gain, $\alpha(\leq 1)$ is interference geometry gain, and the edge geometry gain is normalized to 1.

III. CLUSTERED CELL COORDINATED TRANSMISSION

In this section, we describe the proposed multi-cell coordination where coordination over a cluster consisting of three cells is performed systematically. The effective channel model incurring from the coordination which will be mainly used throughput this paper will be also presented.

The full coordination of all BSs in the system is often infeasible due to the processing delay and backhaul capacity. Thus, a partial coordination of a small number of BSs can be considered as an alternative. We consider a clustered cell coordinated transmission where each cluster consists of three cells working together as shown in Fig-1. For a given center cell BS 1, an edge user of the BS 1 will have a chance to be serviced when the cluster including its edge subgroup is active. This clustering is assumed to be active periodically, meaning that at the first time slot, the cluster with vertical lines is active, at the second slot, one with horizontal lines, and at the third slot, one with both the vertical and horizontal lines. One may decide the shape of clusters adaptive to the channel environment such that it can achieve the optimal performance for a given time instance. However, it requires the complicated computation and large feedback overhead. Thus, we turn more to systematic clustering with period of three time slots. In Fig. 2, with assumption of the infinite number of cells, the proposed systematic clustering of three cells are described more explicitly over the 2 tiers hexagonal cellular network where the shaded region represents the edge subgroups involved in each clustering.

Without loss of generality, we focus on performance analysis of the proposed clustered cell coordination for a fixed cluster of BS1, BS2, and BS3, since each cluster does not interfere with each other and channels are symmetric. Three BSs in CCCT work together as if it is a single BS. In this set up, the effective channel of the user $v(k,q)$ in a cluster which is the kth user in the qth BS, can be expressed from the definition of the channel model in (1) as follows.

$$\bar{\mathbf{h}}_{v(k,q)} = \left[\mathbf{h}^{k^H}_{1\cdot q}\ \mathbf{h}^{k^H}_{2\cdot q}\ \mathbf{h}^{k^H}_{3\cdot q}\right] \tag{2}$$

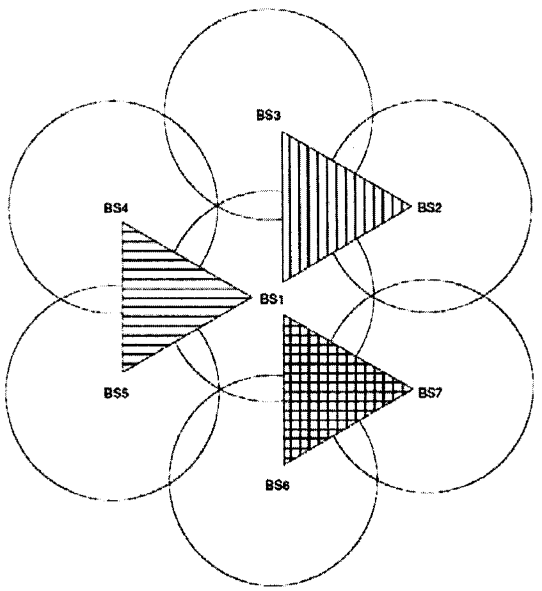


그림 1. 각기 다른 다른 방향의 선을 갖는 삼각형이 각기 다른 군집화를 표시하는 BS1 을 중심으로 한 군집화

Fig. 1. Clustering over the center cell BS1 where triangles with different type of lines represents the different clusterings which change periodically.

