OFDMA-TDD Networks with Busy Burst Enabled Grid-of-Beam Selection

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Abstract—Interference aware user scheduling in fixed grid-of-beam (GoB) transmission is envisaged to significantly benefit from the receiver initiated busy burst (BB) protocol. Fixed GoB scheduling relies on the knowledge of the location of the intended users as well as the vulnerable users which effectively is provided by the BB protocol via exploitation of channel reciprocity. This paper studies the hybrid BB and GoB (BB+GoB) approach in a Manhattan environment. The new proposed hybrid interference avoidance scheme with an underlying score based scheduler is evaluated by means of system level simulations, and is compared against a pure GoB approach with the same scheduler as well as the BB based interference avoidance techniques applied to omnidirectional antennas. The results show an improvement in both system throughput and fairness (defined as cell edge user throughput). In particular, system throughput of up to 238.5 Mbps/cell or user throughput of up to 8.88 Mbps/user for the lower 10%-ile of users are shown to be feasible. In particular, the hybrid BB+GoB scheme exhibits a 16-fold improvement at the lower 10%-ile compared to pure GoB technique.

I. INTRODUCTION

Current and future wireless networks are largely uncoordinated, random and hierarchial in nature. Consequently, these networks typically lack any static network, and frequency planning and co-channel interference (CCI) constitutes a major limiting factor for system performance. Therefore, powerful techniques are needed that avoid and/or eliminate CCI while ensuring high system spectral efficiency and user fairness (especially considering the cell edge users) [1–4]. In addition, these techniques need to take into account the heterogenous QoS (quality of service) and traffic demands prevalent in such systems. Moreover, the anticipated system performance must not be achieved at an expense of excessive signalling and computational complexity as this would significantly affect the power efficiency of the system.

One of the key issues that hinders effective interference avoidance in such networks is the hidden node problem. While a transmitter may infer the interference at its target receiver via SINR (signal-to-interference-plus-noise ratio) feedback and channel knowledge, it is generally unaware of the receiver(s) in its vicinity that receive at exactly the same time/frequency resource (hidden nodes), and which it would force into outage by causing very high CCI. This is a problem not only for cellular and ad hoc networks with specific radio frequency bands, but also a fundamental problem for all cognitive radio approaches.

On the one hand, it has been demonstrated that BB protocol [5–9] effectively solves the hidden node problem. On the other hand, multiple antenna techniques at the base station (BS) such as a switched beam approach [10] or adaptive beamforming with opportunistic scheduling [11, 12] provide a powerful basic mechanism to enhance the reusability of radio resources, but these techniques generally suffer from the hidden node problem. The BB protocol and beamforming techniques seem to perfectly complement each other enabling a high frequency reuse in the system while mitigating CCI. In this paper, a switched beam approach is chosen because of low signalling overhead accompanied. Pre-defined beams are generated at the BS and a user is served by switching on the closest beam. The antenna gain in the direction of the side lobes is significantly lower than that of the main beam.

The BB protocol ensures that beams are only selected for a particular user in the cell if this transmission does not significantly interfere with any of the ongoing transmissions in the neighbouring cells. This interference awareness property of the BB protocol is achieved by a time-multiplexed busy signal transmitted omnidirectionally from the receiving mobile station (MS). Clearly, the TDD (time division duplex) mode is perfectly suited for this purpose. The performance of the hybrid BB+GoB scheme is compared against a ‘blind’ switched beam approach as well as pure BB approach with omnidirectional antennas at the BS.

The remainder of the paper is structured as follows: multi-user resource allocation is discussed in Section II. Section III describes the spatial processing of signals used. Section IV introduces the hybrid BB+GoB scheme considered in this paper. The considered Manhattan grid deployment scenario and the system level simulator are introduced in Section V, and the simulation results are discussed in Section VI. Finally, the conclusions are drawn in Section VII.

