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Joint Cooperative Diversity and Scheduling in OFDMA Relay System

Salma Ait Fares¹, Fumiyuki Adachi¹ and Eisuke Kudoh²

¹-Tohoku University, Japan

²-Tohoku Institute of Technology, Japan

1. Introduction

The most important technical challenge for the realization of 4G mobile networks is to overcome the frequency selective fading channel and significantly reduce the transmitted power from mobile terminals. To meet the challenges of this next generation, wireless *multi-hop virtual cellular network* (VCN) technology is newly proposed (Fitzek & Katz, 2006; Adachi & Kudoh, 2007). Multi-hop VCN is an on-going research and its study and development are still in progress for performance improvements. Before the deployment of Multi-hop VCN technology, many attractive and motivating studies are left in front of researchers. For instance, to avoid large transmission delay, a novel quantitative criterion to determine the optimal number and locations of fixed relay nodes, under the assumption of using orthogonal channels for the hops, has been developed in (Florea & Yanikomeroglu, 2005). To increase the diversity gain, a cooperative diversity between relays and destination has been introduced in (Bletsas et al., 2006) by selecting the best relay to cooperate between the source and the destination. Moreover, to avoid the call blocking when a channel allocation failure occurs, a relay skipping method applied in DS-CDMA system has been presented in (El-Alami et al., 2006). An adaptive antenna array (AAA) has been as well studied in the virtual cellular network (VCN) to optimize the number of relays required in a network area (Adinoyi & Yanikomeroglu, 2006). Also, to enhance the transmit signals from relays to the destination under low transmit power condition, the authors in (AitFares et al., 2009 a) proposed a novel scheme of cooperative relaying network based on data exchange between relays before forwarding data to destination using AAA and transmit beamforming techniques.

In multiuser system, OFDMA based-relay networks have recently received much renewed research interest and recognized as enabling techniques to achieve greater coverage and capacity by exploiting multiuser diversity and allowing efficient sharing of limited resources such as spectrum and transmit power among multiple users (Wittneben et al., 2004; Hammerstrom et al., 2004; Tarasak & Lee, 2007; Tarasak & Lee, 2008). At a particular instant of time, since several users' channels fade differently, the scheduler offer different users the access to the channel based on their channel conditions. In fast-varying fading scenario, if the users have the same average signal-to-noise power ratio (SNR) at their destinations, they will have approximately the same chance to access the channel. However, in slow-varying

fading scenario, some users with highest SNR at the destination will access the channel for a long time while unfortunately others have to wait until their channel condition improves.

For such slowly time-varying channel environment, joint cooperative diversity and scheduling (JCDS) technique has been proposed in (Wittneben et al., 2004; Hammerstrom et al., 2004; Tarasak & Lee, 2007; Tarasak & Lee, 2008) to improve the capacity performance. The authors in (Wittneben et al., 2004; Hammerstrom et al., 2004) introduced a time-varying phase rotation in time domain at relay nodes by multiplying each transmit relay signal by a specific phase rotation. This latter creates a time-variant relay fading channel which can be exploited to provide opportunity for every user to be scheduled. For frequency selective fading channel, the works in (Tarasak & Lee, 2007; Tarasak & Lee, 2008) have extended the JCDS technique by introducing cyclic delay diversity (CDD) at the relay nodes in OFDMA system. Using CDD technique, additional fluctuation among the sub-carriers is produced and as a result the scheduler can successfully provide more chance to users to have access to the channel by allocating subcarriers to users whose SNR are highest.

However, the performance of the JCDS depends as well on the cooperative diversity technique used at relay nodes. It has been shown in (Laneman et al., 2003) that using single Amplify and Forward (AF) relay, second order diversity can be achieved. But, it is not necessarily evident to achieve higher order diversity by using several AF-relays. For instance, if some relays receive noisy signals then the noises contained in these received signals are also amplified during a retransmission process. Without any further signal processing, except amplification relay gain, these noisy signals may disturb the received signal at the destination and hence diversity order is reduced. With proper processing of the received signals at the relay nodes, the performance of the JCDS system may perform better by improving the quality of communication links between relays and destinations. For this aim, several algorithms have been proposed in literature known as cooperative distributed transmit beamforming (DTB) for single carrier transmission (AitFares et al., 2009 a; Wang et al., 2007; Yi & Kim, 2007).

In this Chapter, we will introduce the DTB approach to JCDS OFDMA-based relay network in multi source-destination pair's environment and we will highlight its potential to increase the diversity order and the system throughput performance. By jointly employing the JCDS with DTB, the *aggregate throughput*, defined as the total throughput in given physical resources, is enhanced. On the other hand, the *per-link throughput*, defined as the user throughput in a given transmission cycle, is not significantly improved, since the performance of this per-link throughput depends on how many subcarriers are allocated to the user during a given transmission cycle. In addition, to trade-off a small quantity of the aggregate throughput in return for significant improvement in the per-link throughput, we introduce also the fixed CDD approach at relay stations to the proposed JCDS-DTB. Also we prove that in multi source-destination pairs system, combining DTB with CDD at relay nodes creates more fluctuation among subcarriers resulting in time-variant SNR at each destination and consequently gives more opportunity to users to access to the channel.

