Distributed Antenna Network for Gigabit Wireless Access

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***Abstract*— For gigabit wireless data services, there are three important technical issues to be addressed: limited bandwidth, severe frequency-selective fading, and limited transmit power. A distributed antenna network (DAN) is a promising solution to the above three technical issues. In this paper, recent advance in gigabit DAN is presented. In DAN, each mobile user is served by using multiple distributed antennas close to it. Particular attention is paid to frequency-domain multi-input/multi-output (MIMO) diversity, relay, beamforming, and multiplexing jointly used with frequency-domain equalization (FDE) to significantly improve the signal transmission quality over a service area.**

I. INTRODUCTION

The 3rd generation long term evolution (LTE) systems with 100Mbps peak data rate are now deployed in many countries [1]. A next step is the development of wireless networks which can extend a variety of broadband data services available in the future fixed networks to wireless users. Wireless broadband access of a peak data rate of around 1Gbps is required to provide a gigabit wireless pipe to each user. However, there are three important technical issues to be addressed: limited bandwidth, severe frequency-selective fading, and limited transmit power.

The available bandwidth is limited while gigabit data services are demanded. The gigabit wireless channel is severely frequency-selective and severe inter-symbol interference (ISI) is produced. Frequency-domain signal processing, e.g., frequency-domain equalization (FDE) [2], [3], may play an important role in achieving a good signal transmission performance in such a severe frequency-selective channel. In addition to the above, the path loss and shadowing loss cause a severe received signal power drop since the transmit power is limited. Gigabit data services are available only near the base station (BS) if the present wireless network architecture is employed with limited transmit power. A fundamental change is necessary in wireless access network architecture. A distributed antenna network (DAN) [4], in which each mobile user is served by using multiple distributed antennas close to it, is a promising solution to the above three technical issues.

II. GIGABIT DAN

In DAN, as shown in Fig. 1, the conventional BS is replaced by the signal processing center (SPC) and many antennas or clusters of antennas are spatially distributed around the SPC so that some antennas can always be visible from a mobile user terminal (MT) with a high probability. Antennas or antenna clusters are connected to a SPC by means of optical fiber links or wireless links.

It is desirable to use as many distributed antennas as possible while the number of MT antennas is limited to one or two since there is not enough space to equip too many antennas at an MT. A number of distributed antennas cooperate and act as distributed multiple-input multiple-output (MIMO) antenna diversity, relay, beamforming, or multiplexing.

For the DAN downlink, either the single-carrier (SC) or multi-carrier (MC) transmission can be used. However, for the uplink, SC is promising since it has a lower peak-to-average power ratio (PAPR). Using a transmit power amplifier with the same peak power, SC provides longer communication range than MC. Therefore, we have been investigating the potential of gigabit SC-DAN [4].

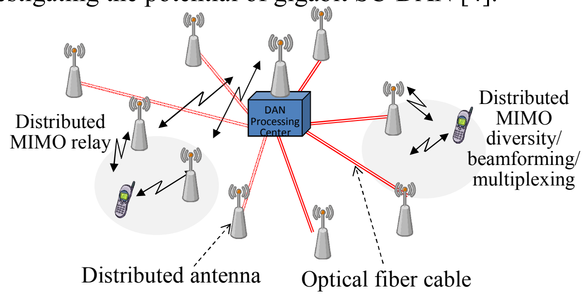

Figure 1. Concept of DAN.

III. DIVERSITY

Probably the most powerful application is the distributed MIMO antenna diversity. The problems can simultaneously be mitigated which result from the distance-dependent path loss and the random shadowing loss as well as the ISI caused by the frequency-selective fading. A frequency-domain space-time block coded joint transmit/receive diversity (FD-STBC-

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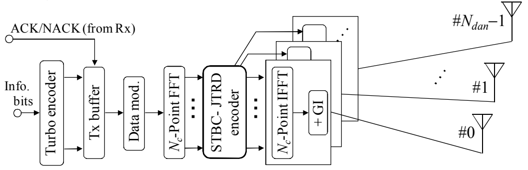
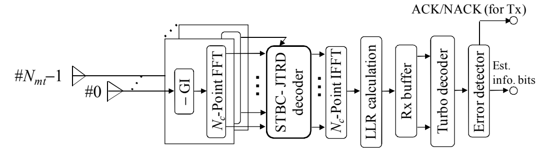
JTRD) combined with transmit FDE allows the use of an arbitrary number N_{dan} of distributed transmit antennas while the number of MT receive antennas is limited to $N_{mt}\leq 6$ [5]. It obtains an $N_{dan}\times N_{mt}$-th order (full) diversity gain. Note that for the uplink, frequency-domain space time transmit diversity (FD-STTD) [6] is promising since it allows the use of an arbitrary number N_{dan} of distributed receive antennas. A combination of FD-STBC-JTRD for downlink and FD-STTD for uplink is suitable for DAN.