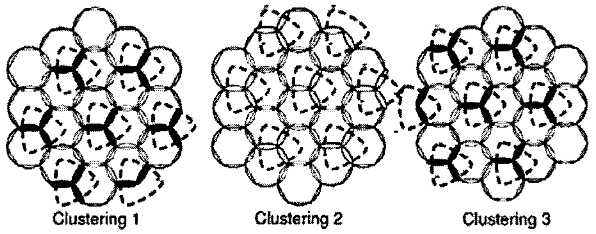

Clustering 1 Clustering 2 Clustering 3

그림 2. 2티어 육각셀 네트워크에서대한 제한된 체계적 군집화의 예

Fig. 2. Example of application of proposed systematic clustering over 2 tier hexagonal cellular networks.

where $v(k,q) = k + \sum_{i=1}^{q-1} K_i$ allows re-indexing of users in the increasing order of BS indices, and K_i is the total number of users in the cell i of the cluster. For the remainder part of the paper, $v(k,q)$ will be denoted by v for notational simplicity.

The sum rate of CCCT depends on both precoding and scheduling schemes. Since every effective channel in the cluster is free from other cell interference, any precoding and scheduling schemes for a single cell environment is directly applicable. Rather than studying optimal precoding schemes with CCCT, we are more interested in the performance of the multi-antenna transmission with the proposed coordination. Thus, for a given cell coordination, we choose the ZF-BF with the SUS as precoding and scheduling scheme, which is known to be simple and optimal in sum rate growth with number of users in a single cell environment[16]. Throughout this paper, we will focus on the SUS based on the max rate scheduling policy and ZF-BF with equal power allocation under the total power constraint.

For clarity, we briefly overview ZF-BF with the SUS. The detailed procedure and performance analysis can be referred to [16]. The SUS consists of a user selection for scheduling and candidates selection for scheduling in the next iteration. Under max scheduling policy, a user for scheduling at the mth iteration will be determined in the following way.

$$\pi(m) = \arg\max_{v \in S_{c,m}} \| \mathrm{Q}_{v,m} \bar{\mathrm{h}}_k \| \tag{3}$$

where $\| \bullet \|$ denotes the l^2-norm, $\mathrm{Q}_{v,m} = \mathrm{I}_{3M \times 3M} - \sum_{j=1}^{m-1} \bar{\mathrm{h}}_{\pi(j)} \bar{\mathrm{h}}_{\pi(j)}^H / \| \bar{\mathrm{h}}_{\pi(j)} \|^2$ is a projection matrix to the null space of the subspace spanned by the effective channels of the selected users in the previous iterations, and $S_{c,m}$ is the set of the candidates for scheduling at the mth iteration of ZF-SUS. $S_{c,m}$ will be updated at each iteration in the following way

$$S_{c,m} = S_{c,m-1} - \left\{ v \,\middle|\, \frac{|\bar{\mathrm{h}}_v^H \mathrm{Q}_{v,m} \bar{\mathrm{h}}_{\pi(m)}|}{\| Q_{v,m} \bar{\mathrm{h}}_{\pi(m)} \| \, \| \bar{\mathrm{h}}_v \|} \geq \delta, v \in S_{c,m-1} \right\} \tag{4}$$

where $S_{c,0} = 1,2,\cdots,K$, K is the total number of users in the cluster, and $0 \leq \delta \leq 1$ is an orthogonalization level threshold (OLT) which decides the tradeoff between the multi-user diversity gain and power loss associated with zero-forcing beamforming. The SUS terminates user selection when the number of selected user is equal to the number of transmit antenna or $S_{c,m}$ is a null set.

The received signal of ZF-BF with the SUS in CCCT can be expressed as

$$r_{\pi(m)} = \sqrt{\frac{3P}{M_0}} \bar{\mathrm{h}}_{\pi(m)}^H \mathrm{u}_{\pi(\mathrm{m})} \mathrm{s}_{\pi(\mathrm{m})} + \mathrm{n}_{\pi(\mathrm{m})} \tag{5}$$

where equal power allocation under total power constraint is assumed, P is the transmit power per BS, $M_0 \leq 3M$ is number of scheduled users, $u_{\pi(m)}$ is a ZF-BF vector with unit norm fo the user $\pi(m)$, $s_{\pi(m)}$ is data symbol with unit power, and $n_{\pi(m)}$ is additive white Gaussian noise (AWGN) with variance σ_n^2. There is no interference present at the user $\pi(m)$ due to ZF-BF. The set of ZF-BF vectors $\mathrm{U}(S_c) = [\mathrm{u}_{\pi(1)}, \cdots, \mathrm{u}_{\pi(\mathrm{M}_0)}]$ is given by