2. Evolution of wireless mobile communication technology

In the 1980s, first generation (1G) cellular mobile phone, consisted of voice-only analog devices with limited range and features, was introduced. In the 1990s, a second generation (2G) of mobile phones was presented with digital voice/data and with higher data transfer

rates, expanded range, and more features. 2G networks saw their first commercial light of day on the *global system for mobile* (GSM) standard. In addition to GSM protocol, 2G also utilizes various other digital protocols including CDMA, TDMA, iDEN and PDC. Afterwards, 2.5G wireless technology was established as a stepping stone that bridged 2G to 3G wireless technology. 3G technology was introduced to enable faster data-transmission speeds, greater network capacity and more advanced network services. The first pre-commercial 3G was launched by NTT DoCoMo in Japan in May 2001.

Actually, wireless mobile communications have become very persistent. The number of mobile phones and wireless internet users has increased significantly. The growth of the number of mobile subscribers over the last years led to a saturation of voice-oriented wireless telephony. From a number of 214 million subscribers in 1997 to 4 billion cellular mobile subscribers in 2008 (Acharya, 2008).

However, modern cellular networks need to provide not only high quality voice service for users, but a large amount of data transfer services as well. Users want to be connected with the networks not only for making voice conversations anytime and anywhere with people but also for data downloading/uploading. It is now time to explore new demands and to find new ways to extend the mobile wireless concept.

The evolution of 3G mobile networks will be followed by the development of next generation mobile networks, called 4th generation (4G) or “beyond 3G” mobile phone technology. 4G refers to the entirely new evolution in wireless communications and will support extremely high-speed packet data service 100M-1Gbps (Adachi & Kudoh, 2007) as shown in Fig. 1.

Fig. 1. Wireless mobile communication network evolution.

Although 4G wireless communication systems are expected to offer considerably higher data-rate services and larger coverage areas compared to these older generations, these expectations about wireless communication systems performance appear to be unfeasible in the conventional cellular architecture due to limited transmission capabilities and spectrum efficiency (Adachi & Kudoh, 2007; Adachi, 2008). Indeed, for a peak data rate of

~1Gbps/Base Station (BS), there are two important technical issues to address: (1) to overcome the highly frequency-selective fading channel, and (2) to significantly reduce the transmit power from mobile terminals.

2.1 Spectrum Efficiency Problem

In terrestrial wireless communications, the transmitted signal is reflected or diffracted by large buildings between transmitter and receiver, creating propagation paths having different time delays. For instant, for 1Gbps transmission, 1bit time length is equivalent to the distance of 0.3 m (Adachi, 2008). Then, many distinct multipaths are created, where strong inter-symbol interference (ISI) may be produced. Consequently, the challenge of 4G realization is to transmit broadband data close to 1 Gbps with high quality over such a severe frequency-selective fading channel. In this case, some advanced equalization techniques are necessary to overcome the highly frequency-selective fading channel (Adachi, 2008).

2.2 Transmit Power Problem

In fact, the peak transmit power is in proportion to “transmission rate”. Hence, for a very high rate transmission, a prohibitively high transmit power is required if the same communication range in distance is kept as in the present cellular systems. Ignoring the shadowing loss and multipath fading, the energy per bit-to-AWGN (additive white Gaussian noise) power spectrum density ratio E_b/N_0 is given by (Adachi & Kudoh, 2007)

$$\frac{E_b}{N_0} = \left(\frac{P_T/B}{N_0} \right) r_0^{-\alpha}, \quad (1)$$

where P_T is the transmit power, B is the bit rate, r_0 is the cell radius, α is the path loss exponent. We can notice from (1), for a given cell radius r_0 , as the bit rate B increases, the transmit power should be increased in order to satisfy the required E_b/N_0 . Therefore, keeping the transmit power the same as in the present conventional cellular network, will result in decreasing of coverage of the BS to r_0' as shown in Fig. 2.

