User Scheduling for Cellular Multi User Access OFDM System Using Opportunistic Beamforming

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***Abstract*— Orthogonal frequency division multiplexing (OFDM) based wireless systems could potentially gain high performance from multi-user diversity due to time varying channels across different users. To further enhance the frequency selectivity at the receiver, transmit antenna diversity can be used at the base station (BS) in combination with opportunistic beamforming (OBF). Resources are assigned to users with the highest instantaneous signal-interference-plus-noise ratio (SINR) at the downlink (DL). The same scheduling is used in uplink (UL). In this paper, time division duplexing (TDD) and full frequency reuse is considered. Simulation results show that the proposed OBF in a cellular system using TDD greatly benefits from channel reciprocity. In addition, the proposed system benefits from scheduling and multi-user diversity in reducing the intercell interference – in particular a the cell boundary.**

***Index Terms*— OFDM, TDD, FDD, Opportunistic beamforming and Multiuser diversity**

I. Introduction

DUE to increase in the demand for high data rates in wireless systems, the spatial reuse of radio resources in the network is subject to intensive research. In a cellular system with frequency reuse of one, it is vitally important to consider the effect of intercell interference on the performance of the system. Intercell interference potentially prevents the system from reusing the same radio resources in all cells of the network. As a consequence, the spectral efficiency suffers.

In this paper, the multi-user access is arranged using OFDMA in combination with frequency division multiple access (FDMA). To effectively support high data rates, the increase of spectral efficiency is of main concern. One possibility for achieving high spectral efficiencies is to exploit multi-user diversity and to optimize user scheduling. In the multi-user, multi-carrier system, as in OFDMA, scheduling is implemented by selecting those sub-carriers with the highest channel gains. Thereby, the fact is exploited that this set of sub-channels varies for different users because of different user locations. Therefore, the normalized throughput increases by increasing the number of users.

Fading, traditionally, has been viewed as a form of unreliability that must be avoided. On the contrary, to keep proportional fairness, [1], [3], among users and to increase the system throughput by exploiting multi-user diversity, the channel dynamics should be increased. This can be accomplished by using the following techniques reported in literature [1], [2]:

a- Transmit diversity with multiple antennas at the BS, where the same symbol is transmitted on all antennas to enhance multipath transmission. It is assumed that the antennas are spaced so that uncorrelatedness is achieved.

b- OBF proposed in [1], in which the transmitted symbol is multiplied with a random complex weighting factor, referred to as an opportunistic weighting factor (OWF).

The total number of sub-carriers is divided into sub-sets which are referred to as clusters in this paper. Scheduling is performed at the BS on the DL. The scheduling metric is the average cluster SINR. A cluster with the highest average SINR, measured at the mobile station (MS), is used for transmission. As a consequence, the metric for the cluster selection includes the level of intercell interference, i.e. despite a favorable channel transfer factor on the desired link, a cluster of sub-carriers might not be used if interference outweighs the good channel gains on the desired link. The mechanism of reducing the interference due to OBF is also called opportunistic nulling (ONU) [1].

This paper investigates the performance of the cellular opportunistic beamforming in the presence of intercell interference. The investigation is based on the cellular system with full frequency reuse, i.e. all cells are assumed to be operated at the same radio frequency. In addition, time division duplexing (TDD) is used and channel reciprocity is exploited. For comparison, frequency division duplexing (FDD) is also considered, in which it is assumed that UL and DL channels are independently fading.

This paper is organized as follows: Section II introduces the system model, the opportunistic beamforming applied to the cellular system and the opportunistic nulling technique. Section III presents the channel models used. Section IV shows the simulation results. Finally, Section V concludes this paper.

II. System Model

A. Multi-User OFDMA Setup

One OFDM symbol having N, sub-carriers, is divided into D, clusters, where each cluster consists of L, consecutive sub-carriers. Each user transmits on a single cluster where the number of users in the system is U, such that $U \leq D$.