$$\mathrm{U}(S_c) = \mathrm{H}(S_c)(\mathrm{H}(S_c)^H \mathrm{H}(S_c))^{-1} \Lambda(S_c) \tag{6}$$

where $S_c = [\pi(1), \cdots, \pi(M_0)]$ is the set of indices of scheduled users, $\mathrm{H}(S_c) = [\bar{\mathrm{h}}_{\pi(1)}, \cdots \bar{\mathrm{h}}_{\pi(\mathrm{M}_0)}]$, and $\Lambda(S_c)$ is a diagonal matrix with the mth diagonal element $[\Lambda(S_c)]_{m,m} = 1/\sqrt{[(\mathrm{H}(S_c)^H \mathrm{H}(S_c))^{-1}]_{m,m}}$ such that each ZF-BF vector can have unit norm. In the next section, the performance of ZF-BF with the SUS in CCCT will be analyzed for large number of users.

Ⅳ. ASYMPTOTIC SUM RATE SCALING OF ZF-BF WITH THE SUS IN CCCT

It is known that asymptotic sum rate growth of

ZF-BF with the SUS in a single cell environment is proportional to $M\log\log(K_s)$ where K_s is the number of users in a single cell. However, the sum rate growth in multi-cell environment may vary depending on each specific coordination and transmission. In this section, we derive the upper bound of the scaling law of the sum rate with number of users for ZF-BF with the SUS in CCCT.

Theorem-1: The asymptotic average sum rate scaling of ZF-BF with the SUS in CCCT is upper bounded by

$$\lim_{K\to\infty}\frac{R_{ave}}{M\log\log K}\le 1 \tag{7}$$

where

$$R_{ave}=\frac{1}{3}E\left\{\sum_{m=1}^{3M}\log\left(1+\frac{P}{M}\frac{\|\mathbf{u}_m^H(b_{\pi(m)})\bar{\mathbf{h}}_{\pi(m)}\|^2}{\sigma_n^2}\right)\right\}$$

Proof: To derive the upper bound of R_{ave}, we consider another modified channel $\bar{\mathbf{h}}_{U,k}$ for all k which is

$$\begin{aligned}\bar{\mathbf{h}}_{U,v}&=[\bar{\mathbf{h}}_{1,U,v}^H,\bar{\mathbf{h}}_{2,U,v}^H,\bar{\mathbf{h}}_{3,U,v}^H]^H\\ \bar{\mathbf{h}}_{i,U,v}^H&=\beta\mathbf{h}'_{k,i,q}\end{aligned} \tag{8}$$

Since, the received signal power of ZF-BF is always less than that of the maximum ratio transmission (MRT) BF in orthogonal channel, R_{ave} is upper bounded by

$$\begin{aligned}R_{ave}&\le\frac{1}{3}E\left\{\sum_{m=1}^{3M}\log\left(1+\frac{P}{M}\max_k\frac{\|\bar{\mathbf{h}}_k\|^2}{\sigma_n^2}\right)\right\}\\ &\underbrace{\le}_{(a)}\frac{1}{3}E\left\{\sum_{m=1}^{3M}\log\left(1+\frac{P}{M}\max_k\frac{\|\bar{\mathbf{h}}_k\|^2}{\sigma_n^2}\right)\right\}\\ &\underbrace{\le}_{(b)}\frac{1}{3}\sum_{m=1}^{3M}\log\left(1+\frac{P}{M}E\left\{\max_k\frac{\|\bar{\mathbf{h}}_k\|^2}{\sigma_n^2}\right\}\right)\\ &\doteq R_{U,ave}\end{aligned} \tag{9}$$