For instant, assume that the required transmit power for 8kbps at 2GHz is 1Watt for a communication range of $r_0 = 1,000m$. Since the peak power is in proportion to (transmission rate) $\times (f_c^{-2.6})$ [Hata-formula] (Kitao & Ichitsubo, 2004) where f_c is the carrier frequency, then, the required peak transmission power for 1Gbps at 3.5GHz needs to be increased by $1Gbps/8kbps \times (3.5GHz/2GHz)^{2.6} = 535,561$ times, that is, $P_T = 536kWatt$. Obviously, this cannot be allowed. Hence, to keep the 1W power, the communication range should be reduced by 43 times if the propagation path loss exponent is $\alpha = 3.5$. Hence, the cell size should be significantly reduced to $r_0' = 23m$ and that leads to increase in the number of BS and consequently gives rise to high infrastructure cost (Adachi, 2008). However, to extend the coverage of BS even at high transmission rate while keeping the transmit power the same as in the present cellular systems, fundamental change in wireless access network is required.

Fig. 2. Decreasing the coverage of BS in the case of keeping the transmit power the same as in the present conventional cellular network for high data rate transmission.

Without reducing the cell size, the direct transmission between widely separated BS and mobile terminal (MT) can be extremely expensive in terms of transmitted power required for reliable communication. Actually, the need of high-power transmissions may increase the co-channel interferences as well as lead to faster battery drain (shorter network life). An alternative approach to direct transmission is to employ *relay* stations as ‘intermediate’ nodes to establish *multi-hop* communication links between BS and MT. Such strategies are named as wireless *multi-hop Virtual Cellular Network* (VCN). This architecture consists of a central port (CP), which is the gateway to the network, and many distributed wireless ports (WP) which directly communicate with the mobile terminals. These WPs, often referred to as relay nodes, are used to forward the information of the users having poor coverage to the CP as shown in Fig. 3. The wireless multi-hop VCN will play key roles in future infrastructure-based wireless networks owing to its considerable economical and technical advantages, including: increase system capacity and spectral efficiency, and reduce transmission energy, compared to other network architectures (Dau et al., 2008; Fitzek & Katz, 2006; Adachi & Kudoh, 2007).

Fig. 3. Multi-hop VCN technology and coverage extension of a multi-hop VCN.

Cooperative relay network is an upgrade technology of multi-hop VCN systems, where relays have to cooperate in relaying information as shown in Fig.4 for 2-hop VCN technology. One advantage of these structures is that it is possible to unite multiple relays in the cellular

network as a “*virtual antenna array*” to forward the information cooperatively while an appropriate combining at the destination realizes diversity gain. Therefore cooperative relaying is regarded as a promising method to the challenging of throughput and high data rate coverage requirements of future wireless networks as it provides flexible extension, capacity increase to the conventional wireless systems (Adachi & Kudoh, 2007).

Fig. 4. Cooperative relay network using 2-hop VCN technology.

2.3 OFDMA - based relay in 2-hop VCN technology

OFDM modulation is a bandwidth-efficient technique to obviate inter-symbol interference arising from multipath fading by transmitting multiple narrowband subcarriers. However, in a multipath fading environment, these subcarriers can experience different fading levels; thus, some of them may be completely lost due to deep fading. Cooperative relay network technique may enhance the reliability of subcarriers through redundancy by exploiting the spatial diversity. In fact, since cooperative relay technique provides spatial diversity gain for each subcarrier, the total number of lost subcarriers due to deep fading may be reduced.

On the other hand, in multi-user system, Orthogonal Frequency Division Multiple Access (OFDMA) based relay networks have recently received much renewed research interest and recognized as enabling techniques to achieve greater coverage and capacity by exploiting multi-user diversity and allowing efficient sharing of limited resources such as spectrum and transmit power among multiple users (Tarasak & Lee, 2007; Tarasak & Lee, 2008; AitFares et al., 2009 b). For instance, OFDMA is very flexible since different subcarriers to different users depending on their channel conditions and as several users' channels fade differently, the scheduler offer the access to the channel to different users based on their channel conditions to increase the system capacity.

In multi-user scheduling, the subcarriers can be allocated using private subcarrier assignment (i.e., one user uses private multiple subcarriers at any given time) or shared subcarrier assignment (i.e., several users use a given subcarrier). The subcarriers can be assigned based on each user-destination's SNR or rate maximization technique (Wong et al., 2004). Allocating carriers based on each user's SNR maximizes the total capacity but without being fair to each user. An example is shown in Fig.5 using three user-destination pairs with total number of subcarriers $N_c=12$.

Fig. 5. OFDMA network architecture and Scheduling technique based on SNR assignment approach.

Fig. 6 illustrates an example of the OFDMA transmitter structure for the system at the BS studied in Fig.5 where the subcarrier and power allocations are carried out relying on the feedback information from the scheduler. As shown in this example over one OFDMA symbol, the scheduler chooses the best link (highest SNR) in each subcarrier taking into consideration the channel information at each destination.

OFDMA technology faces several challenges to present efficiency realizations. For instance, if many users in the same geographic area are requiring high on-demand data rates in a finite bandwidth with low latency, a fair and efficient scheduler is required. In addition, to carry out this scheduling, the transmitter needs the channel state information for the different users, and the receiver need information about its assigned subcarriers and all information exchange should be carried out with low overhead.

