Non-orthogonal Access with Random Beamforming and Intra-beam SIC for Cellular MIMO Downlink

Kenichi Higuchi[†(*)] and Yoshihisa Kishiyama[‡]

[†]Graduate School of Science and Technology, Tokyo University of Science

[‡]Radio Access Network Development Department, NTT DOCOMO, INC.

E-mail: [(*)]higuchik@rs.noda.tus.ac.jp

Abstract—**We investigate non-orthogonal access with a successive interference canceller (SIC) in the cellular multiple-input multiple-output (MIMO) downlink for systems beyond LTE-Advanced. Taking into account the overhead for the downlink reference signaling for channel estimation at the user terminal in the case of non-orthogonal multiuser multiplexing and the applicability of the SIC receiver in the MIMO downlink, we propose intra-beam superposition coding of a multiuser signal at the transmitter and the spatial filtering of inter-beam interference followed by the intra-beam SIC at the user terminal receiver. The intra-beam SIC cancels out the inter-user interference within a beam. Furthermore, the transmitter beamforming (precoding) matrix is controlled based on open loop-type random beamforming, which is very efficient in terms of the amount of feedback information from the user terminal. Simulation results show that the proposed non-orthogonal access scheme with random beamforming and the intra-beam SIC simultaneously achieves better sum and cell-edge user throughput compared to orthogonal access, which is assumed in LTE-Advanced.**

I. Introduction

In the 3rd generation mobile communication systems such as W-CDMA and cdma2000, non-orthogonal access based on direct sequence-code division multiple access (DS-CDMA) is used. The receiver uses simple single-user detection such as the Rake receiver. Orthogonal access based on orthogonal frequency division multiple access (OFDMA) or single carrier-frequency division multiple access (SC-FDMA) is adopted in the 3.9 and 4th generation mobile communication systems such as LTE [1] and LTE-Advanced [2, 3]. Orthogonal access was a reasonable choice for achieving good system-level throughput performance in packet-domain services using channel-aware time- and frequency-domain scheduling with simple single-user detection at the receiver.

However, for systems beyond 4G, e.g., LTE-Advanced, further enhancement of the system throughput and cell-edge user experience is required considering the recent exponential increase in the volume of mobile traffic and the need for enhanced delay-sensitive high-volume services such as video streaming and cloud computing. To accommodate such demands, non-orthogonal access can again be a promising candidate as a wireless access scheme for systems beyond 4G, which is the purpose of this study. To make non-orthogonal access promising, it should be used with advanced transmission/reception techniques such as dirty paper coding (DPC) or a successive interference canceller (SIC) [4-7], which is different from the 3rd generation mobile communication systems. We note that non-orthogonal user multiplexing using a simple spreading code as a channelization code assumed in the 3rd generation systems cannot fully utilize the potential gain of non-orthogonal access with a SIC. We assume that basic transmission signal generation is based on orthogonal frequency division multiplexing (OFDM), including discrete Fourier transform (DFT)-spread OFDM [1], which is robust against multipath interference. The channelization is solely obtained through capacity-achieving channel codes such as the turbo code and low-density parity check (LDPC) code. Thus, non-orthogonal user multiplexing forms superposition coding.

This paper focuses on the downlink. In previous studies by our group, e.g., [8], the potential gain of non-orthogonal access with a SIC was shown compared to the orthogonal access in a cellular system assuming a single-transmitter and multiple-receiver antenna configuration. Non-orthogonal access with a SIC simultaneously improves the cell-edge user throughput and sum throughput compared to orthogonal access in a cellular system where the channel conditions vary significantly among users due to the near-far effect. In this single-input multiple-output (SIMO) downlink, superposition coding with a SIC and DPC are equivalent from the viewpoint of the achievable multiuser capacity region. However, in the multiple-input multiple-output (MIMO) downlink, which is assumed in LTE and LTE-Advanced, the broadcast channel is not degraded. Therefore, the superposition coding with a SIC is not optimal and the DPC should be used to achieve the entire multiuser capacity region [7]. However, DPC is very difficult to implement in practice and is very sensitive to delay in the feedback of the channel state information to the base station transmitter. Furthermore, in order to achieve the multiuser capacity region using DPC, a user-dependent beamforming (precoding) must be employed. This results in increased overhead of the (orthogonal) reference signals dedicated to the respective users as the number of multiplexed users is increased beyond the number of transmitter antennas. This increase in overhead of the reference signal decreases the achievable throughput gain from the DPC in practice.