(a) follows from $\|\bar{\mathbf{h}}_{U,k}\|\ge\|\bar{\mathbf{h}}_k\|$ for all k, and (b) follows from Jessen's inequality. Since $\|\bar{\mathbf{h}}_{U,k}\|$ is i.i.d. chi-square random variable with degrees of freedom $6M$, and $E\left\{\max_k\|\bar{\mathbf{h}}_{U,k}\|^2\right\}\sim\beta^2\log(K)$ where $A_K\sim B_K$ denotes that $\lim_{K\to\infty}A_K/B_K=1$[17]. $R_{U,ave}$ has sum rate scaling as follows.

$$R_{U,ave}\sim M\log\left(1+\frac{P\beta^2}{M\sigma_n^2}\log K\right) \tag{10}$$

Since $R_{U,ave}\le R_{ave}$ for any K, it is evident that

$$\lim_{K\to\infty}\frac{R_{ave}}{M\log\log K}\le\lim_{K\to\infty}\frac{R_{U,ave}}{M\log\log K}=1 \tag{11}$$

which proves the theorem.

V. NUMERICAL RESULTS

In this section, the sum rate performance of ZF-BF of the SUS in CCCT was numerically analyzed. SNR refers to the SNR at the edge user from the serving cell, and it was also assumed that the numbers of users per subgroup are the same for all subgroups. All sum rate results represent the average spectral efficiency per cell. In Fig.-3. the effect of the OLT on the sum rate was analyzed with different OLTs. The number of transmit antennas per cell was set to be 4. The geometry power gain for center user and for interfering channel was set to be $10^{1.5}$ and 1 respectively, while the cell edge SNR was set to be 10dB. For all considered number of users, the large OLT results in the largest sum rate, from which it can be thought that multi-user diversity gain is more significant than ZF-beamforming loss in CCCT even when the number of user is not so large. It can be noted that when the OLT is greater than a certain value, the sum rate is almost identical. This may imply that the probability of surviving at each iteration of the SUS is close to one when the OLT is greater than a certain value.

In Fig.-4, the effect of the number of transmit antennas per BS on the sum rate of ZF-BF with the SUS in CCCT for different SNRs are analyzed. The number of users per subgroup and OLT was set to be 32 and 0.9 respectively. β^2 and α^2 were set to be 16 and 0.5. As expected from the asymptotic growth

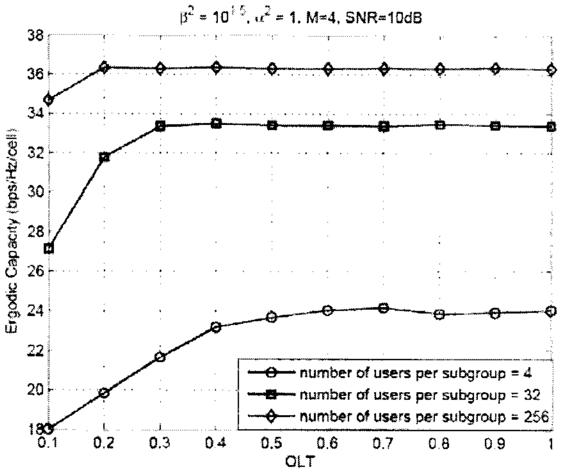


그림 3. OLT에 따른 CCCT에서 SUS 스케줄링 기반 ZF-BF의 셀당 주파수 효율

Fig. 3. Spectral efficiency per cell of ZF-BF with the SUS scheduling in CCCT with different OLTs.

