Adaptive Beamforming with Per-Antenna Feedback for Multi-Cell Cooperative Networks

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Abstract

Beamforming is a signal processing technique that enables antenna arrays to create directional signals, increasing transmitter or receiver gain. We propose a new adaptive user antenna beamforming technique for Multi-cell Cooperative Networks which simultaneously communicates with multiple available BSs and RSs using the MS's multiple antennas. We show that the proposed adaptive beamforming technique outperforms distributed beamforming by increasing the data rate with less degradation of the BER.

Keywords: *Beamforming, MIMO, multi-cell cooperative, feedback*

1. Introduction

MIMO (multiple-input, multiple-output) wireless communications can increase throughput in cellular systems by using multiple antennas in order to simultaneously transmit multiple users' data [1-2]. The beamforming technique is used in MIMO systems to improve link reliability using interference rejection and linear combining [3]. Beamforming is achieved by combining elements in the array antenna. Recently, the number of BSs (base stations) and RSs (relay stations) have been increased to improve network capacity.

Therefore, next generation mobile communication system will most likely employ multi-cell cooperative networks, often referred to as network MIMO[4-7]. One of the main research issues for multi-cell cooperative networks is how to use or improve previous beamforming techniques [8-9]. In the most of previous beamforming techniques, they select the BS or RS that has the strongest signal at the MS through the exchange of feedback information between the MS and the BS or RS. Also in MIMO system, MS can achieve spatial multiplexing or diversity gain by beamforming. Therefore MS can use only spatial multiplexing when the antennas of MS are spaced sufficiently. In contrast, MS can use only diversity gain when the antennas of MS aren't spaced sufficiently. This limitation has motivated the following proposal for an improved beamforming technique for Multi-cell Cooperative Networks.

In this paper, we propose a technique that uses the MS's multiple antennas to simultaneously communicate with multiple available BSs or RSs. So that we can use spatial multiplexing and diversity gain when the antenna of MS isn't spaced sufficiently. This can improve performance by increasing the user's data rate with less degradation of the BER.

2. Related Works

There are various approaches to improve performance of beamforming. One of approaches is about to amount feedback information. Joint beamforming requires MS to send back their channel state information (CSI) [10] basically. As a result, given that all users share a common feedback channel, the sum feedback rate can rapidly become a bottleneck for the system with a large number users [11]. It causes studies that reducing the feedback information for overhead problems and increasing the feedback information for reliability [12]. Thus, there is tradeoff between two approaches.

Therefore beamforming is classified according to amount feedback information. Open Loop techniques [3, 13] are that exchange limited feedback information. In contrast to that, Close Loop [10, 12] techniques are that exchange a number of feedback information relatively compared to Open loop techniques. Most of these beamforming techniques select BS or RS which has the strongest signal strength by MS (Mobile Station) and exchange of feedback information with BS or RS. As a result, MS can communicate only one BS or RS simultaneously. So that they can't use spatial multiplexing when the antennas of MS aren't spaced sufficiently.

Distributed transmit beamforming [8, 9, 14] is a form of cooperative communications in which two or more information sources simultaneously transmit a common message and control the phase of their transmissions so that the signals constructively combine at an intended destination. Depending on the design objectives and constraints, the power gains of distributed beamforming can be translated into increases in range, rate, or energy efficiency. However it is difficult to use practically because the sources must do information sharing and strict timing synchronization when they send same data. Also Distributed transmit beamforming can't use spatial multiplexing because sources send same data.

There are a number of approaches to improve performance of distributed beamforming. However, most of related works focused on scheduling and power allocation techniques for reducing interference [15-16], and limited backhaul capacity for reducing the feedback information[8, 17, 18]. Therefore, there are a little performance improvement compared distributed beamforming.

Our proposed adaptive beamforming technique can use available BS or RS simultaneously using MS's multiple antennas. Therefore available BS or RS send independent data and it can improve performance of user's data rate with less degradation of the BER.

3. System Model

Figure 1 shows a wireless MIMO broadcast channel in which radio BSs or RSs communicate with an MS. The MS has a linear/non-linear reception entity, and its number of receive antennas is Mr. The number of transmit antennas in the BS or RS is Mt. An MS cannot have many antennas due to its size; we assume that Mr is 4 or less.