Due to the above reasons, we utilize a SIC in the MIMO downlink. In the proposed non-orthogonal access with a SIC, the number of transmitter beams is restricted to the number of transmitter antennas (at maximum), which is the same as in LTE-Advanced. Within each of the beams, superposition coding of multiple user signals is performed (thus, intra-beam superposition coding). With this non-orthogonal user multiplexing scheme, the number of reference signals is equal to the number of transmitter antennas, which is the same as in LTE-Advanced, irrespective of the number of non-orthogonally multiplexed users. Furthermore, at the user terminal, the inter-beam interference is suppressed by spatial filtering only by using multiple receiver antennas. After inter-beam interference suppression, successive interference cancellation is processed against the spatially-filtered scalar received signal to remove the inter-user interference within a beam due to the superposition coding (thus, intra-beam SIC). Since the channel among the non-orthogonally multiplexed users by superposition coding within a beam after the spatial filtering is degraded, we can apply the SIC which is easier to implement and more robust against the channel variation compared to DPC. In general, any kind of beamforming matrix determination criteria can be applied to the proposed non-orthogonal access scheme using intra-beam superposition coding and the SIC. In the paper, we employ open loop-based random beamforming [9, 10]. Random beamforming is effective in reducing the channel state information feedback.

The remainder of the paper is organized as follows. Section II describes the proposed non-orthogonal access with random beamforming and the intra-beam SIC. Section III presents simulation results on the system-level throughput and a comparison to orthogonal access. Finally, Section IV concludes the paper.

978-1-4673-6187-3/13/$31.00 ©2013 IEEE

II. Proposed Method

A. Non-orthogonal Access Using Intra-beam Superposition Coding and SIC

We assume OFDM signaling with a cyclic prefix, although we consider non-orthogonal user multiplexing. Therefore, the inter-symbol interference and inter-carrier interference are perfectly eliminated assuming that the length of the cyclic prefix is sufficiently long so that it covers the entire multipath delay spread. There are F frequency blocks and the bandwidth of a frequency block is W Hz. The number of transmitter antennas at the base station is M. The number of receiver antennas at the user terminal is N. For simplicity, in the following, we describe the proposed method at some particular time-frequency block (resource block) f ($1 \le f \le F$). For multiple time-frequency blocks, the same process is performed independently in principle. In this section, the time index, t, is omitted for simplicity.

Fig. 1 illustrates the operational principle of the proposed method using intra-beam superposition coding at the base station transmitter and intra-beam SIC at the user terminal receiver.

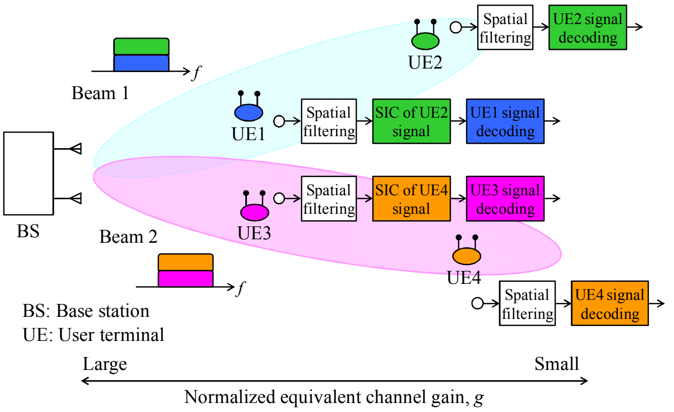


Figure 1. Operational principle of proposed method.

The base station performs MIMO transmission with B beams, where $1 \le B \le M$. The M-dimensional b-th ($1 \le b \le B$) transmitter beamforming (precoding) vector at frequency block f is denoted as $\mathbf{m}_{f,b}$. We assume that the multiuser scheduler schedules a set of users, $S = \{i(f,b,1), i(f,b,2), \ldots, i(f,b,k(f,b))\}$, to beam b of frequency block f. Term $i(f,b,u)$ indicates the u-th ($1 \le u \le k(f,b)$) user index scheduled at beam b of frequency block f, and $k(f,b)$ denotes the number of simultaneously scheduled users at beam b of frequency block f. At the base station transmitter, each $i(f,b,u)$-th user information bit sequence is independently channel coded and modulated. Term $s_{i(f,b,u),f,b}$ denotes the coded modulation symbol of user $i(f,b,u)$ at beam b of frequency block f. We assume $\mathrm{E}[|s_{i(f,b,u),f,b}|^2] = 1$. The allocated transmission power for user $i(f,b,u)$ at beam b of frequency block f is denoted as $P_{i(f,b,u),f,b}$. In the proposed method, $s_{i(f,b,u),f,b}$ of all $k(f,b)$ users is first superposition coded as intra-beam superposition coding and then multiplied by the transmitter beamforming vector, $\mathbf{m}_{f,b}$. Finally, by accumulating all B beam transmission signal vectors, the M-dimensional transmission signal vector, $\mathbf{x}_f$, at frequency block f is generated as

$$\mathbf{x}_f = \sum_{b=1}^{B} \mathbf{m}_{f,b} \sum_{u=1}^{k(f,b)} \sqrt{P_{i(f,b,u),f,b}}\, s_{i(f,b,u),f,b} \,. \tag{1}$$