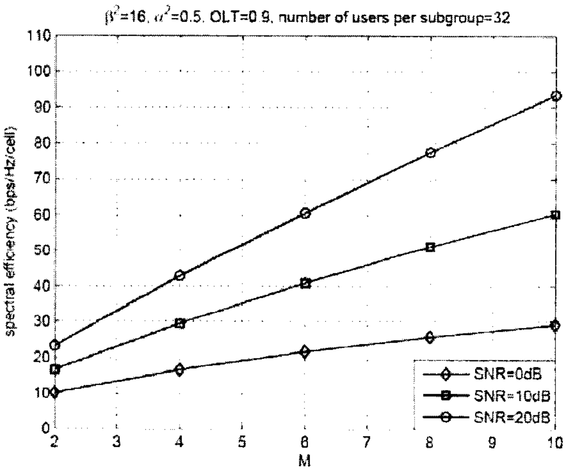


그림 4. 송신 안테나 수에 따른 CCCT에서 SUS 스케줄링 기반 ZF-BF의 셀당 주파수 효율

Fig. 4. Spectral efficiency per cell of ZF-BF with the SUS in CCCT with different number of transmit antennas (M is the number of transmit antennas).

rate, for a given number of users, and SNRs, the sum rate is shown to be linearly proportional to the number of transmit antennas. Since user selection is based on the max-rate scheduling, most of the selected users are center users. Thus, for a fixed number of transmit antennas, the sum rate increases from SNR=0dB to 10dB is almost identical to that from SNR of 10dB to 20dB. For example, for $M=6$, the sum rate increases from SNR=0dB to 10dB and from SNR=10dB to 20dB are 19.1 and 19.7 which can

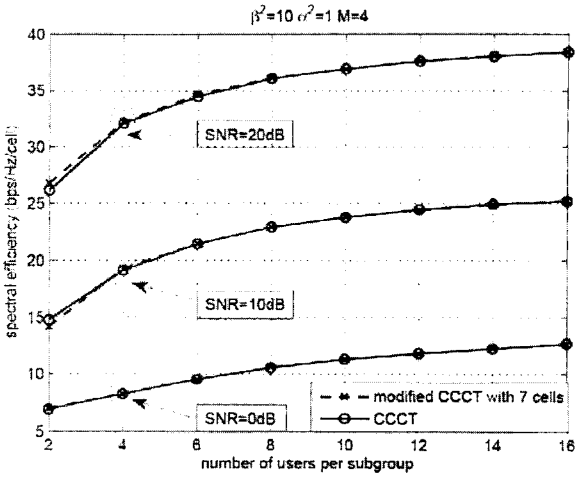


그림 5. 클러스터링 방법에 따른 CCCT에서 SUS 기반 ZF-BF의 셀당 주파수 효율의 비교

Fig. 5. Comparison of the Spectral efficiencies per cell of the ZF-BF with the SUS in CCCT for different types of clusterings.

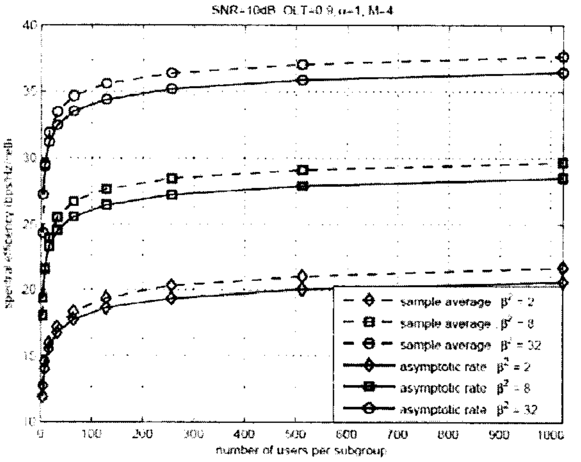


그림 6. 중심셀에 위치한 사용자의 각기 다른 위치 이득에 대한 다수 사용자에 따른 CCCT에서 SUS 기반 ZF-SUS의 셀당 주파수 효율 비교

Fig. 6. Spectral efficiency per cell of ZF-BF with the SUS in CCCT for large number of users under different geometry gains for center users.

be expected from asymptotic sum rate growth which is $6\log_2(10)=19.9$.