Spatial multiplexing is impossible when the antenna of MS isn't spaced sufficiently in the beamforming system. Hkn means nth antenna's channel states of kth MS, CN means Gaussian distribution. Therefore we assume that Hkn is the 1*Mt channel matrix from the BS or RS to the nth antenna of kth MS, Xn is the Mt*1 transmitted symbol vector at the kth MS, and ykn is the received symbol value at the kth MS. In addition, nk is the independent and identically distributed additive white Gaussian noise (AWGN) value.

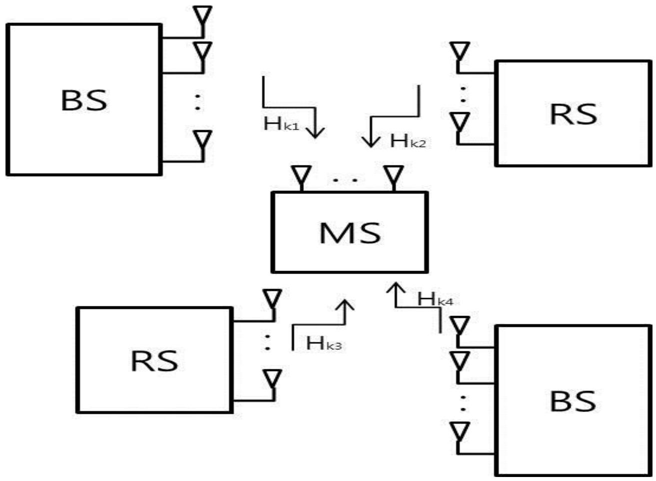

Figure 1. Proposed System Model

Then the received signal for the nth antenna of kth MS in MIMO systems is mathematically described as

$$
\begin{aligned}
y_{k1} &= H_{k1} X_1 + n_{k1} \\
y_{k2} &= H_{k2} X_2 + n_{k2} \\
y_{k3} &= H_{k3} X_3 + n_{k3} \\
&\vdots \\
&\vdots \\
y_{kMr} &= H_{kMr} X_{Mr} + n_{kMr}
\end{aligned} \tag{1}
$$

The mobile channel H_{kn} is modeled as a single path Rayleigh with i.i.d entries ~ CN(0,1) and block fading.

4. Adaptive Beamforming with Per-Antenna Feedback

Figure 2 shows our proposed adaptive beamforming algorithm. When the MS enters the overlapped area, the MS receives a beacon message to scan for BSs and RSs. MS send its CSI and data query message which indicate desired data information to BSs or RSs. And the BSs or RSs send the feedback information to their CP (Central Process), CP checks the CSI in order to determine any CQI (Channel Quality Indicator) [12] of CSI is greater than the threshold and make feedback including estimated CSI. Those below threshold are reduced because that would decrease the BER efficiency. Then CP allocates required data to available BSs or RSs according to CSI. After available BSs or RSs are scheduled by CP, they send independent data to each antenna of MS, as shown in Figure 3. The number of BSs and RSs that communicate simultaneously is dependent on the MS's multiple antennas and the number of available BSs and RSs. MS can use spatial multiplexing when there are the same or more number of available BSs and RSs than number of MS's antenna. Therefore, our proposed system can send independent data from available BSs and RSs to the antenna of the MS.