II. MULTI-USER RESOURCE ALLOCATION

The radio resource unit in OFDMA–TDD (orthogonal frequency division multiple access – time division duplex) air interface based on WINNER (wireless world initiative new radio) TDD mode [13] is a chunk, which comprises of successive $n_c$ subcarriers and $n_t$ OFDM (orthogonal frequency division multiplexing) symbols in a frame as shown in Fig. 1. A frame consists of a downlink (DL) and an uplink (UL) slot, each of which contains $N_C$ chunks. A chunk with frequency index $1 \leq n \leq N_C$ at frame $k$ is denoted by $(n, k)$. Provided that

This work has been performed in part within the framework of the CELTIC project CP5-026 WINNER+.

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channel knowledge is available at the transmitter, users can be assigned those chunks with favorable channel conditions, giving rise to multi-user diversity [14]. A variant of a score-based scheduler [15] is developed to distribute the \(1 \leq n \leq N_C\) chunks among \(1 \leq \nu \leq U\) users served by BS \(q\). The score at time instant \(k\) is computed as
\[
s_{\nu,q}[n,k] = 1 + \sum_{\ell=1}^{N_C} I[\xi_{\nu,q}[n,k] \leq \xi_{\nu,q}[\ell,k]] + \epsilon_{\nu,q}[n,k] + \Psi_{\nu,q},
\]
where \(\xi_{\nu,q}[n,k]\) is the estimated SINR of user \(\nu\) on chunk \((n,k)\) using the amount of interference observed in the previous slot, \(\epsilon_{\nu,q}[n,k] \in \{0, \infty\}\) defines whether or not user \(\nu\) is granted access to chunk \((n,k)\). The Boolean operator \(I_{x} = \{1,0\}\) is set to 1 or 0 when the condition \(x\) is true or false, respectively. Furthermore, it is proposed here that the scores should be adjusted with a fairness parameter \(\Psi_{\nu,q}\), which grows exponentially with every additional chunk allocated to \(\nu\) so that when allocating a new chunk, priority is given to the users with fewer number of chunks already allocated.

User \(\nu = \zeta_{q}[n,k]\) is assigned chunk \((n,k)\) if either a reservation indicator was set in the previous frame \(b_{\nu,q}[n,k-1]=1\), or the score (1) is minimized
\[
\zeta_{q}[n,k] = \arg \min_{\nu} s_{\nu,q}[n,k], \quad b_{\nu,q}[n,k-1] = 0 \forall \nu, \quad b_{\nu,q}[n,k-1] = 1.
\]

In the full frequency reuse OFDMA-TDD system with blind beam switching, considered as a benchmark, \(\epsilon_{\nu,q}[n,k]=0\) for all users in the cell. As a result, all users compete for being scheduled in the chunk \((n,k)\) using (2). However, for reservation based medium access control (MAC) protocols such as BB-OFDMA (see Section IV), some chunks are excluded for certain users. To this end, \(\epsilon_{\nu,q}[n,k] \rightarrow \infty\) indicates that the user \(\nu\) in cell \(q\) is denied access to chunk \((n,k)\). We note that if \(\epsilon_{\nu,q}[n,k] \rightarrow \infty\) for all users, cell \(q\) leaves chunk \((n,k)\) unallocated, so that \(\zeta_{q}[n,k]=\emptyset\).

### III. Spatial Signal Processing

We start with a general consideration of an OFDMA–TDD network where each of the BSs and MSs is equipped with \(N_T\) and \(N_R\) antennas respectively. Data transmission in the downlink is considered. The matrix \(V = [v^{(1)}, \ldots, v^{(N_b)}]\) is the spatial precoding matrix for \(N_S\) spatial layers available at the BS. The \(i\)th column of the matrix \(V\), \(v^{(i)}\), contains the precoder of spatial layer \(i\). The precoder is a vector \(v^{(i)} = [v_1, \ldots, v_{N_T}]^T\), where \(v_i\) is the complex coefficient applied to antenna element \(t\).