Figure 2 illustrates the transmitter/receiver structures using FD-STBC-JTRD for the downlink packet access with turbo-coded hybrid automatic repeat request (HARQ) using type-II S-P2 strategy [7]. A sequence of J blocks of N_c symbols each is transformed by an N_c-point fast Fourier transform (FFT) into a sequence of J frequency-domain blocks and encoded into N_{dan} streams of Q coded signal blocks each. FD-STBC-JTRD encoding/decoding scheme depends on the number N_{mt} of receive antennas. A combination of J and Q is found in [5].

After performing the transmit FDE weight multiplication and inserting a cyclic prefix (CP) into the guard interval (GI) of each N_c-symbol block, N_{dan} streams of Q blocks each are transmitted from N_{dan} distributed antennas. At an MT, a superposition of N_{dan} transmitted signals is received by N_{mt} receive antennas. After removing the GI, FD-STBC-JTRD decoding is carried out to obtain the frequency-domain soft-decision signal.



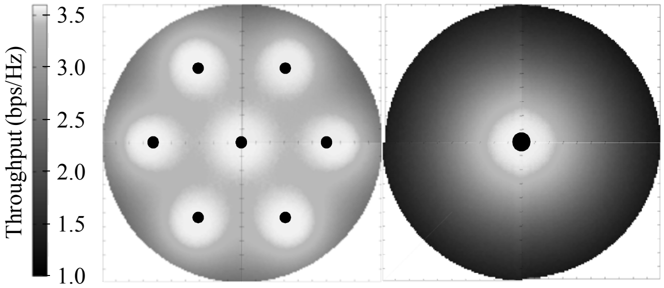
(a)SPC



(b)Mobile terminal (MT)

Figure 2. Transmitter/receiver structures of FD-STBC-JTRD downlink.

The computer-simulated spatial distribution of the throughput in a cell is plotted in Fig. 3 for (N_{dan}, N_{mt}) = (4, 2), 16QAM data modulation, and the normalized transmit symbol energy-to-AWGN power spectrum density ratio E_s/N_0=0dB. In the case of DAN, 7 antennas, which are illustrated by black dots in Fig. 3(a), are distributed over an entire cell and N_{dan}=4 antennas are selected based on the local average received signal power (i.e., based on the path loss plus shadowing loss). On the other hand, in the case of the conventional network (CN), 7 antennas are localized at the BS and N_{dan}=4 antennas are selected based on the instantaneous received signal power. It can be seen from Fig. 3 that DAN can achieve much higher throughput over an entire area; it is found that the throughput at the cell edge is about 2.6 (bps/Hz) in DAN while it is about 1.2 (bps/Hz) in CN.



(a) DAN (b) CN

Figure 3. Spatial distribution of throughput (7 antennas and 16QAM).

IV. RELAY

The cooperative amplify-and-forward (AF) relay using 2-time slots [8] is a powerful means to extend the coverage with limited MT transmit power. Figure 4 illustrates a DAN with 6 distributed relay stations (RSs) and one central antenna at SPC. It is assumed that an MT has a single antenna (N_{mt}=1) and one RS (N_{dan} =1) is selected from 6 RSs. In the first time slot, MT broadcasts to SPC and RS. In the second time-slot, RS transmits an amplified version of its received signal to BS.

SC uplink block transmission of M symbols per block is considered. SC frequency domain signal (consisting of M orthogonal subcarrier components) is divided into D frequency sub-blocks of M/D components each. Each sub-block is mapped onto a different frequency resource block based on the channel conditions of MS-RS-BS and MS-BS. Spectrum division/adaptive subcarrier allocation (SDASA) [9] is considered, in which a total of N_c subcarriers $(N_c \geq M)$ are divided into $N_c/(M/D)$ resource blocks of M/D consecutive subcarriers each. An example of SDASA when (M, D, N_c)=(8, 4, 16) is illustrated in Fig. 5. The best combination is chosen which provides the maximum channel capacity.

Relaying is not always effective; sometimes, the direct communication provides higher capacity. In the direct/cooperative AF relay (D/AR) switching, the cooperative AF relay is used only if it provides larger channel capacity than the direct communication.

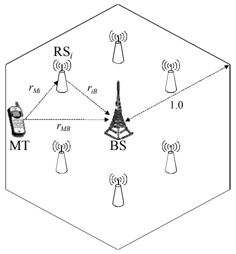


Figure 4. Cooperative AF relay.