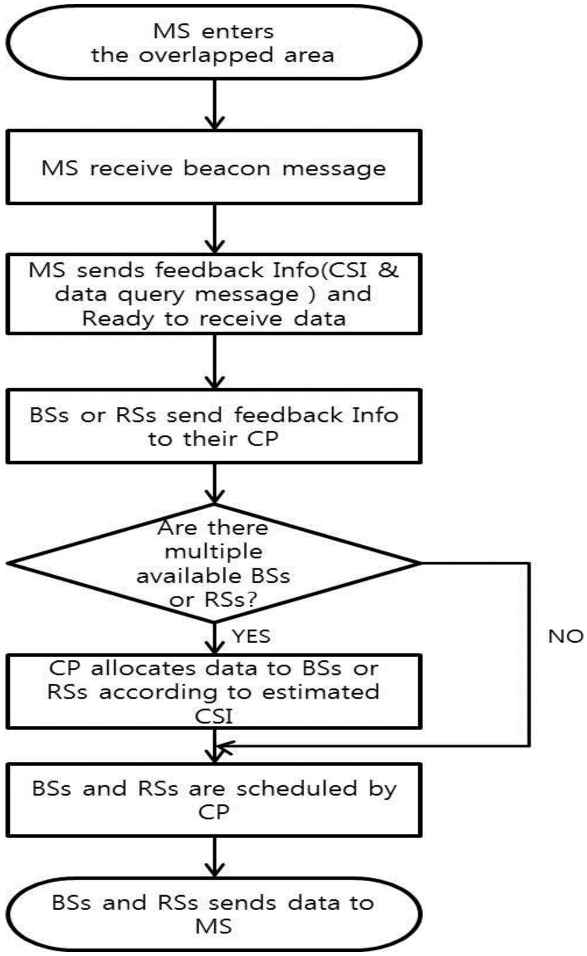

Figure 2. Proposed Beamforming Algorithm

In general, the MS's antenna interval is very small due to limited size. However, the distance from the BS or RS to the MS is very large. Therefore, each antenna's DOA (direction of arrival) is considered to be the same in the antennas of MS are not spaced sufficiently; that is, they are essentially the same path. For this reason, the system in conventional beamforming cannot utilize separate paths to achieve spatial multiplexing when the antennas of MS aren't spaced sufficiently.

In contrast, our proposed adaptive beamforming can achieve spatial multiplexing and diversity gain when the antennas of MS aren't spaced sufficiently because the MS simultaneously uses multiple paths from the available BSs or RSs.

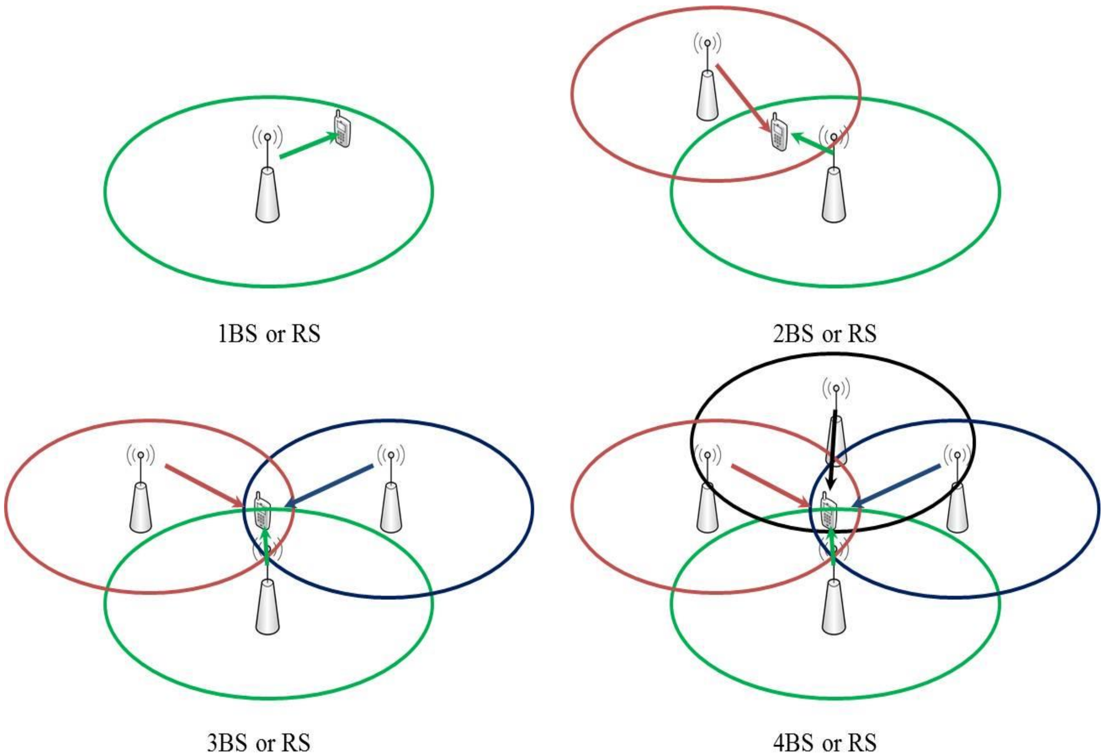

Figure 3. Different Cooperative Scenarios for available BSs or RSs

5. Performance Evaluation

Table 1. Performance Evaluation Parameters

Parameters	Value
Path loss Model	Rayleigh Fading for small city
The number of cell	4
The number of MS's antenna	2~4
Available Bandwidth(MHz)	0~20
Shadowing Mean(dB)	0
Shadowing Variance(dB)	10
Edge SNR	7~10dB
Frequency reuse ratio per cell	4