The transmission power allocation constraint is represented as

$$\sum_{u=1}^{k(f,b)} P_{i(f,b,u),f,b} = P_b, \quad \sum_{b=1}^{B} P_b = P_{\mathrm{total}} \,, \tag{2}$$

where P_b is the transmission power of beam b and P_{total} is the total transmission power. We assume that P_b and P_{total} are identical for all frequency blocks in the paper.

The N-dimensional received signal vector of user $i(f,b,u)$ at frequency block f, $\mathbf{y}_{i(f,b,u),f}$, is represented as

$$\begin{aligned} \mathbf{y}_{i(f,b,u),f} &= \mathbf{H}_{i(f,b,u),f}\mathbf{x}_f + \mathbf{w}_{i(f,b,u),f} \\ &= \mathbf{H}_{i(f,b,u),f} \sum_{b'=1}^{B} \mathbf{m}_{f,b'} \sum_{u'=1}^{k(f,b')} \sqrt{P_{i(f,b',u'),f,b'}}\, s_{i(f,b',u'),b'} + \mathbf{w}_{i(f,b,u),f} \end{aligned} \,, \tag{3}$$

where $\mathbf{H}_{i(f,b,u),f}$ is the $N \times M$-dimensional channel matrix between the base station and user $i(f,b,u)$ at frequency block f and $\mathbf{w}_{i(f,b,u),f}$ denotes the receiver noise plus inter-cell interference vector at frequency block f.

In the proposed method, the user terminal first performs spatial filtering to suppress the inter-beam interference. Assuming that user $i(f,b,u)$ uses the N-dimensional spatial filtering vector, $\mathbf{v}_{i(f,b,u),f,b}$, to receive beam b of frequency block f, the scalar signal after the spatial filtering, $z_{i(f,b,u),f,b}$, is represented as

$$\begin{aligned} z_{i(f,b,u),f,b} &= \mathbf{v}^H_{i(f,b,u),f,b}\mathbf{y}_{i(f,b,u),f} \\ &= \mathbf{v}^H_{i(f,b,u),f,b}\mathbf{H}_{i(f,b,u),f}\mathbf{m}_{f,b} \sum_{u'=1}^{k(f,b)} \sqrt{P_{i(f,b,u'),f,b}}\, s_{i(f,b,u'),f,b} \\ &\quad + \mathbf{v}^H_{i(f,b,u),f,b}\mathbf{H}_{i(f,b,u),f} \sum_{\substack{b'=1 \\ b' \ne b}}^{B} \mathbf{m}_{f,b'} \sum_{u'=1}^{k(f,b')} \sqrt{P_{i(f,b',u'),f,b'}}\, s_{i(f,b',u'),f,b'} \\ &\quad + \mathbf{v}^H_{i(f,b,u),f,b}\mathbf{w}_{i(f,b,u),f} \end{aligned} \,. \tag{4}$$

In the paper, we assume that $\mathbf{v}_{i(f,b,u),f,b}$ is calculated based on the minimum mean squared error (MMSE) criteria. The second and third terms of (4) are the inter-beam interference and receiver noise plus inter-cell interference observed at the spatial filtering output, respectively. By normalizing the aggregated power of the inter-beam interference and receiver noise plus inter-cell interference to be one, (4) can be rewritten as

$$z_{i(f,b,u),f,b} = \sqrt{g_{i(f,b,u),f,b}} \sum_{u'=1}^{k(f,b)} \sqrt{P_{i(f,b,u'),f,b}}\, s_{i(f,b,u'),f,b} + q_{i(f,b,u),f,b} \,, \tag{5}$$

where $q_{i(f,b,u),f,b}$ denotes the sum of the inter-beam interference, receiver noise, and inter-cell interference terms after normalization (thus, $\mathrm{E}[|q_{i(f,b,u),f,b}|^2] = 1$). Term $g_{i(f,b,u),f,b}$ is represented as

$$g_{i(f,b,u),f,b} = \frac{|\mathbf{v}^H_{i(f,b,u),f,b}\mathbf{H}_{i(f,b,u),f}\mathbf{m}_{f,b}|^2}{\left\{ \begin{aligned} &\sum_{b'=1, b' \ne b}^{B} P_{b'} |\mathbf{v}^H_{i(f,b,u),f,b}\mathbf{H}_{i(f,b,u),f}\mathbf{m}_{f,b'}|^2 \\ &+ \mathbf{v}^H_{i(f,b,u),f,b}\mathrm{E}[\mathbf{w}_{i(f,b,u),f}\mathbf{w}^H_{i(f,b,u),f}]\mathbf{v}_{i(f,b,u),f,b} \end{aligned} \right\}} \,. \tag{6}$$

Thus, among users to which beam b of frequency block f is allocated, the channel after the spatial filtering is a degraded SISO channel, and the equivalent normalized channel gain of user $i(f,b,u)$ becomes $g_{i(f,b,u),f,b}$.