The transmitted sequence of spatial stream \(i\) is designated \(x^{(i)}\). The output of spatial precoding on the \(i\)th stream can be represented as
\[
s^{(i)} = v^{(i)} x^{(i)}.
\]

The output of spatial precoding is transmitted over a MIMO channel \(H_{p,\mu}\), where \(p\) and \(\mu\) are BS and MS indices respectively. The MIMO channel is represented as a \(N_R \times N_T\) matrix of the form
\[
H_{p,\mu} = \begin{pmatrix}
h_{1,1}^{p,\mu} & \cdots & h_{1,N_T}^{p,\mu} \\
\vdots & \ddots & \vdots \\
h_{N_R,1}^{p,\mu} & \cdots & h_{N_R,N_T}^{p,\mu}
\end{pmatrix},
\]
where \(h_{i,j}^{p,\mu}\) represents the channel gain between transmitting antenna \(t\) of BS \(p\) and receiving antenna \(r\) of MS \(\mu\) given by [16]
\[
h_{p,\mu}^{r,t} = a \exp \left(-\frac{j2\pi d}{\lambda}\right) \exp(-j2\pi(t-1)\Delta_T \cos \phi_T) \\
\exp(-j2\pi(r-1)\Delta_R \cos \phi_R).
\]

In (5), \(d\) is the distance between the centers of the transmit and the receive antenna arrays and \(\lambda\) is the carrier wavelength. \(\phi_T\) and \(\phi_R\) are the angles of incidence of the line-of-sight (LOS) path with the planes of the transmit and receive antenna arrays respectively as depicted in Fig. 2. \(\Delta_T\) and \(\Delta_R\) are separation of antenna elements normalized to \(\lambda\). The factor \(a\) represents the attenuation of the propagation path and incorporates distance dependent path loss, log–normal shadowing and small scale fading effects of the channel, given by the deployment scenario.

The signal of the spatial stream \(i\) received at antenna array of the MS \(\mu\) is represented as
\[
r^{(i)}_{\mu} = H_{p,\mu} s_p = H_{p,\mu} v^{(i)} x^{(i)}.
\]

The vector \(r^{(i)}_{\mu}\) is a \(N_R \times 1\) vector, where the \(k\)th element of \(r^{(i)}_{\mu}\) represents the signal received at the \(k\)th antenna of MS \(\mu\).
The received signal on the antenna array is spatially processed using vector \( \mathbf{u}_\mu^{(i)} = [u_1^{(i)}, \ldots, u_{N_R}^{(i)}]^T \), where \( u_k \) is the complex antenna weight applied to the antenna element \( k \). The output of spatial processing at the receiver is

\[
y_\mu^{(i)} = [\mathbf{u}_\mu^{(i)}]^T \mathbf{r}_\mu^{(i)} = [\mathbf{u}_\mu^{(i)}]^T \mathbf{H}_{p,\mu} \mathbf{v}^{(i)} x_i^{(i)}.
\]

(7)

The scalar \( y_\mu^{(i)} \) is the received signal at MS \( \mu \) on the \( i \)-th spatial stream. The term \( y_{\mu,p}^{(i)} = [\mathbf{u}_\mu^{(i)}]^T \mathbf{H}_{p,\mu} \mathbf{v}^{(i)} \) represents the effective channel between BS \( p \) and MS \( \mu \) for spatial stream \( i \). The term \( G_{p,\mu}^{(i)} = \mathbb{E} |y_{\mu,p}^{(i)}|^2 \) represents the average channel gain of spatial stream \( i \) from transmitter (i.e. BS \( p \)) in the direction of the receiver (i.e. MS \( \mu \)).

In this paper, we concentrate on the system where BSs are equipped with multiple antennas and MSs are omnidirectional transceivers with \( N_R \) = 1. The choice of omnidirectional antennas at the MSs eliminates spatial processing operations at the MS, thereby allowing less complex MS units to be used. With the above underlying assumptions, \( \mathbf{H}_{p,\mu} \) from generalized MIMO description in (4) reduces to a row vector \( \mathbf{h}_{p,\mu} \) of size \( 1 \times N_T \) and \( \mathbf{u}_\mu^{(i)} = 1, \forall i \). Consequently, \( r_{\mu}^{(i)} \) in (6) reduces to a scalar \( r_{\mu}^{(i)} = y_{\mu}^{(i)} \) in (7). The overall channel gain between BS \( p \) and MS \( \mu \) reduces to

\[
G_{p,\mu}^{(i)} = \mathbb{E} \left[ |\mathbf{h}_{p,\mu} \mathbf{v}^{(i)}|^2 \right] = \mathbb{E} \left[ \mathbf{v}^{(i)} H \mathbf{h}_{p,\mu} \mathbf{v}^{(i)} \right]
\]