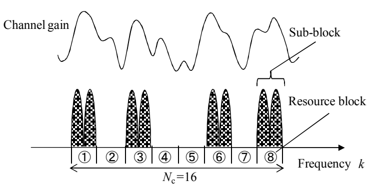


Figure 5. An example of SDASA when (M, D, N_c) = (8, 4, 16).

Figure 6 plots the 1%- and 50%- outage capacities of the D/AR switching (SDASA is not used), obtained by the computer simulation, as a function of the normalized transmit power-to-noise power ratio Γ_t, where the x%-outage capacity is the capacity below which the measured channel capacity falls with probability of x%. It can be seen from Fig. 6 that the D/AR switching can reduce the transmit power compared to the direct communication and the cooperative AF relay. The required transmit power for 1%-outage capacity of 4bps/Hz can be reduced by about 4dB compared to the direct communication and by about 2dB compared to the cooperative AF relay. It is interesting to note that the D/AR switching and direct communication provide almost the same 50%-outage capacity while the cooperative AF relay provides much lower capacity. Since 50%-outage capacity can be achieved when the MT-BS distance is shorter (i.e., better link quality) than the MT-RS-BS distance and hence relaying is not advantageous.

Figure 7 shows the 1%- and 50%- outage capacities of the D/AR switching jointly used SDASA. It can be seen from Fig. 7 that the additional use of SDASA obtains the frequency diversity gain and can further reduce the required transmit power compared to the D/AR switching without SDASA.

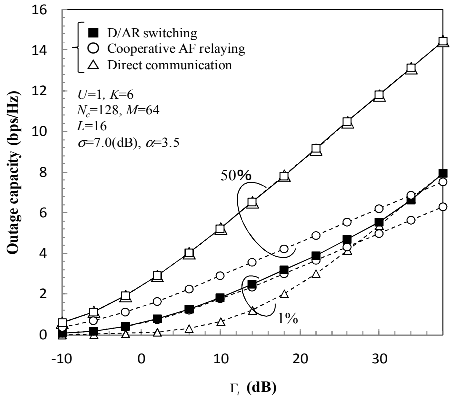


Figure 6. Capacity improvement by D/AR switching.

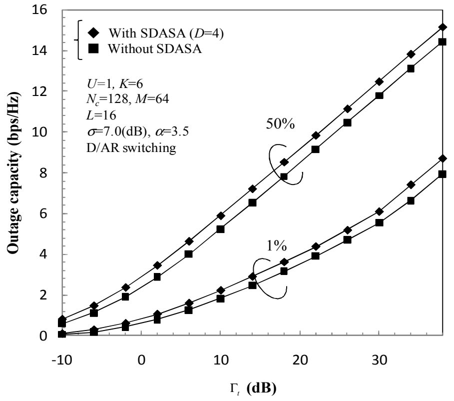


Figure 7. Additional capacity improvement by SDASA.

V. BEAMFORMING

The beamforming implemented by frequency-domain adaptive antenna array (FDAAA) [10] is effective to increase the received signal power while suppressing own signal ISI and the other users' co-channel interference (CCI) [4]. Two types of FDAAA are considered: distributed and unified SC-FDAAA. In the distributed SC-FDAAA, the weight control is performed on the received signals of each cluster of antennas before combining the signals received on all antenna clusters. While in the unified SC-DAAA, the signals received on all antenna clusters are weighted and combined simultaneously. The uplink performance of the distributed SC-FDAAA and unified SC-FDAAA schemes [11] are investigated by computer simulations assuming frequency reuse factor (FRF) =1, 3, 4 and 7. It is assumed that each distributed antenna cluster has 4 antennas. Any scheduling among clusters of antennas is not considered and up to two (D=1, 2) active clusters of antennas, which are randomly located in a cell, are assumed for simplicity. The scheduling algorithm and more complicated situation remains as the topics of our future work.

The uplink average bit error rate (BER) performances using the distributed and unified SC-FDAAA schemes are compared in Fig. 10. The uplink average BER performance using the distributed SC-FDAAA scheme is represented by solid curve while the performance of the unified SC-FDAAA scheme is represented by the dotted curve. It is observed that the unified SC-FDAAA scheme achieves much better performance than the distributed SC-FDAAA scheme. However, to realize the unified SC-FDAAA scheme, more computationally demanded weight control is necessary.

In addition, good synchronization among different antenna clusters is required for both schemes. In this study, perfect synchronization has been assumed and how to synchronize the active antenna clusters remains as our future work.