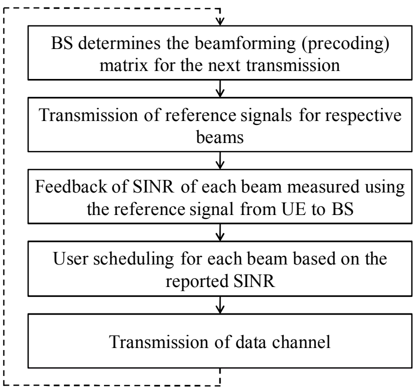
We apply the intra-beam SIC to signal $z_{i(f,b,u),f,b}$ in order to remove the inter-user interference within a beam. Similar to the SISO downlink [5], the optimal order of decoding is in the order of the increasing normalized channel gain, $g_{i(f,b,u),f,b}$. Based on this order, any user can correctly decode the signals of other users whose decoding order comes before that user for the purpose of interference cancellation. Thus, user $i(f,b,u)$ can remove the inter-user interference from user $i(f,b,u')$ whose $g_{i(f,b,u'),f,b}$ is lower than $g_{i(f,b,u),f,b}$. As a result, the throughput of user $i(f,b,u)$ at beam b of frequency block f is represented as

$$R_{f,b}(i(f,b,u)) = W\log_2\left(1+\frac{g_{i(f,b,u),f,b}P_{i(f,b,u),f,b}}{\sum_{u'=1, g_{i(f,b,u),f,b}<g_{i(f,b,u'),f,b}}^{k(f,b)} g_{i(f,b,u),f,b}P_{i(f,b,u'),f,b}+1}\right), \quad (7)$$

B. Random Beamforming

In general, any kind of $M \times B$-dimensional beamforming matrix determination criteria can be applied to the proposed non-orthogonal access scheme using the intra-beam superposition coding and SIC described in the previous subsection. In the paper, we employ open loop-based random beamforming [9, 10]. Random beamforming is effective in reducing the channel state information feedback.

Fig. 2 shows the operational flow of random beamforming. First, the base station randomly determines B beamforming vectors without the aid of feedback information from the user terminals. Then, the base station transmits the downlink reference signals before the actual data transmission. The number of reference signals equals the number of beams, B, and the respective reference signals are beamformed by the respective predetermined beamforming vectors. By using the b-th reference signal, the estimate of $\mathbf{H}_{k,f}\mathbf{m}_{f,b}$ is obtained at user terminal k. Using the estimate of $\mathbf{H}_{k,f}\mathbf{m}_{f,b}$ for all B beams, the spatial filtering vector, $\mathbf{v}_{k,f,b}$, is calculated. With $\mathbf{v}_{k,f,b}$ and the estimate of $\mathbf{H}_{k,f}\mathbf{m}_{f,b}$, the equivalent channel gain, $g_{k,f,b}$, is measured using (6). For user k, the signal-to-interference and noise power ratio (SINR) of beam b at frequency block f becomes $\mathrm{SINR}_{k,f,b} = g_{k,f,b}P_b$. User k feeds back $\mathrm{SINR}_{k,f,b}$ to the serving base station. The base station performs multiuser scheduling based on the reported $\mathrm{SINR}_{k,f,b}$. Actual data transmission for the set of the scheduled users is performed using the predetermined beamforming vectors. Since the random beamforming only requires the SINR feedback, the feedback overhead can be reduced compared to closed loop-type beamforming such as the codebook-based or explicit channel feedback-based approaches.



BS: Base station, UE: User equipment

Figure 2. Operational flow of random beamforming.

Although the beamforming vectors are determined independently of the user channel conditions, when the number of candidate users for scheduling is sufficiently large, we can expect that the randomly selected beamforming vector is matched to the channel of some user with high probability. With multiuser scheduling based on the reported SINR, we can select that user effectively. Furthermore, since the beamforming matrix of all cells are determined at the SINR measurement stage, by adequately designing the configuration of the reference signal, the SINR measurement results at the user terminal can take into account the inter-cell interference with beamforming, which is beneficial in achieving distributed inter-cell interference coordination.

