Distributed Antenna System | Antenna Selection | Capacity Maximization

Collaboration Projects

Capacity-based Antenna Selection Scheme for Downlink Transmission in Distributed Antenna System

Recognizing the potential of a DAS as a future radio access network architecture, we propose a RAU selection scheme based on capacity maximization for downlink transmission in DAS. This research was conducted jointly with the National Mobile Communications Research Laboratory (Professor Xiaohu You), Southeast University, China.

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1. Introduction

The IMT–Advanced[*1] standard calls for high-speed data transmission in the range of 100 Mbit/s to 1 Gbit/s. However, future wireless systems based on this standard will be allocated to high-frequency bands, and in general, a higher frequency band means more propagation loss. Furthermore, considering that a high Signal-to-Noise Ratio (SNR) is needed to achieve high-speed transmission by spatial multiplexing or multilevel modulation, the coverage area of a single base station can be expected to be quite small compared to that of a Third-Generation (3G) system.

In order to solve this issue, the Wireless world INitiative NEw Radio (WINNER)[*2] forum and the working group for the Institute of Electrical and Electronics Engineers (IEEE) 802.16j[*3] standard have been discussing multihop[*4] system networks using relay stations (**Figure 1**). At the same time, Future Technologies for Universal Radio Environment (FuTURE), a Chinese national project toward IMT-Advanced, has been investigating the Distributed Antenna System (DAS) shown in **Figure 2** as a key technology. DoCoMo Beijing Communications Laboratories have been examining the potential of DAS and conducting joint research with Professor You of Southeast University, the leader of the FuTURE project, on DAS-related transmission and system control technologies.

In this article, we propose an optimal Remote Antenna Units (RAU) selection scheme to maximize downlink capacity in DAS and conduct computer simulations for performance evaluation. The proposed scheme has been deployed in a test bed for field experiments now being held in Shanghai as part of the FuTURE project, phase 2.

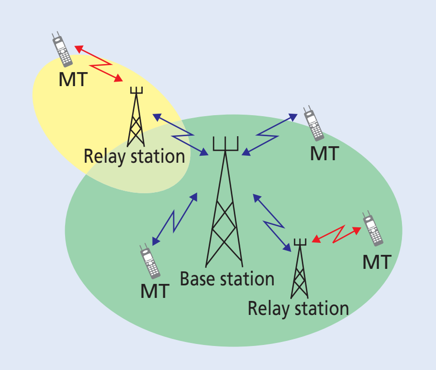

Figure 1 Multihop system

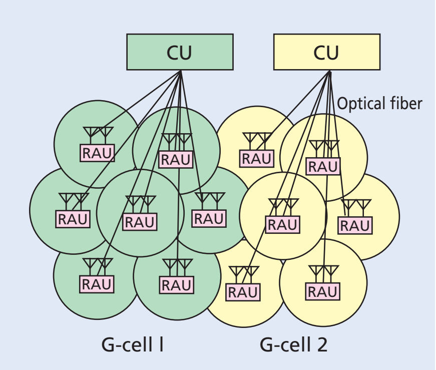

Figure 2 DAS example

2. DAS Architecture and Transmission Capacity

In DAS, geographically distributed RAU are connected by optical fiber to one Central Unit (CU) to form a single Generalized cell (G-cell). Here, a RAU consists

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*1 **IMT-Advanced**: A standard ranked as the successor to IMT-2000 at International Telecommunication Union–Radiocommunication Sector (ITU-R). It calls for data rates of about 100 Mbit/s for high mobility and 1 Gbit/s for low mobility.

*2 **WINNER**: A European research forum established in 2004 with the aim of developing radio transmission technologies for next-generation mobile communications.

*3 **IEEE802.16j**: A next-generation wireless Metropolitan Area Network (MAN) standard based on IEEE802.16 to provide a relay environment. It achieves a communication range of several kilometers square (maximum 50 km), which represents a significant jump in coverage compared to IEEE802.11, the existing wireless LAN standard.

of one or more antennas, and the role of the CU is to centrally process the transmit/receive signals of all antennas belonging to all RAUs in the G-cell. This architecture makes it easy to centrally process signals that overlap multiple RAUs. That is, it simplifies the process of achieving a diversity effect using multiple antennas or of performing Multiple Input Multiple Output (MIMO) transmission for increasing transmission speed using multiple RAUs. It also enables signal quality to be improved at the edge of each microcell that constitutes the small service area of each RAU, and it facilitates handover between microcells under the same CU.