We tested our proposed adaptive technique, setting the number of available BSs or RSs to 4 and setting signal strengths to 10, 9, 8, and 7 dB (0dB=1Vrms), respectively. These levels were set through feedback information exchanged between the MS and each available BS or RS. An MS cannot have many antennas due to its size. Therefore we assume that the number of antennas in the MS varied from 2 to 4. User location in each cell follows a uniform distribution.

Distributed transmit beamforming selects the multiple BSs or RSs. But its sources can transmit a common message at a time, and its channel capacity can be calculated with Equation (2).

Distributed transmit beamforming:

$$C = W * F_{BF} * \log_2(1 + \frac{n_t P}{\sigma^2}|h|^2) \quad [19] \tag{2}$$

Here, W is bandwidth, FBF is the frequency reuse ratio in a cell, and P is transmit power. Our proposed adaptive beamforming technique can simultaneously use multiple available BSs or RSs using the MS's multiple antennas, and its channel capacity can be calculated with Equations (2)-(4).

Proposed adaptive beamforming with two antennas:

$$C = W * F_{BF} * \{\log_2\left(1+\frac{n_{t1}P_1}{\sigma_1^2}|h_1|^2\right) + \log_2\left(1+\frac{n_{t2}P_2}{\sigma_2^2}|h_2|^2\right)\} \tag{3}$$

Proposed adaptive beamforming with one Mr antenna:

$$C = W * F_{BF} \sum_{n=1}^{M_r} \log_2(1 + \frac{n_{tn} P_n}{\sigma_n^2} | h_n |^2) \tag{4}$$

Figure 4 shows that our proposed adaptive beamforming technique outperforms distributed transmit beamforming with respect to data rate. It shows the more antennas MS has, the data rate of MS becomes higher. Our proposed adaptive beamforming technique can achieve spatial multiplexing and diversity gain when the antennas of MS aren't spaced sufficiently because the MS simultaneously uses multiple paths from the available BSs or RSs.

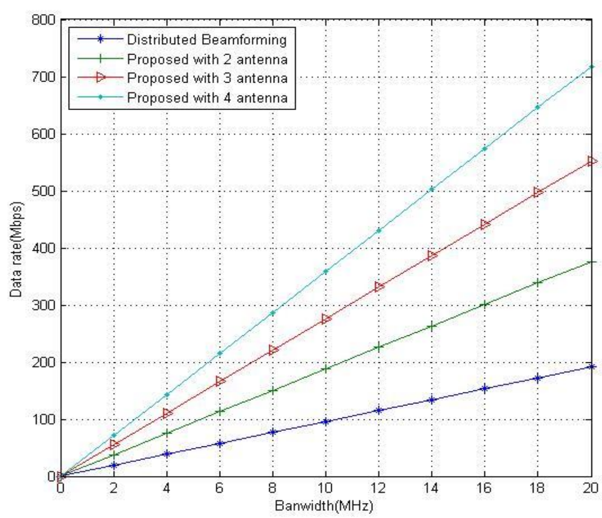

Figure 4. Data Rate per Bandwidth

Figure 5 presents the transmission time at 20 MHz. The more antennas in the MS, the greater reduction in transmission time because of increasing the data rate.