III. Simulation Results

A. Simulation Assumptions

Here we evaluate the distribution of the user throughput in a multi-cell downlink. Table I gives the simulation parameters. A 19-cell model with a hexagonal grid assuming universal frequency reuse is used. The inter-site distance is 500 m. The number of users per cell, U, is parameterized from 5 to 50 in the following evaluation. The locations of the user terminals in each cell are randomly assigned with a uniform distribution. The values for W and F are set to 180 kHz [1] and 24, respectively (overall transmission bandwidth is 4.32 MHz). The transmission power at the base station is 40 dBm. The transmission power per beam is assumed to be the same for all frequency blocks. The randomly generated unitary matrix is used as a beamforming matrix. Term M is set to one or two. Term N is set to two and B is set equal to M. We take into account the distance-dependent path loss with the decay factor of 3.76, lognormal shadowing with the standard deviation of 8 dB and 0.5-correlation among sites, 6-path Rayleigh fading with the rms delay spread of 1 μs, and the maximum Doppler frequency of 55.5 Hz. The receiver noise density of the user terminal is −169 dBm/Hz.

The radio resource (beam of each frequency block and power) allocation to users is updated every 1 ms. The radio resource allocation policy significantly affects the system efficiency (measured by, for example, the sum average user throughput) and cell-edge user experience (measured by, for example, the cell-edge average user throughput). We assume proportional fair (PF)-based resource allocation [11, 12] to achieve a good tradeoff between them by maximizing the product of the average user throughput among users within a cell.

The average user throughput of user k per beam of one frequency block is defined as

$$T(k;t+1) = \left(1-\frac{1}{t_c}\right)T(k;t) + \frac{1}{t_c}\left(\frac{1}{FB}\sum_{f=1}^{F}\sum_{b=1}^{B} R_{f,b}(k;t)\right), \quad (8)$$

where t denotes the time index representing a 1-ms subframe index. Parameter t_c defines the time horizon for throughput averaging. We assume the t_c of 100 with the subframe length of 1 ms in the following evaluation (thus 100-ms average user throughput is measured). Term $R_{f,b}(k;\ t)$ is the throughput of user k at beam b of frequency block f at time instance t. Throughput $R_{f,b}(k;\ t)$ can be calculated using (7) and is zero if user k is not scheduled at beam b of frequency block f at time slot t.

In non-orthogonal access with a SIC, the scheduler can allocate a beam of a certain frequency block to more than one user simultaneously. By extending the multiuser scheduling version of the PF scheduler in [13], we use the following multiuser resource (beam and power) allocation policy that maximizes the product of the average user throughput among users within a cell. The resource allocation policy selects user set $S = \{i(f,b,1), ..., i(f,b,k(f,b))\}$ and allocation power set $P = \{P_{i(f,b,1),f,b}, ..., P_{i(f,b,k(f,b)),f,b};\ \Sigma_u\{P_{i(f,b,u),f,b}\} = P_b\}$ for beam b of frequency block f according to the following criteria.

$$\gamma_{f,b}(S,P;t) = \prod_{k\in S}\left(1+\frac{R_{f,b}(k\,|\,S,P;t)}{(t_c-1)T^{\alpha}(k;t)}\right). \quad (9)$$

$$S^*_{f,b}(t), P^*_{f,b}(t) = \arg\max_{S,P} \gamma_{f,b}(S,P;t). \quad (10)$$

Term $R_{f,b}(k\ |\ S,P;\ t)$ is the instantaneous throughput of user k at time t assuming scheduled user set S and power set P, which can be calculated using (7). Term $\gamma_{f,b}(S,P;\ t)$ is the resource allocation metric for user set S and allocation power set P at beam b of frequency block f. Here, α ($\alpha \geq 0$) is the weighting factor introduced in [14]. The α of one corresponds to pure PF resource allocation and an α of greater than one tends to achieve better user fairness at the cost of reduced system efficiency.

Maximization in (10) is in general difficult. However, when $t_c >> 1$, which is valid in the paper where $t_c = 100$, (9) can be approximated as

$$\gamma_{f,b}(S,P;t) \approx \sum_{k \in S} \frac{R_{f,b}(k \mid S,P;t)}{T^{\alpha}(k;t)}, \tag{11}$$

after removing constants. Equation (11) represents a weighted sum of the instantaneous user throughput, $R_{f,b}(k \mid S,P;\ t)$, where the weighting factor for user k is $1/T^{\alpha}(k;\ t)$. Therefore, for given candidate scheduling user set S, the metric can be maximized by power allocation P, which maximizes the weighted sum of the instantaneous user throughput. We use the iterative water-filling power allocation algorithm [15] that achieves the maximum weighted sum of the user throughput utilizing the uplink-downlink duality presented, for example, in [5] and [6]. With the optimum P for every given S, the maximization in (10) is performed with regard to S.