Fig. 6. OFDMA transmitter structure for subcarrier and power allocations at the BS.

2.4 Multi source-destination pairs in OFDMA – based relay in 2-hop VCN technology

OFDMA wireless network architecture in 2-hop VCN technology, illustrated in Fig. 5, can be extended and applied for multi-source destination pairs, where multiple sources communicating with their corresponding destinations utilizing same half-duplex relays as

shown in Fig. 7. This kind of network architecture, typically applied in ad-hoc network, presented promising techniques to achieve greater capacity. Analyzing and evaluating the capacity of wireless OFDMA-based relay in multi-source destination pair's networks is one of the most important issues. However, if the wireless nodes are using the same physical resources (i.e., same subcarriers), the problem of evaluating the throughput becomes much more challenging since the transmission of other sources acts as co-channel interference for the others destinations.

In this Chapter, we are interested to study the OFDMA-based relay network in multi-source destination pair's system. In addition, to avoid interferences, instead of using all the orthogonal subcarriers, according to the rate of transmission required by an MT, only the subcarriers with highest received SNR can be allocated independently to the source-destination links.

Fig. 7. Multi source-destination pairs via relay routes.

3. JCDS with Distributed Transmit Beamforming and fixed Cyclic Delay Diversity

3.1 System Model

Consider a wireless system composed of M user-destination pairs. R relays are assisting the communication link. Each source needs to communicate with its own destination with the help of these relays. We assume the destinations are far away from sources and there are no direct paths between source-destination pairs. Fig. 8 illustrates an example of the system model with two source-destination pairs ($M=2$) using four relays ($R=4$). We assume that the relays operate in duplex mode where in the first time slot, they receive the OFDMA signals from sources that are transmitting simultaneously but with different non-overlapping sub-channels (i.e., a set of OFDM subcarriers), while in the second slot they forward concurrently their received signals to destinations. The channels are assumed time-invariant over one OFDMA block and i.i.d. frequency selective Rayleigh fading with the channel

order L . The l -th path complex-valued gains of the channels between the i -th user and the r -th relay and between the r -th relay and the i -th destination are denoted by $h_{i,r}(l)$ and $g_{r,i}(l)$, respectively. Both $h_{i,r}(l)$ and $g_{r,i}(l)$ are zero mean complex Gaussian random and their variances follow an exponential delay profile such as $E \left[|h_{i,r}(l)|^2 \right] = E \left[|g_{r,i}(l)|^2 \right] = e^{-l/\tau_{rms}} / \sum_{l=0}^L e^{-l/\tau_{rms}}$.

Fig. 8. Multi source-destination pairs in OFDMA 2-hop VCN technology.

The structure of the OFDMA signal transmitted from user U_i is depicted in Fig.9 where N_c represents the N_c -point (I) FFT in the OFDMA transmitters and receivers, N_{ci} is the number of subcarriers allocated to the user U_i , where the remaining subcarriers ($N_c - N_{ci}$) are padded (e.g., zero padding) and N_{GI} is the guard interval (GI) length and assumed to be longer than the maximum channel delay spread.

Fig. 9. Transmit OFDMA signal structure and subcarrier allocation scheme.

After removing GI and applying FFT transform the received signal of the p -th subcarrier at the r -th relay is given by

$$Y_r(p) = \sqrt{P_s} \cdot H_{i,r}(p) \cdot S_i(p) + \eta_r(p), \quad r = 1, \dots, R. \quad (2)$$

where $S_i(p)$ is a unit-energy data symbol transmitted from user U_i ($1 \leq i \leq M$) whose subcarrier p has been assigned by the scheduler, P_s is the transmit power used by the user U_i , $H_{i,r}(p)$ is the channel gain of the subcarrier p from the i -th user to the r -th relay and $\eta_r(p)$ is the AWGN's in the corresponding channels with variance σ_R^2 . Before forwarding the received signals to the destination, the relays may perform some signal processing as shown in Fig.10

(a, b, and c), such as jointly AF and CDD proposed in (Tarasak & Lee, 2008), jointly AF and DTB or jointly AF, DTB and fixed CDD as will be studied in the following.

Fig. 10. Relay node structure using different cooperative techniques.

In AF scheme, the relay normalizes its received signal by multiplying it with a relay gain given by

$$\beta_{i,r}(p) = 1 / \sqrt{P_s \cdot |H_{i,r}(p)|^2 + \sigma_R^2}, \quad r = 1, \dots, R. \quad (3)$$

With channel order equal to L , the channel gain $H_{i,r}(p)$ at the p -th subcarrier can be written as

$$H_{i,r}(p) = \sum_{l=0}^L h_{i,r}(l) \cdot e^{-j2\pi lp/N_c}. \quad (4)$$

The output of the transmit beamforming can be expressed by

$$Y_r^{TB}(p) = \beta_{i,r}(p) \cdot W_{TB,r}(p) \cdot Y_r(p), \quad r = 1, \dots, R, \quad (5)$$

where $W_{TB,r}(p)$ represents the weight element of the p -th subcarrier at the r -th relay.