B. Scheduling for TDD and FDD

Scheduling and cluster selection is done on the DL. The same cluster is then used for UL transmission. Both TDD and FDD are considered in this investigation. It is assumed that UL and DL transmission is within the coherence time of the channel so that the channel can be assumed to be reciprocal in TDD. In FDD, as the UL and DL transmission is on separate channels, the channels fade independently regardless of the coherence time.

C. Opportunistic beamforming and user-scheduling

The frequency selective channels are exploited to obtain multi-user diversity as mentioned before. In the case of flat fading channels, the *transmit diversity* in combination with *OBF* is used to artificially increase the channel fluctuations.

The transmit diversity is done by allowing the BS to use up to M, different transmitters, and the opportunistic beamforming is done by weighting the transmitted D clusters by the random complex OWFs $[W_1, W_2, ..., W_M]$. The OWF power is normalized to one across the antennas at the transmitter such that,

$$\sum_{i=0}^{M} W_i^2 = 1 \ . \qquad (1)$$

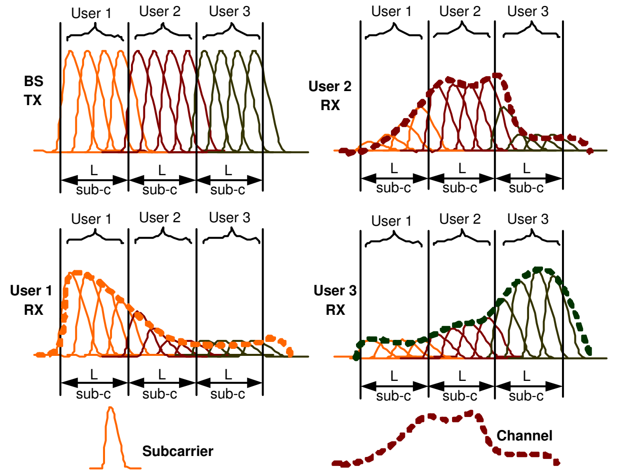

Fig. 1. The induced frequency selectivity is exploited for user scheduling

In this paper, M is restricted to two antennas and thus the OWF are obtained as follows,

$$W_1 = [w_{11}, w_{11}, ..., w_{1D}], \ W_2 = [w_{21}, w_{21}, ..., w_{2D}] \ , \qquad (2)$$

with,

$$w_{1n} = \sqrt{\alpha_n} e^{j\phi_n}, \ w_{2n} \sqrt{1-\alpha_n} e^{j\theta_n} \ , \qquad (3)$$

where α_n is the random magnitude, θ_n and ϕ_n are the random phases of the weighting factor of the n^{th} cluster. W_1 and W_2 are assumed to be constant for, S, OFDM symbols, where $S \leq R$, assuming R is the number of OFDM symbols in the transmission block.

The use of OWFs will create random variations of the resultant channel at the user location. As a consequence, the probability that a high average cluster SINR can be achieved at the user location is increased. The principle of this mechanism is depicted in Fig. 1.

D. Scheduling

The average SINR of each cluster is estimated by the MS [7]. These SINRs are fed back to the BS for user scheduling. The scheduler works on a table with the maximum dimension equal to the number of users, U, times the number of clusters, D. For each cluster, the scheduler selects those users which report the highest SINRs and blocks the other users for that particular cluster.

It is assumed that the feedback information is transmitted on an error-free channel, and that the feedback information can be reduced by using the reduced feedback scheme in [2]. This means that the number of clusters, for which the average SINR is fed back, is restricted to, Z, where $Z \leq D$.

E. Cellular system and opportunistic nulling

The cellular system is implemented assuming a frequency reuse pattern of one. In addition, OBF is applied at the BSs. In the cellular system, OBF in combination with user scheduling, as described before, is equivalent to ONU [1].

F. Interference

Intercell interference from the first tier of cells is considered. In the DL, the MS of interest is interfered by the BS in the neighbouring cells, while in the UL, all MSs in the neighbouring cells contribute to interference at the BS of interest. The users in the cell of interest are assumed to be uniformly distributed over the cell area and the BS is located at the cell center. Transmissions in the neighbouring cells take place on the entire bandwidth with constant power.