A Mobile Terminal (MT) will use more than one RAU in a G-cell to communicate, but transmission capacity per MT will differ according to which RAUs are used. Although detailed studies have been performed on calculating degradation rate and transmission capacity in uplink and downlink channels, these characteristics have not been clarified for multiple RAUs [1][2].

In addition, it is generally possible in uplink communications to maximize capacity by having all RAUs in a G-cell receive signals and transfer them to the CU for synthesizing. In the downlink, however, transmission power per CU is fixed so that transmission rate differs according to the number of selected RAUs. Past selection schemes proposed for the downlink include diversity selection [2], which always selects the RAU that maximizes the Signal-to-Interference-plus-Noise Ratio (SINR)[*5] , and blanket transmission [3] that uses all RAUs in a G-cell. Neither of these schemes, however, can be called optimal from the viewpoint of transmission capacity.

In the research described below, we use transmission-capacity equations from information theory to propose a RAU selection scheme that determines how many and which RAUs to use to maximize capacity in downlink transmission.

3. Capacity-based RAU Selection Scheme

3.1 System Model

Letting N denote the number of RAUs under a single CU, L the number of antennas per RAU, and M the number of antennas per MT, the received signal can be given by equation (1).

$$\mathbf{y}(\mathbf{d}) = \mathbf{H}(\mathbf{d})\mathbf{x} + \eta \qquad (1)$$

Here, y(d) is the received-signal vector ($M \times 1$) of a MT, H (d) is the channel matrix ($M \times NL$)[*6] between the RAUs and the MT, d is the distance vector d= [d_1, d_2,…,d_N], where d_i is the distance from the ith RAU to the MT, x is the transmission-signal vector ($NL \times 1$) from all RAUs, and η is Gaussian noise[*7]. **Figure 3** shows the channel matrix H from the transmitters to the receiver.

Here, g_i denotes signal attenuation based on the distance from a RAU to the MT (including shadowing[*8]) and h^w_{ij} denotes channel response[*9].

3.2 Derivation of Transmission-Capacity Equation

From information theory, downlink capacity can be given by equation (2):

$$C_e = \max_{Q_{xx}: tr\{Q_{xx}\} \le P} E\left\{\log_2\left[\det\left(\mathbf{I} + \mathbf{H}\mathbf{Q}_{xx}\mathbf{H}^{\dagger}\right)\right]\right\} \qquad (2)$$

Here, Q_{xx} is the transmit-signal covariance matrix[*10]. In this system, transmit power is allocated equally to the selected RAUs in the following way:

$$p_i = \begin{cases} p/n & i \in RAU_{sel-set} \\ 0 & others \end{cases} \qquad (3)$$