The received signal at the i -th destination after performing FFT is written as

$$Y_i(p) = \sum_{r=1}^R G_{r,i}(p) \cdot S_{Rr}(p) + \gamma_i(p), \quad i = 1, \dots, M. \quad (6)$$

where $S_{Rr}(p)$ is the p -th subcarrier component of the OFDMA signal transmitted from the r -th relay, $G_{r,i}(p)$ denotes the channel gain at the p -th subcarrier from the r -th relay to the i -th destination, calculated using (4) by replacing $h_{i,r}(l)$ by $g_{r,i}(l)$, and $\gamma_i(p)$ is the AWGN's with variance σ_D^2 .

By substituting (2) and (5) into (6), we obtain

$$Y_i(p) = \sqrt{P_s} \cdot S_i(p) \cdot \mathbf{a}(p) \cdot \mathbf{W}_{TB}^H(p) + v_i(p), \quad (7)$$

where

$$\mathbf{a} = [\beta_{i,1} \cdot H_{i,1} \cdot G_{1,i}, \dots, \beta_{i,R} \cdot H_{i,R} \cdot G_{R,i}], \quad (8)$$

$$v_i = \boldsymbol{\eta} \cdot \mathbf{A}_m \cdot \mathbf{W}_{TB}^H + \gamma_i, \quad (9)$$

$$\mathbf{A}_m = \text{diag}[\beta_{i,1} \cdot G_{1,i}, \dots, \beta_{i,R} \cdot G_{R,i}], \quad (10)$$

$\mathbf{W}_{TB} = [W_{TB,1}^*, \dots, W_{TB,R}^*]$, $(\cdot)^*$ is the conjugate and $\boldsymbol{\eta} = [\eta_1, \dots, \eta_R]$.

To ensure that all relays transmit data with total energy P_r , the transmit beamforming weight vector should satisfy

$$\mathbf{W}_{TB} \cdot \mathbf{W}_{TB}^H = P_r. \quad (11)$$

From (7), the instantaneous SNR of the p -th subcarrier at the i -th destination can be expressed as

$$SNR_i(p) = P_s \cdot \frac{\mathbf{W}_{TB}(p) \cdot \mathbf{a}^H(p) \cdot \mathbf{a}(p) \cdot \mathbf{W}_{TB}^H(p)}{\mathbf{W}_{TB}(p) \cdot \boldsymbol{\Omega}_m(p) \cdot \mathbf{W}_{TB}^H(p) + \sigma_D^2(p)}, \quad (12)$$

where

$$\boldsymbol{\Omega}_m = \sigma_R^2 \cdot \mathbf{A}_m^H \cdot \mathbf{A}_m. \quad (13)$$

Let define $\boldsymbol{\Omega}_{1m} = \boldsymbol{\Omega}_m + \sigma_D^2/P_r \cdot \mathbf{I}_{R \times R}$ and since $\mathbf{W}_{TB} \cdot \mathbf{W}_{TB}^H = P_r$ is assumed in (11), (12) can be written as

$$SNR_i(p) = P_s \cdot \frac{\mathbf{W}_{TB}(p) \cdot \mathbf{a}^H(p) \cdot \mathbf{a}(p) \cdot \mathbf{W}_{TB}^H(p)}{\mathbf{W}_{TB}(p) \cdot \boldsymbol{\Omega}_{1m}(p) \cdot \mathbf{W}_{TB}^H(p)}. \quad (14)$$

From (14), the source destination channel capacity of the p -th subcarrier for the i -th user is given by

$$C_{i,p}(p) = \frac{B}{2N_c} \cdot \log_2(1 + SNR_i(p)), \quad (15)$$

where B is the total bandwidth. It can be seen from (15) that in order to maximize the aggregate channel capacity, each destination's SNR should be maximized at each subcarrier. Therefore, we develop in the following section a transmit beamforming technique that maximizes the SNR at each destination and for each subcarrier.