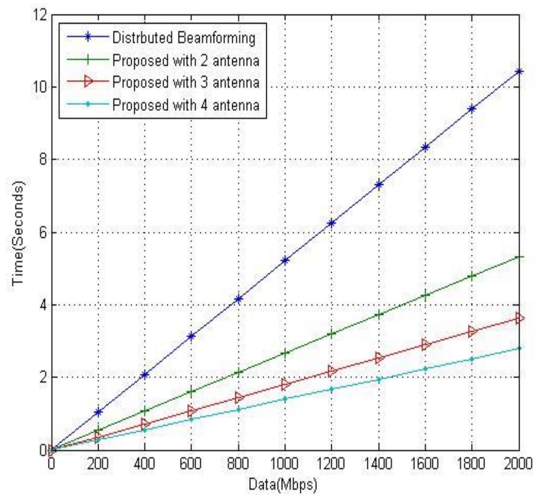

Figure 5. Transmission Time at 20 MHz

Figure 6 presents the data rate per SNR at 20 MHz. It also shows that our proposed adaptive beamforming technique outperforms distributed transmit beamforming.

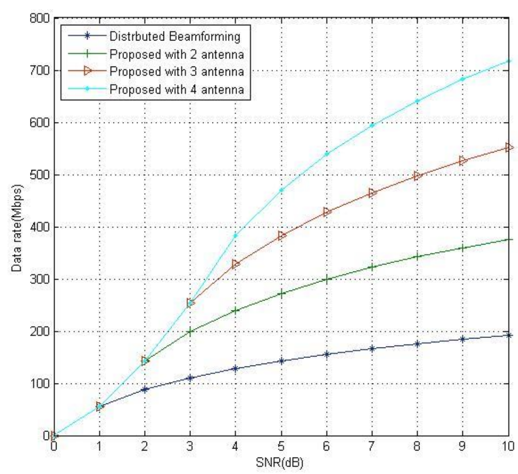

Figure 6. Data Rate per SNR at 20MHz

Table 1 shows the BER performance of the system based on Equation (5) [20] in the codebook [21] (N=4).

Table 2. Bit Error Rate at N=4

Distributed Beamforming	Proposed with 2	Proposed with 3	Proposed with 4
0.0033	0.0069	0.0081	0.0089

$$P_e = \int_{-\infty}^{\infty} P_e(\gamma) f_{\gamma\max}(\gamma) d\gamma$$
$$= \frac{a}{2(2\pi)^N} * \int_{-\infty}^{\infty} \dots \int_{-\infty}^{\infty} \det(\mathrm{I} - \mathrm{SI})^{-1} \prod_{m=1}^{N} \left(jt_m \right)^{-1} * \left\{ 1 + \sum_{m=1}^{n} (-1)^m \sum_{b_1 + \dots + b_N = m} \sqrt{\frac{c}{c + jb_T}} \right\} dt_1 \dots dt_N \tag{5}$$

Some degradation of the BER will occur in the proposed adaptive beamforming system due to the use of multiple beams. However, this degradation is small if the differences among SNR of the beams are not significant. In Table 1, all the systems have about $10^{-2} \sim 10^{-3}$ BER performance. This illustrates the importance of the chosen SNR threshold that determines available BSs or RSs.

6. Conclusion

Most of beamforming techniques select the BS or RS which has the strongest signal strength at the MS via exchange of feedback information between the MS and the BS or RS. If an RS is used, it has a simple role of retransmitting the overheard data of a BS, and the MS can communicate with only one BS or RS at a time. Also sources can't send independent data although they use multiple sources simultaneously. Our proposed adaptive beamforming technique allows for simultaneous communication by independent beam with multiple available BSs or RSs using the MS's multiple antennas. As a result, we can use spatial multiplexing when the antenna of MS isn't spaced sufficiently. Therefore, it can improve performance of user's data rate with less degradation of the BER.

In our proposed adaptive beamforming technique, the threshold that determines the availability of a BS or RS and that cooperation of the available BSs or RSs is a major issue because of BER efficiency. Therefore, we are going to focus on these problems in our next study.

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References

[1] K. K. Wong, R. D. Murch and K. B. Letaief, "Performance enhancement of multiuser MIMO wireless communication systems", IEEE Trans. Commun., vol. 50, no. 12, **(2002)** December, pp. 1960-1970.

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

[3] M. Sharif and B. Hassibi, "A comparision of time-sharing, DPC and beamforming for MIMO broadcast channels with many users", IEEE Trans. Commun., **(2007)** January.