To simulate the performance for different user locations, the MS of interest moves away from the BS towards the cell boundary on a straight line radially from the cell center.

G. Calculation of Throughput

The maximum throughput (in bits/OFDM symbol) for the OFDM system with two transmit antennas is calculated using the Shannon capacity equation as described in [2], [4]. This means that perfect channel coding is assumed, and that intercell interference can be approximated as white Gaussian noise. Using the OWF in (3), Shannon capacity can be expressed as

$$C = 1/2 \sum_{n}^{N} \log_2 \{1 + \frac{\rho_n}{M} \sum_{j=1}^{M} |h_{n,j}\, w_{j,\lceil n/L \rceil}|^2\} \quad (4)$$

and,

$$\rho_n = \frac{P_n}{\sigma_z^2 + I_n} \ , \quad (5)$$

where ρ_n is the ratio of the power on the n^{th} sub-carrier, P_n, to the noise variance, σ_z^2, and average interference power I_n; and $h_{n,j}$, is the complex channel transfer factor for the n^{th} sub-carrier linked to the j^{th} antenna.

At the transmitter, the power across all sub-carriers selected for transmission is normalized to one, where it generally holds that $z \subset N$.

$$\sum_{z \subset N} P_z = P_{max} = 1 \quad (6)$$

where $\lfloor z/L \rfloor$ is the number of admitted users constrained to $\lfloor z/L \rfloor \leq U$.

H. Calculation of Outage

Outage is defined as the average ratio of the number of users that are permitted into the system, $\lfloor z/L \rfloor$, to the maximum number of users, U,

$$\text{Outage} = \frac{1}{U} \left\lfloor \frac{z}{L} \right\rfloor \quad (7)$$

III. Channel Model

A. Channel Fading Model

In this paper, it is assumed that the channel is slow fading, i.e. the channel impulse response from antenna, M, to user, k, $h_{M,k}(t)$, remains constant for all t, where t is the time required for transmitting, R, OFDM symbols. The OWF, as well as the scheduling rate, is assumed to be changed every $t/5$.

The multipath effect is simulated by a Rayleigh fading channel with exponential decaying power profile as in [2]. The impulse response from the M^{th} transmitter antenna to the k^{th} user is modeled as

$$h_{M,k}(t) = \sum_{i=0}^{\ell-1} \beta_i^{Mk} \delta(t - iT_s) \ , \quad (8)$$

where ℓ is the number of channel taps equal to the ratio of the root mean square delay spread, γ, to the sampling period, T_s, [5]. The channel gain, $\beta_i^{M,k}$, is an independent complex Gaussian random variable with an exponentially decaying power profile.

B. Pathloss Model

The interference is calculated using the UMTS (universal mobile telecommunications system) outdoor pathloss model in [6],

$$\text{PL}(d)|_{dB} = 49 + 40\log(d) + X_\sigma \quad (9)$$

where d is the distance between the source and the destination in kilometer (km), and X_σ is a log-normally distributed random variable with standard deviation, $\sigma_X = 10$ dB to model shadowing effects.

IV. Simulation Results

The OFDMA simulation parameters used are presented in Table I.

A. Throughput and Outage Analysis

System performance is assessed using the throughput analysis and the outage ratio. A comparison between a single cell model and the cellular model for the TDD based system is carried out, and the following results are obtained,

TABLE I

OFDMA SYSTEM PARAMETERS

Parameter	Value
Sampling rate	40 Msps
Symbol interval	4 μsec
Useful symbol part duration	3.2 μsec
Cyclic prefix & max. delay spread	0.8 μsec
Sub-carriers spacing	0.3125 MHz
Number of data carriers, N	96
Number of carriers per cluster, L	6
Number of clusters, D	16
Number of feedback clustered, Z	3
Cell radius, r	3 km