In Fig.-5, the number of cells cooperating in a cluster were extended to the seven and its performance was compared with the proposed CCCT of three cells. The number of transmit antennas per BS is 4, OLTs are chosen differently for the proposed CCCT and modified CCCT for seven cells respectively such that it can maximize the sum rate for each coordination scheme. Interestingly, the proposed partial coordination of three cells is found to provide almost the same sum rate performance as that of the partial coordination of seven cells. Since the scheduled users are most likely to be center users as the number of users increases, the cell coordination over large number of cells does not improve the performance much. For only small number of users, modified CCCT with 7 cells provides marginal gain over the proposed CCCT.

In Fig.-6, the sum rate growh with increasing number of users is evaluated for different geometry gains for center users. The number of transmit antennas and OLT was set to be 4 and 0.9 respectively. The SNR and α were set to be 10dB and 1. The sample averaged sum rate growth with increasing number of users is found almost identical to the upper bound of asymptotic sum rate which is $M\log(1+\beta^2 P/M)$. It can be seen that the sum rate growth with increasing number of users is proportional to $M\log\log K$ when the number of users are large regardless of the geometry gain. It shall be noted that when $\beta^2=2$ which is the case that average channel powers of the center user and the edge user are the same, the sum rate growth follows the analysis.

Ⅵ. CONCLUSIONS

In this paper, a simple and efficient downlink multi-cell coordination based on the periodic clusterings of three cells was proposed. The performance of the proposed cell coordination was analyzed for ZF-BF with the SUS which is known to be optimal in sum rate growth for a single cell environment. The upper bound of asymptotic sum rate growth with increasing number of users was proved to be proportional to the double logarithm of the number of users and the number of transmit antennas. Numerical results show that the sum rate growth rate of ZF-BF with the SUS actually achieves the upper bound.

There are many open issues associated with cell coordination. The processing delay and infinite backhaul capacity are likely to be main bottleneck in the implementation point of views. In performance wise, the joint channel estimation from all BS interfering with each other are yet to be studied to reveal the limitation of the sum rate with cell coordination in a practical communication system.

REFERENCES

[1] S. Catreux, P. F. Driessen, and L. J. Greenstein, “Simulation results for an interference-limited multiple-input multiple-output cellular system,” IEEE Commun. Lett., vol. 4, pp. 334-336, Nov. 2000.

[2] S. Shamai, O. Somekh, and B. M. Zaidel, “Multi-cell communications: An information theoretic perspective,” in Proc of JWCC, Florence Italy, Oct, 2004.

[3] H. Zhang, H, Dai, and Q. Zhou, “Base Station Cooperation for Multiuser MIMO: Joint Transmission and BS Selection,” in Proc of Conf. on Information Sciences and Systems, Princeton Univ. Mar. 2004.

[4] O. Somekh, B. M. Zaidel, S. Sahmai, “Sum Rate Characterization of Joint Multiple Cell-Site Processing,” IEEE Trans. Inf. Theory. vo. 53, pp.4473-4497, Dec. 2007.

[5] O. Somekh, O. Simeone, Y. Bar-Ness, A. M. Haimovich, “Distributed Multi-Cell Zero-Forcing Beamforming in Cellular Downlink Channels,” in Proc of Globecom'06, Nov. 2006.

[6] W. Choi, and J. G. Andrews, “The Capacity Gain from Intercell Scheduling in Multi-Antenna Systems,” IEEE Trans. Wireless Commun., Vol.. 7, No. 2, Feb. 2008.

[7] M. K. Karakayali, G. J. Foschini, and R. A. Valenzuela, “Network Coordination for Spectrally Efficient Communications in Cellular Systems,” IEEE Wireless Commun. Mag. pp. 56-61, Aug. 2006.

[8] G. J. Foschini, K. Karakayali, and R. A. Valenzuela, “Coordinating Multiple Antenna Cellular Networks to Achieve Enormous Spectral Efficiency,” IEE Proc-Commun., Vol. 153, pp.548-555, Aug. 2006.