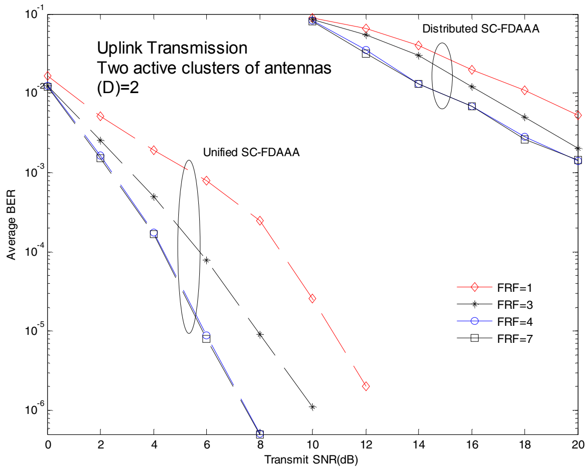


Figure 10. Performance comparison between distributed SC-FDAAA and unified SC-FDAAA.

VI. MULTIPLEXING

Distributed MIMO multiplexing can achieve highly spectrum-efficient transmission [12]. Multiple distributed antennas in DAN can be used not only for spatial diversity but also for the spatial multiplexing to improve the packet throughput [13].

The same antenna distribution pattern as in Sect. III is assumed. The single-user and single-cell uplink SC-DAN is considered. An MT transmits N_{mt} parallel data streams simultaneously from N_{mt} different distributed antennas nearest from the MT.

Near maximum likelihood (ML) performance can be achieved using training-sequence (TS) inserted SC (TS-SC) with frequency-domain ML block signal detection using QR decomposition and M-algorithm (QRM-MLBD) [14]. TA-SC MIMO multiplexing using QRM-MLBD is illustrated in Fig. 8. The use of TS instead of CP can reduce the required number of surviving paths in the M-algorithm. At the SPC, QRM-MLBD is applied to the overall frequency-domain received signal by treating a concatenation of the space and frequency-domain channel and discrete Fourier transform as the equivalent channel.

QRM-MLBD consists of three steps: ordering, QR decomposition and, M-algorithm. The ML solution can be obtained by searching for the best path having the minimum Euclidean distance in the tree diagram. In each stage, the best *M* paths are selected as surviving paths by comparing the path metrics. The symbol sequence estimation is carried out by tracing back the path having the smallest path metric at the last stage.

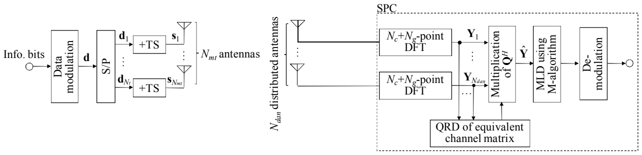


Figure 8. TS-SC MIMO multiplexing.

Figure 9 plots the complementary cumulative distribution function (CCDF) of the computer simulated BER when N_{mt}=N_{dan}=2 and normalized transmit E_s/N_0=10dB. It can be seen that DAN can significantly reduce the BER compared to the conventional network (CN). When QRM-MLBD with M=16 is used, DAN can reduce the outage probability to 0.1% while the outage probability of CN is 15% (the outage probability is defined as the probability that the BER exceeds the required BER=10^{-3} in this paper). Furthermore, QRM-MLBD can reduce the BER compared to the MMSE signal detection. The performance improvement is significant in DAN.

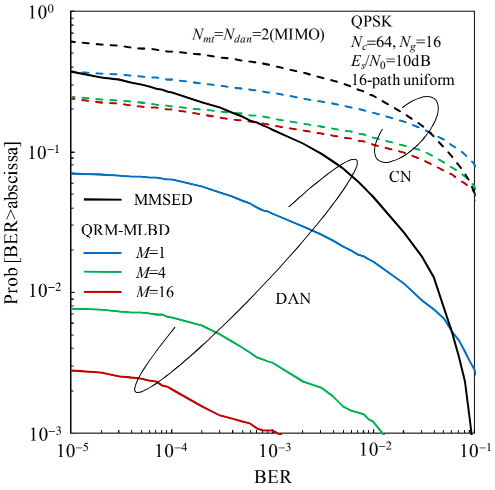


Figure 9. CCDF of the measured BER when N_{mt}=N_{dan}=2.

VII. CONCLUSION

In this paper, we have introduced gigabit DAN combined with SC frequency-domain signal processing. Distributed MIMO diversity, relay, beamforming, and multiplexing can solve the problems arising from the limited bandwidth, severe channel selectivity, and limited transmit power. It is desirable to use as many distributed antennas as possible while limiting the number of MT antennas to one or two so as to alleviate the complexity problem of MT. It was confirmed by the computer simulation that the gigabit DAN can be a promising future wireless network to provide gigabit wireless data services to mobile users.

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