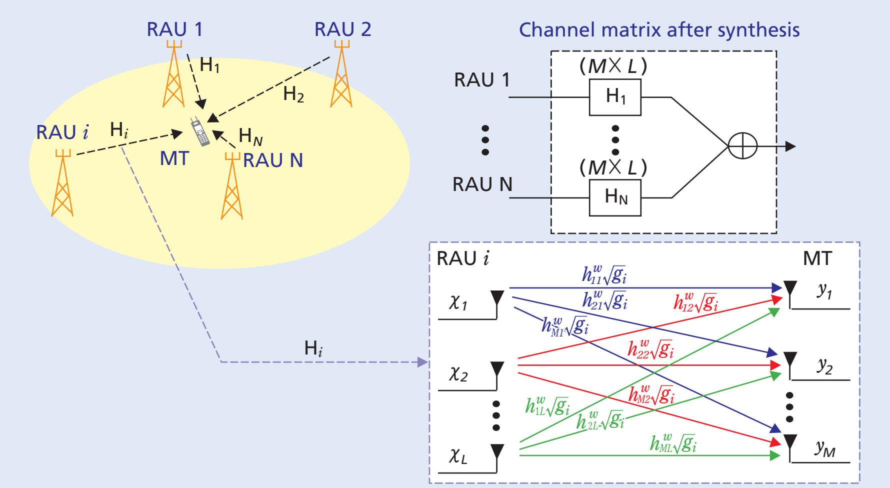

Figure 3 Channel matrix from transmitters to receiver

*4 **Multihop**: A communication system that allows terminals to communicate directly with each other and enables widely separated terminals to exchange data by relaying via multiple terminals in a network composed of hierarchically arranged terminals.

*5 **SINR**: In contrast to SNR, the ratio of signal strength to noise strength, SINR is the ratio of signal strength to the sum of noise strength and interference strength.

*6 **Channel matrix**: Channel response (see *9) between multiple transmit/receive antennas expressed in matrix form.

*7 **Gaussian noise**: Noise that has a normal distribution.

*8 **Shadowing**: A phenomenon in which radio waves are blocked by buildings, signs, vehicles, or other objects.

Here, n denotes the number of selected RAUs and P the total transmit power of the CU. Transmission capacity when using n-selected RAUs can be given by equation (4) from equations (2) and (3).

$$C_e = E\left\{ \begin{array}{l} \log_2 \det[\mathbf{I} + \mathbf{H}^w diag\{\sqrt{g_1'}, \sqrt{g_2'} \ldots \sqrt{g_{n_T}'}\}\mathbf{Q}_n \\ diag\{\sqrt{g_1'}, \sqrt{g_2'} \ldots \sqrt{g_{n_T}'}\}\mathbf{H}^{wt}] \end{array} \right\} \quad (4)$$

Here,

$$Q_n = \begin{bmatrix} \frac{P}{n}\mathbf{I}_n & 0 \\ 0 & 0 \end{bmatrix} \quad (5)$$

and $\{g_i'\}$ denotes $\{g_i\}$ in descending order.

3.3 RAU Selection Scheme Based on Capacity Maximization

We now describe an optimal RAU selection scheme for maximizing transmission capacity. Here, for the sake of simplicity, we assume transmission to only one user at a certain point in time in one G-cell. The proposed RAU selection procedure consists of the following steps:

Step 1: Each RAU sends the MT a pilot signal. The MT measures the SINR received from each RAU and feeds back the average value over a certain time interval to the CU.

Step 2: The CU arranges the RAUs in order of large to small SINR and continues to select RAUs until downlink capacity becomes maximum using equation (5).

Step 3: The system allocates transmit power equally to the selected RAUs.

Repeating the above procedure at fixed intervals enables optimal RAUs to be selected at all times in accordance with MT mobility, i.e., with fluctuations in the measurement of received SINR of each RAU. **Figure 4** shows an example of RAU dynamic selection in conjunction with MT mobility. In this example, the MT moves from point A to point B and finally to point C, and the number of RAUs selected for the MT changes dynamically from 4 to 1 and 2, respectively.