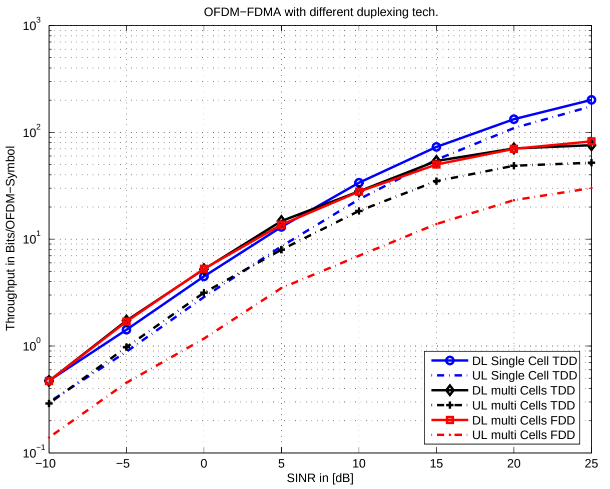

Fig. 2. Maximum throughput of a TDD-OFDMA and FDD-OFDMA cellular and single cell system

1) TDD and FDD throughput results: Throughput performances vs. SINR is analyzed. Fig. 2 shows the performance degradation for the cellular deployment compared to the single cell model. The throughput is reduced by 20% at an SINR of 15 dB. In the TDD case, the DL:UL throughput ratio is 1.4:1. The 40% higher throughput in the DL is because of the channel variations as a consequence of the OWFs. In the FDD case, the DL:UL throughput ratio is about 3.5:1 which primarily is because of the independent fading characteristic of UL and DL channel. In the cellular deployment, the DL performance of the TDD and FDD systems is almost the same as expected. However, the UL performance in the TDD case is improved by a factor greater than two which can be jointly attributed to the channel reciprocity and OBF.

2) Varying the number of users: In the following, only a cellular system is considered. Fig. 3 shows the throughput results for varying the number of users

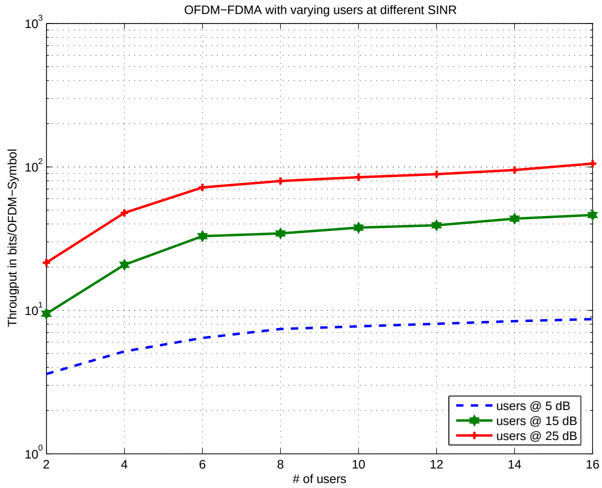

Fig. 3. Throughput for varying the number of users

in the system from 2 to 16 users. Similarly, Fig. 4 shows the outage ratio of the system. Notice, that the transmission power is normalized to one. The outage ratio remains almost constant for all given SINRs until there are 8 users (50%-loaded system). For more than 8 users, outage starts increasing significantly. It is interesting to note, that although outage is increasing with the number of users, the total throughput of the system, too, increases. This means that more users are put into outage, but at the same time the likelihood of very favorable channel and interference conditions for the remaining users increases because of multiuser diversity. This means that there is exists a trade-off between the throughput and the number of users in the system. The results suggest that the system should be operated at half the maximum user capacity.

B. System with and without OBF

1) Throughput: This section compares the proposed system to the normal antenna diversity system without OWF (non-OBF). Fig. 5 shows the results for the DL throughput, for the single cell and the cellular system with and without OBF. These results demonstrate that the system with OBF performs 3 times better than the non-OBF system. It further shows that the performance degradation as a result of the cellular deployment as opposed to single cell deployment in the case of OBF is by a factor of approximately 1.4 less than in the non-OBF case.