The user throughput averaged over 100 ms is measured. The user throughput is calculated based on the Shannon formula with the maximum limit of 6 b/s/Hz (corresponding to 64QAM). We assume that the receiver spatial filtering for inter-beam interference suppression is based on the MMSE criteria. The maximum number of non-orthogonally multiplexed users per frequency block, N_{max}, is parameterized from 1 to 4. In the resource allocation, all possible user sets S, where $|S| \leq N_{max}$, are examined and the user set achieving the highest resource allocation metric is selected. The N_{max} of one corresponds to the orthogonal access based on OFDMA as in LTE and LTE-Advanced. In the following, we simply denote the average user throughput of 100 ms as the user throughput to avoid confusion with the average of the throughput among users within a cell.

TABLE I. SIMULATION PARAMETERS

Cell layout		Hexagonal 19-cell model without sectorization
Frequency reuse		Universal frequency reuse
Inter-site distance		0.5 km
Overall transmission bandwidth		4.32 MHz
Resource block bandwidth		180 kHz
Number of resource blocks		24
Number of UEs per cell		U = 5, 10, 20, 30, 40
BS transmitter antenna	Number of antennas	M = 1, 2
	Antenna gain	14 dBi
	Number of beams	$B = M$
UE receiver antenna	Number of antennas	N = 2
	Antenna gain	0 dBi
Beamforming matrix		Random unitary matrix (orthonormal vectors)
Receiver linear filtering		MMSE based
Maximum transmission power		40 dBm
Distance-dependent path loss		$128.1 + 37.6 \log_{10}(r)$ dB, r: kilometers
Log-normal shadowing		δ = 8 dB, Correlation among cell sites = 0.5
Instantaneous fading		Six-path Rayleigh, rms delay spread = 1 μs, f_D = 55.5 Hz
Receiver noise density		-169 dBm/Hz
Scheduling interval		1 ms
Throughput calculation		Based on Shannon formula (Max. 6 b/s/Hz)
Averaging interval of user throughput		100 ms (1-ms packet length)

B. *Simulation Results*

Fig. 3 shows the cumulative distributions of the user throughput. The N_{max} values of one, two, and four are shown. The values of M and B are set to two. Term U is 30 and α is set to 1. Fig. 3 clearly shows that non-orthogonal access with a SIC (thus $N_{max} > 1$) achieves better throughput than orthogonal access for the entire region of the cumulative distribution. This is because the user throughput of the orthogonal access is severely limited by the orthogonal bandwidth allocation, which reduces the bandwidth for the respective users. Non-orthogonal access with a SIC allows for wider bandwidth usage of all users irrespective of the channel conditions. Allocating high power to the power-limited cell-edge users associated with the SIC process, which is applied to the bandwidth-limited cell-interior users, enhances the throughput of the users under a wide range of channel conditions. The impact of the transmission bandwidth limitation on orthogonal access is especially clear in the high cumulative distribution probability region, where the users are under bandwidth-limited conditions. The gain by further increasing N_{max} from two to four is relatively small. This indicates that it is sufficient to multiplex non-orthogonally a moderate number of users to obtain the most from the potential gain using non-orthogonal access with a SIC. It should be noted that the overhead required for the transmission of a downlink reference signal for the proposed non-orthogonal access using intra-beam superposition coding and a SIC is the same as that for the orthogonal access irrespective of the N_{max} value. In the following, the user throughput value at the cumulative probability of 5% is denoted as the cell-edge user throughput [1, 2].

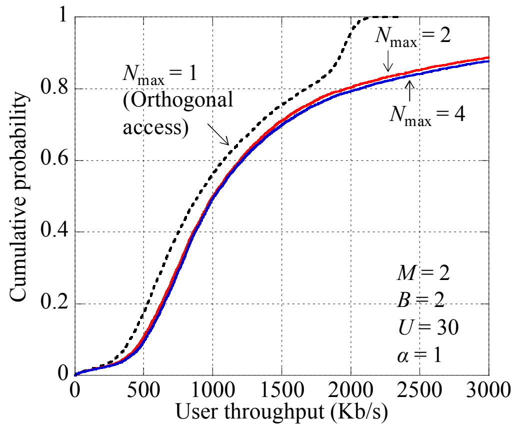
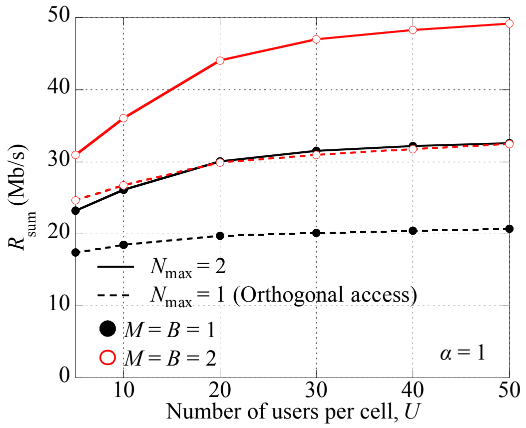


Figure 3. Cumulative distribution of user throughput.