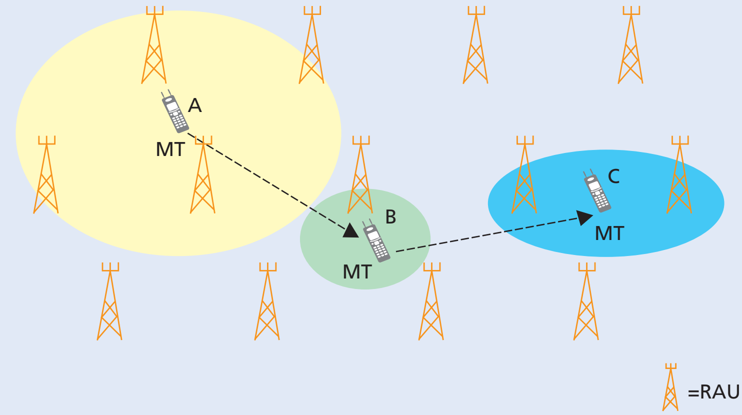

Figure 4 Example of RAU dynamic selection

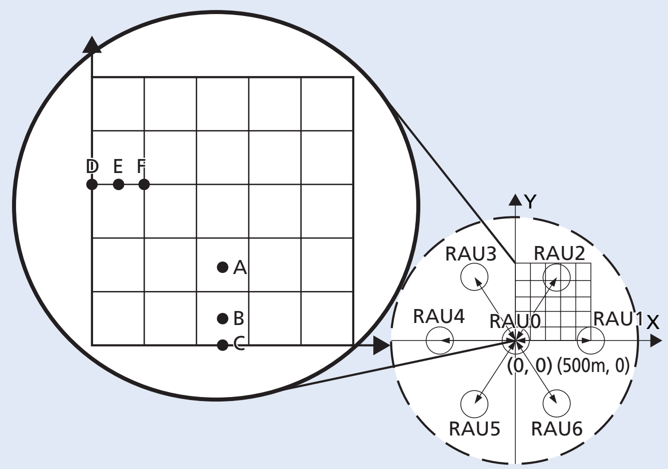

Figure 5 G-cell configuration

3.4 Performance Evaluation

We consider the case of seven RAUs distributed in a single G-cell with each RAU having one antenna (**Figure 5**). As one example, we set distance attenuation coefficient[*11] to 4 and averaged received SNR to 10 dB. Targeting the area shown by the grid in Fig. 5, we assume that a MT is located at coordinate points A (250, 145), B (250, 50), C (250, 0), D (0, 300), E (50, 300), and F (100, 300).

Figure 6 shows the number of transmit RAUs for which capacity is maximum for MTs at the six locations from A to F. As shown, the optimal number of

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*9 **Channel response**: A parameter expressing the attenuation, phase rotation, and delay received by a signal while passing along the radio propagation path from transmit to receive points.

*10 **Covariance matrix**: A matrix whose diagonal components express the variance of each variable in a set of variables and whose other elements each express the degree of correlation between two variables with respect to their direction of change (positive/negative).

*11 **Distance attenuation coefficient**: The nth power of the distance between the transmitter and receiver is used when calculating propagation loss in mobile communications. This “n” is the distance attenuation coefficient.

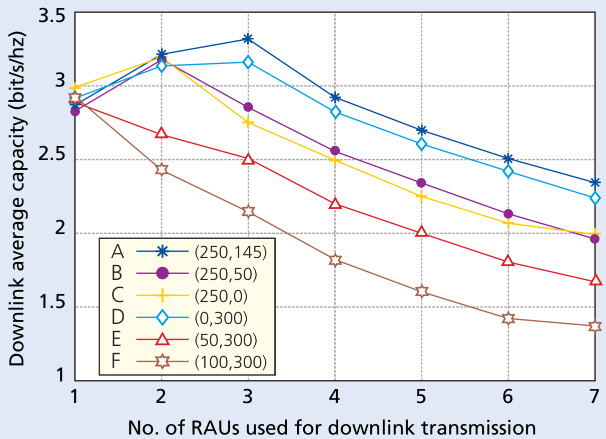
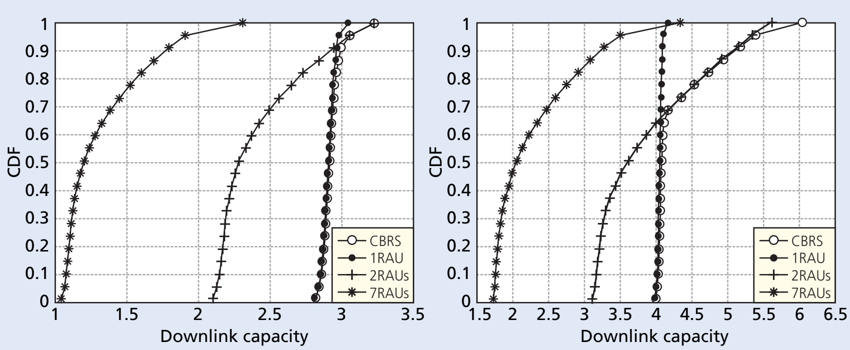


