Downlink Node Cooperation with Node Selection Diversity

Jeongkeun Lee*, Sungjin Kim†, Taekyoung Kwon* and Yanghee Choi*

*School of Computer Science and Engineering, Seoul National University
Email: jklee@mmlab.snu.ac.kr, tkkwon@snu.ac.kr, yhchoi@snu.ac.kr

†School of Electrical Engineering, Seoul National University, Email: kimsj@mobile.snu.ac.kr

***Abstract*— The cooperative utilization of antenna diversity among closely-located nodes is referred to as *node cooperation* or *cooperative diversity*. To realize this, a group of nodes are first to form a *cluster*, which necessitates a node selection algorithm. We propose a few node selection algorithms that form a cluster with "best" cooperation nodes based on various criteria. Simulation results indicate that the performance of the node selection algorithms is highly dependent on the distances among nodes.**

I. Introduction

Recently the idea of the MIMO antenna system is extended in a distributed fashion where a group of closely-located but separate nodes, each of which has its own antenna, can "cooperate" together to utilize antenna diversity among themselves.

For example, suppose a person carries a cellular phone and a PDA, both of which are equipped with CDMA and Bluetooth interfaces. They can form a wireless personal area network using their Bluetooth interfaces. Note that the distance between the CDMA base station (BS) and the group of these nodes is in general much longer than the one between the cellular phone and the PDA. Then, this group of closely-located WPAN nodes can form a cooperating cluster. The intra-cluster channel uses Bluetooth communications, while the inter-cluster (between the BS and the cluster) channel uses CDMA cellular communications. The nodes in this cluster can cooperate to utilize their antennas diversity among their CDMA interfaces as if their antennas belong to the same node.

References [1], [2] consider node-collaborative signal processing, but with only two cooperating nodes. In our preliminary work [3], we generalize this two-node cooperation model by introducing an intra-cluster multiple access channel (MAC), which is a key factor to realize a cluster of more than 2 nodes.

Numerous MIMO antenna selection schemes (e.g. [4], [5]) that optimally choose a subset of the available receiver antennas have been proposed in original MIMO systems (multiple antennas in a single node) to reduce implementation cost due to multiple RF chains. Node selection in the case of receiver node cooperation is an even more crucial issue because of intra-cluster relaying cost. That is, the intra-channel is noisy and its gain is smaller compared to the above single node case where every antenna is directly connected to the others. Taking lessons from these, we propose a few node selection schemes and investigate their applicability in terms of the inter-cluster distance.

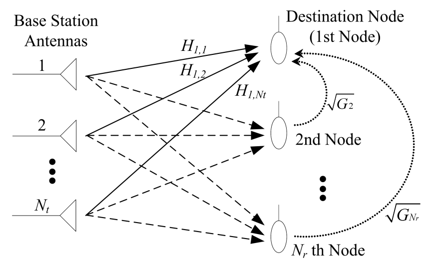

Fig. 1. System Model

II. Downlink Cooperation Model

For illustration, we will consider the infrastructure-mode wireless communications such as cellular networks. Under these circumstances, node cooperation matters only in downlink since the BS (as a single node) can readily harness the power of the MIMO system in uplink. Thus, we consider receiving node cooperation in downlink only. Let us assume that a BS is equipped with N_t transmitting antennas and there is a cluster of $N_r(\geq N_t)$ receiving nodes as shown in Fig. 1.

The BS first converts a single bitstream into N_t parallel streams of symbols. On the receiver side, the destination node forms a receiving cluster by selecting the best $N_t - 1$ relaying nodes out of $N_r - 1$ neighboring nodes. Then the selected cooperating nodes will cooperate by forwarding their received streams to the destination node that would then decode them.

The above clustering scenario allows us to assume that the distance between the BS and the receiving cluster is sufficiently large so that the distance between any antenna in the BS and any node in the receiving cluster can be assumed to be equal. The channel gain amplitudes between these two sets (N_t transmitting antennas and N_r receiving antennas) are then normalized to one. The inter-cluster channel and the intra-cluster channel are assumed to be orthogonal. The bandwidth of them is assumed to be 1 Hz each.

We first consider the inter-cluster channel, which is characterized by the $N_r \times N_t$ matrix. Let $\mathbf{x}$ denote the $N_t \times 1$ transmit vector and $\mathbf{y}$ is the $N_r \times 1$ vector of received signal at the receiving nodes. Then the channel equation will be expressed by

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} \quad (1)$$

where each element of the vector $\mathbf{n}$ is an independent $\mathcal{N}(0,1)$ noise.

Now, we look at the intra-cluster channel at the receiving end. We denote by G_i the intra-channel gain from the ith node to the destination node (1st node) where $2 \leq i \leq N_r$. This is equivalent to a situation where the distance between the BS and the receiving cluster is $(G_i)^{1/l}$ times as large as the one between the destination node and the ith receiving node where l is the path loss exponent.

The total power cost of receiver cooperation is P_r and the total BS transmission power is constrained to P.