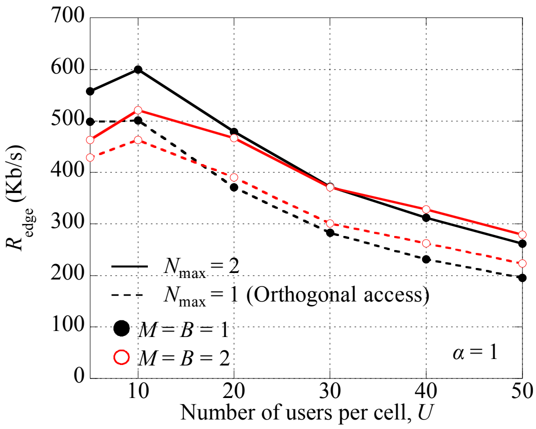
Figs. 4(a) and 4(b) show the sum user throughput (R_{sum}) and cell-edge user throughput (R_{edge}) as a function of the number of users per cell, U. We tested the cases with N_{max} of one and two and evaluate $M = B$ of one and two. From Fig. 4(a), assuming the same M (= B), the non-orthogonal access with SIC using the N_{max} of two significantly increases R_{sum} compared to the orthogonal access. Interestingly, R_{sum} of the non-orthogonal access with SIC assuming the M of one is very similar to that of the orthogonal access with the M of two. This implies that the non-orthogonal access with a SIC has an effect similar to spatial multiplexing using random beamforming and achieves a competitive level of performance to the orthogonal access by using a smaller number of base station transmitter antennas. It may also be noted that as M (= B) and N_{max} increases, the required number of U for obtaining sufficiently saturated R_{sum} is increased. This is because as M and N_{max} increases, we need more candidate users in order to select an appropriate user set to be scheduled to achieve a sufficient multiuser diversity gain. The performance improvement of the non-orthogonal access with a SIC for the case with a small number of users may be an issue to be investigated in the future.

From Fig. 4(b), we also see a clear gain in R_{edge} by increasing N_{max} from one to two similar to that for R_{sum}. Thus, the proposed non-orthogonal access with a SIC using random beamforming and intra-beam superposition coding and SIC is effective in simultaneously improving the system efficiency, e.g., R_{sum}, and cell-edge user experience, e.g., R_{edge}.

Fig. 5 shows the user throughput gain by using non-orthogonal access with a SIC assuming the N_{max} of two relative to orthogonal access for the respective user coverage positions (0 indicates the cell edge and 1 indicates the vicinity of the base station). The values of M and B are set to two. Term U is set to 30. In the orthogonal access, the α of 1.0 is assumed. For the proposed non-orthogonal access with a SIC, the α of 1.0 and 1.5 are tested. The R_{sum} values of the orthogonal access with the α of 1.0 and non-orthogonal access with the α of 1.0 and 1.5 are approximately 31, 47, and 40 Mb/s, respectively. Fig. 5 shows that a user throughput gain of greater than one by using the proposed non-orthogonal access using random beamforming and the intra-beam SIC is achieved for the entire region of the user coverage position. We see that the cell-edge user throughput gain is especially significant, which means improvement in the user fairness. This will be very beneficial in accommodating future traffic demands. When the α of 1.0 is assumed, the proposed non-orthogonal access achieves approximately 1.5 and 1.2-fold gains in R_{sum} and R_{edge}, respectively, compared to the orthogonal access which is assumed in LTE-Advanced. When α is increased to 1.5 for the proposed non-orthogonal access scheme, the proposed scheme increases the throughput gain at the cell-edge to approximately 1.6 fold at the cost of a moderate reduction in R_{sum} (however, it is still higher than that of the orthogonal access with the α of 1.0), since as α is increased, more radio resources tend to be allocated to the cell-edge users.



(a) Sum user throughput, R_{sum}



(b) Cell-edge user throughput, R_{edge}

Figure 4. R_{sum} and R_{edge} as a function of U.