2) MS-to-BS separation distance variation: The results for varying the user location in the cell of interest is depicted in Fig. 6. It can be seen that the

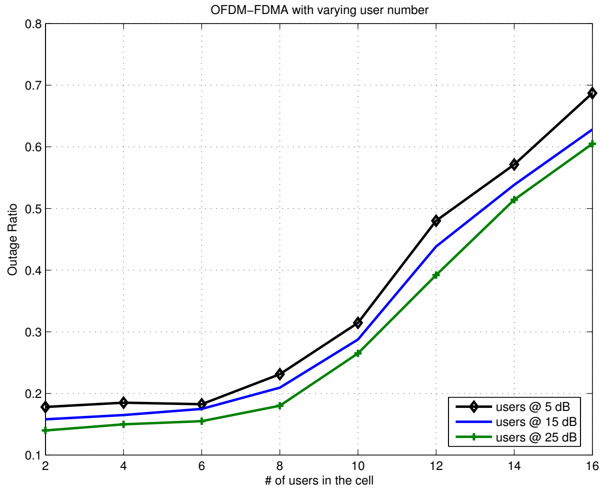

Fig. 4. Outage ratio for varying the number of users

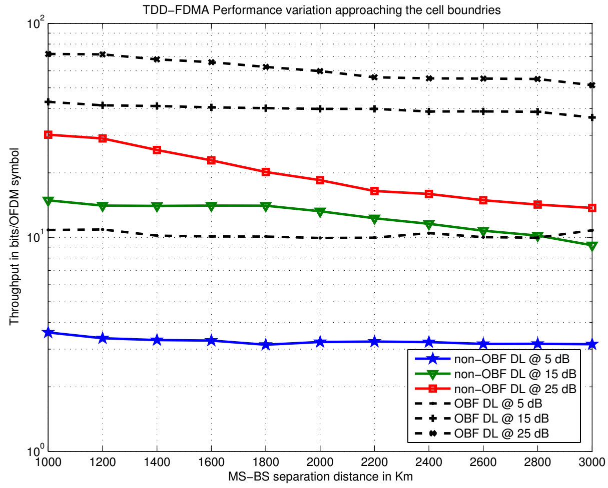

Fig. 6. Varying MS to BS distance

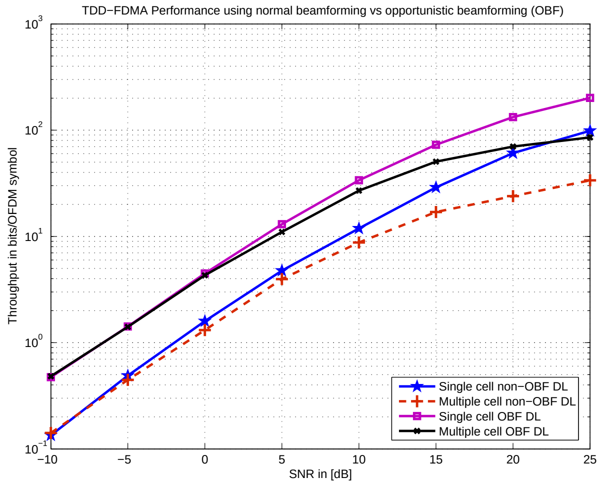

Fig. 5. OBF versus non-OBF results

throughput remains constant at the lower SINR (5dB and 15dB). The throughput decreases only 20% for an SINR of 25dB.

This means that in the case of OBF, the system performance remains almost constant for any position in the cell. In contrast, the performance for the non-OBF system is clearly worse. The throughput decreases by 60% for an SINR of 25dB and by 40% for an SINR of 15dB.

V. Conclusion

It has been found that opportunistic beamforming in a cellular OFDMA system greatly benefits from channel reciprocity of a TDD based air-interface. The UL throughput can be improved by a factor of two compared to an FDD system. It has been found that the trade-off between system throughput and user outage only becomes effective when the system is more than 50% loaded, i.e. the outage starts increasing significantly if the system is more than 50% loaded. However, due to exploitation of multiuser diversity induced by opportunistic beamforming, the throughput still increases if the system load is above 50% causing the mentioned trade-off between outage and throughput.

Opportunistic beamforming results in a three-fold throughput increase as compared to a pure transmit diversity system. Furthermore, the throughput reduction at the cell boundary is significantly reduced, i.e. the 'dead zone' problem of a cellular system is eased.

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