3.2 Derivation of the distributed transmit beamforming weight

To combat fading effects and then improve the link level performance, the distributed spatial diversity created by the relay nodes can be effectively exploited using a transmit diversity weight technique. To determine the transmit beamforming vector we develop the optimal weight vector that maximizes the SNR at the destination given by (14), as

$$\mathbf{W}_{TB} = \arg \max_{\mathbf{W}} \left(\frac{\mathbf{W} \cdot \mathbf{a}^H \cdot \mathbf{a} \cdot \mathbf{W}^H}{\mathbf{W} \cdot \boldsymbol{\Omega}_{1m} \cdot \mathbf{W}^H} \right). \quad (16)$$

The weight optimization criterion expressed by (16) is in the form of Rayleigh quotient, and can be derived by solving the generalized Eigen-value problem (Yi & Kim, 2007; AitFares et al., 2009 a). Hence, for any weight vector $\mathbf{W}_{TB}$, we have

$$SNR_i \leq \lambda_{max}, \quad (17)$$

where λ_{max} is the largest Eigen-value of $(\boldsymbol{\Omega}_{1m}^{H/2})^{-1} \mathbf{a}^H \mathbf{a} (\boldsymbol{\Omega}_{1m}^{1/2})^{-1}$.

The equality holds if

$$\mathbf{W}_{TB}(p) = c \cdot \mathbf{a}(p) \cdot \boldsymbol{\Omega}_{1m}^{-1}(p), \quad (18)$$

where

$$c = 1/\sqrt{|\mathbf{a} \cdot \boldsymbol{\Omega}_{1m}^{-1}|^2}. \quad (19)$$

By using this derived optimal transmit beamforming that maximizes the SNR at the destination, the aggregate channel capacity is significantly enhanced while in parallel the per-link capacity is not much improved and in particularly in slow-varying fading scenario. To overcome this problem we applied the fixed cyclic delay diversity (CDD) approach (Tarasak & Lee, 2007; Tarasak & Lee, 2008) in the time domain (after IFFT) at relay nodes as shown in Fig. 10 (c) in order to create a phase rotation in frequency domain and hence the scheduler will offer opportunity to more users to get channel access. Hence, after performing IFFT at the r -th relay, the output of the fixed CCD block is given by

$$y_r^{CDD}(l) = y_r^{TB}(l - \Delta_r), r = 1, \dots, R \quad (20)$$

where $y_r^{TB}(l)$ represents the l -th element of the IFFT of the $Y_r^{TB}(p)$ signal and Δ_r represents the cyclic delay value used at the r -th relay. Δ_r is selected as a fixed cyclic delay given by

$$\Delta_r = \text{Int}\left(\frac{N_c}{R} \cdot (r - 1)\right), r = 1, \dots, R \quad (21)$$

where $\text{Int}(x)$ represents the nearest integer function of x .

Subsequently by using the fixed CDD approach, the instantaneous SNR given in (14) is expressed as

$$SNR_i(p) = P_s \cdot \frac{\mathbf{W}(p) \cdot \mathbf{a}^H(p) \cdot \mathbf{a}(p) \cdot \mathbf{W}^H(p)}{\mathbf{W}(p) \cdot \mathbf{\Omega}_{1m}(p) \cdot \mathbf{W}^H(p)}. \quad (22)$$

where

$$\mathbf{W}(p) = \mathbf{W}_{TB}(p) \cdot \text{diag}(\mathbf{a}_1(p)), \quad (23)$$

and

$$\mathbf{a}_1(p) = \left[e^{-j\frac{2\pi p \Delta_1}{N_c}}, \dots, e^{-j\frac{2\pi p \Delta_R}{N_c}} \right]. \quad (24)$$

An adaptive scheduling in OFDMA-based relay network is adopted to allocate the subcarriers to each source based on SNR channel assignment approach. This adaptive scheduler allocates the p -th subcarrier to the i -th user destination pair with the highest SNR such that

$$U_i(p) = \arg \max_{i \in \{1, \dots, M\}} (SNR_i(p)), \quad p \in \{1, \dots, N_c\} \quad (25)$$

Two significant measured performances, highlighted in Fig.8, are studied, the *aggregate throughput* and the *per-link throughput*. By ignoring the loss from GI, the aggregate throughput (in bit per complex dimension) is expressed by

$$C_{agr} = \frac{1}{2N_c} \cdot \sum_{p=0}^{N_c-1} \log_2(1 + SNR_i(p)). \quad (26)$$

While the per-link throughput or average user throughput is defined by

$$C_{per-link} = M \cdot \frac{1}{2N_c} \cdot \sum_{p \in \Gamma} \log_2(1 + SNR_i(p)), \quad (27)$$

where Γ is the set of subcarriers allocated to the i -th user and M represents the number of user-destination pairs.

It should be noticed from (26-27) that increasing the user-destination pairs increases the aggregate throughput while the per-link throughput is reduced since the number of allocated subcarriers for each user is largely reduced. Hence using our proposed JCDS with adaptive scheduling based on SNR channel assignment; a trade-off between aggregate throughput and per-link throughput is achieved and that guarantees the per-link throughput to have at least the same QoS as in the static scheduling (SS) where all users get an equal share of the allocated resources.