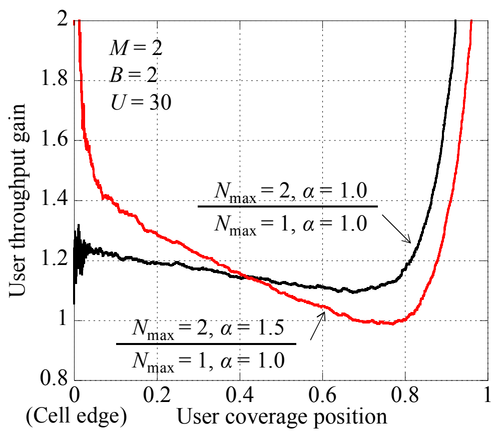


Figure 5. User throughput gain.

IV. CONCLUSION

Aiming at further enhancement of the system efficiency and cell-edge user experience for the systems beyond LTE-Advanced, this paper proposed a non-orthogonal access scheme with a SIC in the cellular MIMO downlink. The first feature of the proposed method is a use of intra-beam superposition coding and intra-beam SIC for non-orthogonal multiuser multiplexing within a beam. This brings about the effective use of the receiver SIC and avoidance of the increase in overhead of the downlink orthogonal reference signals dedicated to the respective users when the number of multiplexed users is increased beyond the number of transmitter antennas. The second feature is the application of the random beamforming for the beamforming matrix determination. With the appropriate resource allocation (scheduling and power control) strategy, random beamforming effectively achieves a large spatial multiplexing gain along with multiuser diversity with limited channel state information feedback. From the simulation results, we show that the proposed non-orthogonal access with random beamforming and the intra-beam SIC simultaneously achieve better sum and cell-edge user throughput compared to the orthogonal access which is assumed in LTE-Advanced. To verify the effectiveness of the proposed non-orthogonal access with a SIC, a performance evaluation is needed assuming a realistic channel code, QAM data modulation, and residual interference in the SIC process. The design of realistic control signaling is also an important issue. These issues are left for future study.

REFERENCES

[1] 3GPP TS36.300, Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description.

[2] 3GPP TR36.913 (V8.0.0), "3GPP; TSG RAN; Requirements for further advancements for E-UTRA (LTE-Advanced)," June 2008.

[3] 3GPP TR36.814 (V9.0.0), "Further advancements for E-UTRA physical layer aspects," Mar. 2010.

[4] G. Caire and S. Shamai (Shitz), "On the achievable throughput of a multi-antenna Gaussian broadcast channel," IEEE Trans. Inf. Theory, vol. 49, no. 7, pp. 1692-1706, July 2003.

[5] P. Viswanath and D. N. C. Tse, "Sum capacity of the vector Gaussian broadcast channel and uplink-downlink duality," IEEE Trans. Inf. Theory, vol. 49, no. 8, pp. 1912-1921, Aug. 2003.

[6] S. Vishwanath, N. Jindal, and A. Goldsmith, "Duality, achievable rates and sum rate capacity of Gaussian MIMO broadcast channel," IEEE Trans. Inf. Theory, vol. 49, no. 10, pp. 2658-2668, Oct. 2003.

[7] H. Weingarten, Y. Steinberg, and S. Shamai (Shitz), "The capacity region of Gaussian MIMO broadcast channel," in Proc. IEEE ISIT2004, Chicago, IL, Jun./Jul. 2004.

[8] N. Otao, Y. Kishiyama, and K. Higuchi, "Performance of non-orthogonal access with SIC in cellular downlink using proportional fair-based resource allocation," in Proc. IEEE ISWCS2012, Paris, France, Aug. 2012.

[9] P. Viswanath, D. N. C. Tse, and R. Laroia, "Opportunistic beamforming using dumb antennas," IEEE Trans. Inf. Theory, vol. 48, no. 6, pp. 1277-1294, June 2002.

[10] M. Sharif and B. Hassibi, "On the capacity of MIMO broadcast channels with partial side information," IEEE Trans. Inf. Theory, vol. 51, no. 2, pp. 506-522, Feb. 2005.

[11] F. Kelly, "Charging and rate control for elastic traffic," European Transactions on Telecommunications, vol. 8, pp. 33-37, 1997.

[12] A. Jalali, R. Padovani, and R. Pankaj, "Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system," in Proc. IEEE VTC2000-Spring, May 2000.

[13] M. Kountouris and D. Gesbert, "Memory-based opportunistic multi-user beamforming," in Proc. IEEE ISIT2005, Adelaide, Australia, Sep. 2005.

[14] R. Agrawal, A. Bedekar, R. J. La, and V. Subramanian, "Class and channel condition based weighted proportional fair scheduler," in Proc. ITC2001, Sept. 2001.

[15] M. Kobayashi and G. Caire, "An iterative water-filling algorithm for maximum weighted sum-rate of Gaussian MIMO-BC," IEEE J. Sel. Areas. Commun., vol. 24, no. 8, pp. 1640-1646, Aug. 2006.