The aggregated signal at the destination receiver is then given by [1], [3]:

$$\widetilde{\mathbf{y}_1} = \mathbf{H}'\mathbf{x} + \mathbf{n}' \quad (2)$$

where $\mathbf{n}'$ is the intra-channel noise vector and

$$\mathbf{H}' = \begin{bmatrix} H_{11} & H_{12} & \cdots & H_{1N_t} \\ \alpha_2 H_{21} & \alpha_2 H_{22} & \cdots & \alpha_2 H_{2N_t} \\ \cdots & & & \\ \alpha_{N_r} H_{N_r 1} & \alpha_{N_r} H_{N_r 2} & \cdots & \alpha_{N_r} H_{N_r N_t} \end{bmatrix}.$$

Notice that $\tilde{\mathbf{y}_1}$ differs from $\mathbf{y}$ only due to the α_i factor, which is caused by noise amplification during intra-channel relaying and is a parameter less than 1. The sum rate decodable at the destination receiver is given by:

$$R_{downlink} = \log \left| \mathbf{I} + \frac{P}{N_t} \mathbf{H}'\mathbf{H}'^H \right| \quad (3)$$

where the superscript ^{H} denotes the Hermitian transpose.

III. Node Selection Algorithms

A. Optimum Node Selection

Since the sum achievable rate of a downlink node cooperation is defined as (3), the destination now selects those neighbor nodes that allow the maximization of the rate, so that

$$R_{select} = \max_{S(\widetilde{\mathbf{H}'})} \left(\log \left| \mathbf{I} + \frac{P}{N_t} \mathbf{H}'\mathbf{H}'^H \right| \right) \quad (4)$$

where $\widetilde{\mathbf{H}'}$ is created by deleting $N_r - N$ rows from $\mathbf{H}'$, and $S(\widetilde{\mathbf{H}'})$ denotes the set of all possible $\widetilde{\mathbf{H}'}$.

The optimum selection of nodes requires $\binom{N_r}{N_t}$ computations of determinants, which is computationally burdensome.

B. Channel information based selection

If there are two rows of the $\mathbf{H}'$ that are identical, we can delete any row of these two rows without losing any information about the transmitted signal. In addition if they have different powers, we delete the row with lower power. When there are no identical rows we select next two rows for the deletion whose correlation is the highest. If we repeat this deletion until $N_r - N_t$ rows are eliminated, we can have the $N_t \times N_t$ channel matrix $\widetilde{H'}$ whose rows are maximally uncorrelated and have maximum powers. Somewhat similar approach is to delete one of two rows whose mutual information has maximum value. This correlation based method (CBM) and mutual information based method (MIBM) require less than ${N_t}^2$ vector multiplications while providing comparable performance.

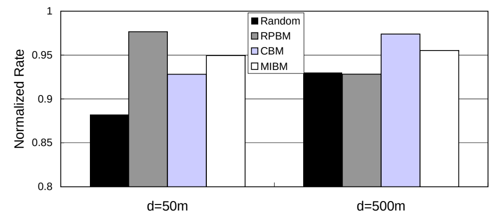

Fig. 2. Normalized performance of node selection algorithms

C. Relaying Power based selection

Although [4] showed that simply choosing the antennas that instantaneously receive the most energy does not give good performance in MIMO antenna selection, it is worthwhile to consider power based selection in the case of node selection. In particular, if the inter-cluster distance is not so much larger than the distance between the destination and relaying nodes, the distribution of G_i has a large effect on the downlink rate. If relaying nodes use equal power to transmit to the destination node, the received signal power from the ith relaying node is directly mapped to G_i at the destination node and eventually to the intra-cluster distance. Thus, relaying power based method (RPBM) that selects $N_t - 1$ nodes with highest received signal power can be effective despite its simplicity.

IV. Results

Fig. 2 shows the performance of node selection algorithms when $N_t = 4$ and $N_r = 8$. SNR is set to 0 dB, which gives a value for P as 1 as the noise is normalized to one and P_r is set to 0.1. We set the intra-cluster channel gain of each ith relaying node as $G_i = (\frac{d}{(i-1)*1})^3$ where d is the inter-cluster distance in meter, the numerator $((i-1) \times 1)$ denotes the distance between the destination node and the ith relaying node, and 3 is the path loss exponent. For comparison purposes, we add the random selection algorithm. The downlink rate of each RPBM, CBM, MIBM and the random selection is normalized by the rate of optimum selection algorithm. RPBM outperforms other methods when $d = 50m$, i.e., the receiving cluster is located relatively close to the BS. CBM outperforms others in the long inter-cluster distance case ($d = 500m$). MIBM shows steady capacity enhancement regardless of the distance d.

References

[1] N. Jindal et al.,"Capacity of Ad-Hoc Networks with Node Cooperation," in *Proc. of IEEE ISIT*, June 2004.

[2] M. Dohler et al.,"Virtual Antenna Arrays for Future Wireless Mobile Communication Systems," in *Proc. of ICT*, June 2002.

[3] J. Lee, et al., "RX node cooperation to enhance downlink capacity," unpublished, [Online] Available: http://mmlab.snu.ac.kr/∼jklee/papers/.

[4] A. F. Molish and M. Z. Win, "MIMO systems with antenna selection," *IEEE Microwave Magazine*, March 2004.

[5] Y. S. Choi, et al., "Fast antenna selection algorithms for mimo systems," in *Proc. VTC fall 2003* (invited).