4. Computer simulation results

In this section, we compare the performance of the proposed JCDS using both DTB and fixed CDD with different cooperative diversity techniques such as JCDS with DTB, JCDS with AF and JCDS with fixed CDD where adaptive scheduling based on SNR channel assignment is employed. This adaptive scheduler allocates the subcarriers to the source whose SNR is highest as illustrated in the example shown in Fig. 5. Both techniques, JCDS-AF and JCDS-CDD, are using equal divided transmit power at relay stations, i.e., $P=P_r/R$. While, in JCDS-DTB the relays are using DTB under constraint of (11). We evaluate the system performance by taking the same simulation scenario presented in (Tarasak & Lee, 2007) for comparison purpose. In this scenario, two types of fading are studied, the flat fading where the normalized *rms* delay spread (τ_{rms}) is relatively short and equals to 0.3; corresponding to $L=3$, and the frequency selective fading where the normalized *rms* delay spread is relatively large and equal to 1.5; corresponding to $L=15$. The number N_c of subcarriers is equal to 256, $R=20$ and the average SNR at the relay and at the destination are defined to be the same 20dB which is equivalent to $\sigma_R^2 = \sigma_D^2 = 0.01$.

Fig. 11 illustrates the cumulative distribution functions (CDF) of the aggregate throughput, $P(C_{agr} < \text{throughput})$, and the per-link throughput, $P(C_{per-link} < \text{throughput})$ in short delay spread scenario ($\tau_{rms} = 0.3$) using our proposed method; i.e., JCDS with DTB and CDD for different user-destination pairs. Aggregate and per-link throughput's results are shown by solid and dashed lines, respectively. A comparison of the static scheduling with $R=1$ (single relay node), in which the aggregate throughput and per-link throughput are equal, is also studied. It should be noticed that when $M=1$ (single source-destination pair), the aggregate throughput is equal to the per-link throughput and the employed adaptive scheduler is equivalent to the static scheduling. Hence, from Fig. 11, by comparing the throughput using static scheduling and $R=1$ with that of our proposed method using $M=1$ and $R=20$, we can see clearly the cooperative relay diversity gain.

Furthermore, we can observe as well the user diversity effect in both aggregate and per-link throughputs. It is intuitively clear that when the number of users increases the aggregate throughput is improving since the scheduler switches to the user whose link is better. In contrast, the per-link throughput is decreasing when the number of source-destination pairs is getting higher. Thus the QoS of each source-destination pair is severely affected due to the reduced number of assigned subcarriers. In addition, at 1% outage per-link throughput, if we want to maintain the per-link throughput at least equal to that of static scheduling, it is seen that 5 users can be handled by this system.

Fig. 11. CDF of the aggregate and per-link throughput for short delay spread ($\tau_{rms} = 0.3$) using JCDS with DTB and fixed CDD.

Fig. 12. 1% outage throughput comparison for short delay spread ($\tau_{rms} = 0.3$) using different cooperation diversity methods.

Fig. 12 compares the 1% outage aggregate throughput and 1% outage per-link throughput, using different cooperative diversity and scheduling approach in short delay spread

scenario in terms of the number M of source-destination pairs. Aggregate and per-link throughput's results are shown by solid and dashed lines, respectively. From this figure, and for aggregate throughput curves comparison, we notice that the aggregate throughput of all cooperative diversity techniques exceeds that of the static scheduling with $R=1$. In addition, the throughput using JCDS - DTB is the largest followed by JCDS with DTB & CDD and both of them significantly outperform the JCDS with DTB & CDD using static scheduling with $R=20$. Moreover, the aggregate throughputs obtained by using JCDS-CDD and JCDS-AF exceed that of using JCDS with DTB & CDD using static scheduling with $R=20$ when $M>1$ and $M>3$, respectively. However, for per-link throughput curves comparison in the same figure, we notice that the per-link throughputs of all cooperative diversity techniques are lower than those of the JCDS-(DTB & CDD) with $R=20$ and using static scheduling. This indicates the impact of the unfair SNR assignment relative to user throughput. In addition, the per-link throughput using JCDS-(DTB & CDD) is the largest followed by JCDS-CDD. The JCDS-(DTB & CDD) achieves the highest throughput while JCDS-DTB and JCDS-AF have the worst performance. By comparing aggregate and per-link throughputs of JCDS-(DTB & CDD) with JCDS-DTB, the proposed method JCDS-(DTB & CDD) sacrifices a small quantity of the aggregate throughput in return for significant improvement in the per-link throughput.