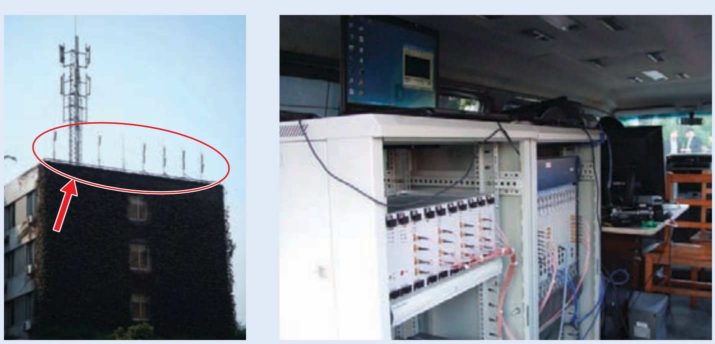
Figure 6 Capacity versus no. of RAUs for MTs at different locations



(a) One receive antenna

(b) Two receive antennas

Figure 7 CDF of downlink capacity



(a) RAU (8 antennas)

(b) MT interior (4 antennas)

Photo 1 External view of RAU and MT

RAUs for the MTs at locations A and D is 3, that at locations B and C is 2, and that at E and F is 1. These results demonstrate that the optimal number of RAUs differs according to MT location.

Next, we conducted a performance comparison with existing RAU selection schemes. In the following, the proposed scheme is abbreviated as Capacity Based RAU Selection (CBRS), the diversity-selection scheme that selects only one RAU as 1RAU, and the schemes that select 2 and 7 RAUs as fixed number of RAUs as 2RAUs and 7RAUs. **Figure 7** shows the Cumulative Density Function (CDF)[*12] for downlink capacity for the cases of 1 and 2 MT receive antennas. Compared with conventional schemes that select a fixed number of RAUs, the proposed scheme always selects an optimal number of RAUs so that capacity is maximum. In short, transmission capacity is always maximum with the proposed scheme compared with the conventional schemes. These results also show that capacity is greater for the case of 2 receive antennas.

4. Field Experiments

As part of the FuTURE project, phase 2, a test bed was constructed in Shanghai and field experiments conducted with the purpose of testing both Time-Division-Duplex (TDD)[*13] and Frequency-Division-Duplex (FDD)[*14] types of MIMO-Orthogonal Frequency Division Multiplexing (OFDM)[*15] wireless transmission technology. **Photo 1** shows the RAU and MT used in the experiments.

*12 **CDF**: A function that represents the probability that a random variable will take on a value less than or equal to a certain value.

For these experiments, a 20-MHz bandwidth in the 3.5-GHz band and a configuration consisting of 3 G-cells and 6 RAUs were used. The experiments showed that a peak data rate of 100 Mbit/s (5bit/s/Hz) could be achieved, that DAS was feasible, and that packet error rate could be improved with the proposed scheme. They also showed that RAU selection and switching based on the algorithm presented here operated as designed.

5. Conclusion

We proposed an optimal RAU selection scheme achieving maximum capacity in the downlink for DAS, which is considered to be a promising wireless network structure for enhancing the capacity of mobile communication systems. We also demonstrated the effectiveness of the proposed system by computer simulations.

Future work includes studies on combining transmit-power allocation and multi-user MIMO scheduling in a multi-G-cell environment.

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[3] C. Shen, L. Dai, S. Zhou and Y. Yao: "A novel spectrally efficient transmit diversity scheme in MIMO–DAS," Military Communications Conference, Vol. 1, pp. 638-642, Oct. 2003.

*13 **TDD**: A bidirectional transmit/receive system. It achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions that use the same frequency.

*14 **FDD**: A bidirectional transmit/receive system. Different frequency bands are allocated to the uplink and downlink to enable simultaneous transmission and reception.

*15 **OFDM**: A digital modulation system developed to improve resistance to multi-path interference. It converts a signal with a high data rate to multiple low-speed narrow-band signals and transmits those signals in parallel along the frequency axis. OFDM enables signal transmission with high spectrum efficiency.