[4] P. Marsch and G. Fettweis, "On base station cooperation schemes for downlink network MIMO under a constrained backhaul", Proc. IEEE Global Telecommun. Conf. (Globecom), **(2008)** November, pp. 1-6.

[5] A. Tudzarov and T. Janevski, "Functional Architecture for 5G Mobile Networks", IJAST, vol. 32, **(2011)** July, pp. 65-78.

[6 M. M. Alkhawlani and A. M. Mohsen, "Hybrid Approach for Radio Network Selection in Heterogeneous Wireless Networks", IJAST, vol. 44, **(2012)** July, pp. 33-48.

[7] A. Afzaal Abbasi and A. Florentina, "An Analysis of QoS specific Coherence Issues in Distributed Networks", IJAST, vol. 49, **(2012)** December, pp. 73-82.

[8] H. Dahrouj and W. Yu, "Coordinated Beamforming for the Multicell Multi-antenna Wireless System", IEEE Trans. Wireless Commun., vol. 9, no. 5, **(2010)**, pp. 1748-1759.
[9] R. Zakhour, Z. K. M. Ho and D. Gesbert, "Distributed Beamforming Coordination in Multicell MIMO Channels", IEEE VTC, **(2009)**.
[10] Q. Li, G. Li, W. Lee, M. il Lee, D. Mazzarese, B. Clerckx and Z. Li, "MIMO techniques in WiMAX and LTE: a feature overview", IEEE Commun. Magazine, vol. 48, no. 5, **(2010)** May, pp. 86-92.
[11] K. Huang, R. Wheath and J. G. Andrews, "Space Division Multiple Access with a sum Feedback Rate Constraint", IEEE Trans. Signal processing, vol. 55, no. 7, **(2007)** July.
[12] S. Kim, H. Kim, C. S. Park and K. B. Lee, "On the Performance of Multiuser MIMO Systems in WCDMA/HSDPA: Beamforming, Feedback and User Diversity", IEICE Trans. Commun., vol. E98-B, no. 8, **(2006)** August, pp. 2161-2169.
[13] S. Sanayei and A. Nosratinia, "Opportunistic beamforming with limited feedback", IEEE Trans. Wireless Commun., vol. 6, no. 8, **(2007)** August, pp. 2765-2771.
[14] R. Mudumbai, D. R. Brown, U. Madhow and H. V. Poor, "Distributed transmit beamforming: Challenges and recent progress", IEEE Commun. Mag., vol. 47, no. 2, **(2009)** February, pp. 102-110.
[15] L. Venturino, N. Prasad and X. Wang, "Coordinated Scheduling and Power Allocation in Downlink Multicell OFDMA Networks", IEEE Trans. Veh.Tech., vol. 58, no. 6, **(2009)**, pp. 2835-2848.
[16] J. Yuan and W. Yu, "Distributed Cross-layer Optimization of Wireless Sensor Networks: A Game Theoretic Approach", IEEE Globecom Conf, **(2006)**.
[17] H. Huh, S.-H. Moon, Y.-T. Kim and I. Lee, "Multi-cell MIMO Downlink with Cell Cooperation and Fair Scheduling: A Large-System Limit Analysis", IEEE Trans. Inf. Theory, vol. 27, no. 12, **(2011)**, pp. 7771-7786.
[18] H. Huh, A. M. Tulino and G. Caire, "Network MIMO with linear zeroforcing beamforming: Large system analysis, impact of channel estimation, and reduced-complexity scheduling", IEEE Trans. Inf. Theory, vol. 58, no. 5, **(2012)** May, pp. 2911-2934.
[19] P. Xia and G. B. Giannakis, "Design and analysis of transmit-beamforming based on limited-rate feedback", IEEE Trans. Signal Process., vol. 54, no. 5, **(2006)** May, pp. 1853-1863.
[20] J. Lee and Y.-C. Ko, "Performance improvement of transmit beamforming MISO system using optimum codebook indexing over feedback error channel", Proc. IEEE Int. Symp. Info. Th., **(2008)** July, pp. 2558-2562.
[21] D. J. Love, R. W. Heath and T. Strohmer, "Grassmannian beamforming for multiple input multiple output wireless systems", IEEE Trans. on Inf. Theory, vol. 49, no. 10, **(2003)** October, pp. 2735-2747.

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