[9] D. Gesbert, S. Ghazanfar Kiani, A. Gjendemsjo, and G. E. Oien, “Adaptation, Coordination, and Distributed Resource Allocation in Interference-Limited Wireless Networks,” Proc

Of IEEE, Vol. 95, pp.2393-2409, Dec. 2007.

[10] D. Gesbert, and M. Kountouris, "Joint Power Control and User Scheduling in Multicell Wireless Networks: Capacity Scaling Laws," submitted to IEEE Trans. Inf. Theory.

[11] M. Vemula, D. Avidor, J. Ling, and C. Papadias, "Inter-Cell Coordination, Opprotunistic Beamforming and Scheduling," in Proc of ICC, Istanbul, Turkey, Jun. 2006.

[12] Y. Liang, R. Valenzuela, G. Foschini, D. Chizhik, and A. Goldsmith, "Interference Suppression in Wireless Cellular Networks through Picocells," in Proc of Asilomar Conf. on signals, systems, and computers, Pacific Grove, USA, Nov. 2007.

[13] F. Boccardi, and H. Huang, "Limited Downlink Network Coordination in Cellular Networks," in Proc of PIMRC'07. Athens, Greece, Sept. 2007.

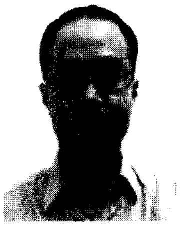
[14] S. Jing, D. N. C. Tse, J. Hou, J. B. Soriaga, J. E. Smee, R. Padovani, "Multi-Cell Downlink Capacity with Coordinated Processing," in Proc. of Information Theory and Applications Workshop (ITA), San Diego, CA , Jan 2007.

[15] T. Tamaki, K. Seong, J. M. Cioffi, "Downlink MIMO Systems Using Cooperation among Base Stations in a Slow Fading Channel," in Proc of ICC, pp.4728-2733, Glasgow, Scotlland, Jun. 2007.

[16] T. Yoo, and A. Goldsmith, "On the Optimality of Multiantenna Broadcast Scheduling Using Zero-Forcing Beamforming," IEEE Select. Areas in Commun,. Vol. 24. No.3. pp.528-541, Mar. 2006.

[17] M. Sharif, and B. Hassibi, "On the capacity of MIMO broadcast cahnnels with partial side information," IEEE Trans. Inf. Theory, vol. 51, pp. 506-522, Feb. 2005.

저 자 소 개



양 장 훈(정회원)

1996년 연세대학교 전파공학과 공학사.

2001년 U.S.C Dept. of Electrical Engineering 공학석사

2001년 U.S.C Dept. of Electrical Engineering 공학박사

2001년～2006년 삼성전자 책임 연구원

2006년～현재 연세대학교 공과대학 전기전자공학부 연구교수

<주관심분야 : CDMA, OFDMA, MIMO, Relay, 정보이론, neural signal processing>

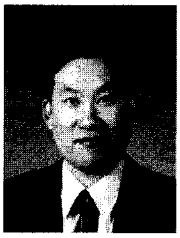
장 승 훈(정회원)

2002년 연세대학교 전기전자 공학과 공학사

2005년 연세대학교 전기전자 공학과 공학사 공학석사

2005년～현재 연세대학교 전기전자공학과 박사과정

<주관심분야 : Multi-user MIMO, Cooperative communication>



김 동 구(정회원)

1983년 2월 한국항공대학교 통신 공학과 공학사

1985년 U.S.C. Dept. of Electrical Engineering 공학석사

1992년 U.S.C. Dept. of Electrical Engineering 공학박사

1999년～현재 연세대학교 공과대학 전기전자공학과 교수

<주관심분야 : CDMA 이동통신, 다중접속 기술, 변조 및 채널 부호화 기술, 스케줄링/MAC기술, 순방향링크 빔성형 기술 및 MIMO기술,UWB, Binary CDMA>