Using the same propagation environment but having long normalized delay spread ($\tau_{rms} = 1.5$), Fig. 13 illustrates CDFs of the aggregate throughput and per-link throughput using our proposed JCDS with DTB and CDD method for different number M of source-destination pairs. Similar observation given in Fig.11 can be provided herein regarding the cooperative diversity gain and user diversity gain which are positive on the aggregate throughput and negative on the per-link throughput. However, we notice that all per-link throughput curves exceed largely that of static scheduling with $R=1$. This can be explained by the higher multipath diversity in the large delay spread scenario where more fluctuation in frequency domain is provided and hence more users are scheduled.

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Fig. 13. CDF of the aggregate and per-link throughput for long delay spread ($\tau_{rms} = 1.5$) using JCDS with DTB and CDD.

Fig. 14 compares the 1% outage aggregate and per-link throughputs, using different cooperative diversity and scheduling approaches in long delay spread scenario ($\tau_{rms} = 1.5$) in terms of the number M of source-destination pairs. Aggregate and per-link throughput's results are shown by solid and dashed lines, respectively. From this figure, and for aggregate throughput curves comparison, the gain of the aggregate throughput using all JCDS techniques with static scheduling is smaller compared to short delay case ($\tau_{rms} = 0.3$). Also, the aggregate throughput of all cooperative diversity techniques exceeds that of the static scheduling. However, for per-link throughput curves comparison in the same figure, we notice that the per-link throughput of JCDS-(DTB& CDD) is the best followed by JCDS-CDD and both of them outperform that of static scheduling with $R=1$ irrespective to the number M of source-destination pairs. This result is due to the increase in frequency selectivity in such long delay spread channel. Moreover, the JCDS-(DTB & CDD) achieves highest throughput while JCDS with DTB provides the lowest throughput when $M>1$. When $M=2$, the JCDS- (DTB & CDD) achieves the highest throughput due to the increase in path and user diversities.

Fig. 14. 1% outage throughput comparison for long delay spread ($\tau_{rms} = 1.5$) using different cooperation methods.

5. Conclusion

In this Chapter, we studied the JCDS for active source/destination pairs in OFDMA-based relay system. We investigated the performance of the JCDS technique by introducing and developing a distributed transmit beamforming approach jointly used with cyclic delay diversity (CDD) at the relay nodes. Combining transmit beamforming with fixed CDD approach creates more fluctuation among subcarriers and gives more opportunity to users to access to the channel and thus to increase considerably the diversity order and the throughput performance. Therefore, time-varying SNR at the destination is created and more users can be efficiently assigned by the scheduler. Simulation results show that the system performance using our proposed JCDS improves considerably compared with the other previously proposed cooperative diversity techniques.

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Mobile and Wireless Communications Physical Layer Development and Implementation

Edited by Salma Ait Fares and Fumiyuki Adachi

ISBN 978-953-307-043-8

Hard cover, 290 pages

Publisher InTech

Published online 01, January, 2010

Published in print edition January, 2010

Mobile and Wireless Communications have been one of the major revolutions of the late twentieth century. We are witnessing a very fast growth in these technologies where mobile and wireless communications have become so ubiquitous in our society and indispensable for our daily lives. The relentless demand for higher data rates with better quality of services to comply with state-of-the art applications has revolutionized the wireless communication field and led to the emergence of new technologies such as Bluetooth, WiFi, Wimax, Ultra wideband, OFDMA. Moreover, the market tendency confirms that this revolution is not ready to stop in the foreseen future. Mobile and wireless communications applications cover diverse areas including entertainment, industrialist, biomedical, medicine, safety and security, and others, which definitely are improving our daily life. Wireless communication network is a multidisciplinary field addressing different aspects ranging from theoretical analysis, system architecture design, and hardware and software implementations. While different new applications are requiring higher data rates and better quality of service and prolonging the mobile battery life, new development and advanced research studies and systems and circuits designs are necessary to keep pace with the market requirements. This book covers the most advanced research and development topics in mobile and wireless communication networks. It is divided into two parts with a total of thirty-four stand-alone chapters covering various areas of wireless communications of special topics including: physical layer and network layer, access methods and scheduling, techniques and technologies, antenna and amplifier design, integrated circuit design, applications and systems. These chapters present advanced novel and cutting-edge results and development related to wireless communication offering the readers the opportunity to enrich their knowledge in specific topics as well as to explore the whole field of rapidly emerging mobile and wireless networks. We hope that this book will be useful for students, researchers and practitioners in their research studies.

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Salma Ait Fares, Fumiyuki Adachi and Eisuke Kudoh (2010). Joint Cooperative Diversity and Scheduling in OFDMA Relay System, Mobile and Wireless Communications Physical Layer Development and Implementation, Salma Ait Fares and Fumiyuki Adachi (Ed.), ISBN: 978-953-307-043-8, InTech, Available from: <http://www.intechopen.com/books/mobile-and-wireless-communications-physical-layer-development-and-implementation/joint-cooperative-diversity-and-scheduling-in-ofdma-relay-system>

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No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
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