(8)

where the operator \((\cdot)^H\) represents the Hermitian transpose of a vector. Note that by selecting a different precoding vector \( \mathbf{v}^{(j)} \), where \( j \neq i \), the channel gain in the direction of the observed receiver \( \mu \) is adjusted. Provided that the BS is aware of the amount of CCI it potentially causes to an active receiver, it can apply appropriate precoding vector so as to attenuate the channel gains in the direction of such vulnerable receiver. To this end, in Section IV, a hybrid technique is proposed where the interference awareness property of BB signalling is exploited to enable the beam selection such that strong interference is avoided and the hidden node problem is solved.

**IV. HYBRID BB+GoB SCHEME**

The basic principle of the combined use of fixed GoB approach and interference aware BB protocol\(^1\) in the downlink is described with the help of Fig. 3. It is assumed that the chunk \((n, k)\) is being used by BS\(_1\) to serve MS\(_1\). Since BS\(_2\) is generally unaware of the positions of the user population in cell 1, with random beam switching, BS\(_2\) might select to reuse the chunk \((n, k)\) for MS\(_2\) resulting in outage of both MS\(_1\) and MS\(_2\) on chunk \((n, k)\). However, if MS\(_1\) were to send a busy signal omnidirectionally on the same radio frequency carrier in a time-multiplexed mini slot (the BB), BS\(_2\) would sense a strong signal in its ‘beam 1’, and a low signal its ‘beam 2’. Therefore, with the proposed hybrid BB+GoB approach, BS\(_2\) would reuse the same chunk to serve MS\(_1\) using ‘beam 2’ resulting in no outage on chunk \((n, k)\) both at BS\(_1\) and BS\(_2\).

\(^1\)BB protocol for OFDMA–TDD system with omnidirectional antennas is covered in detail in our earlier paper [1].
If \( T^b = T^d \), (14) reduces to
\[
I_q^{b,(l)}[n,k] \leq I_{th},
\]  
(15)

The CCI caused to active receiver is remains lower than the threshold if the chunk \((n, k + 1)\) is reused on at most one of the beams that satisfy (15). The beam selected for chunk \((n, k + 1)\) depends on the outcome of the scheduler discussed in Section II. To ensure that the chunk is allocated to one of the beams satisfying (15), the access control indicator is set as follows
\[
\epsilon_{\nu,q}[n,k+1] \rightarrow \begin{cases} 0, & I_q^{b,(\nu)}[n,k] \leq I_{th} \\ \infty, & \text{otherwise}, \end{cases}
\]
(16)
where \( \epsilon_{\nu,q} \) refers to the the beam providing maximum channel gain to the user \( \nu \). The user that is scheduled on chunk \((n, k + 1)\) is \( \zeta_q[n,k+1], \) obtained using (2). The beam that is activated at BS \( q \) is given by
\[
\xi_q[n,k] = \omega_{\epsilon_q[n,k+1]}.
\]
(17)

The BS \( q \) transmits to MS \( \nu \) on chunk \((n, k + 1)\) by activating the beam \( \xi_q \) during the \((k + 1)^{th}\) frame. The scheduled beam is activated by applying the precoding vector \( v(\xi_q) \), to antenna array at the BS \( q \).

In the following section, the performance of novel BB-based beam selection described above (referred to as ‘BB+GoB’) is compared to BB signaling assuming omnidirectional antennas. In addition, we consider a BB disabled beam selection algorithm that allocates chunk to users purely based on (2) with \( b_{\nu,q}[n,k-1] \) and \( \epsilon_{\nu,q}[n,k] \) both set to zero. This is simply referred to as ‘GoB’ technique in the following sections.

V. MANHATTAN GRID DEPLOYMENT

An urban microcell deployment defined in scenario B1 in WINNER with a rectangular grid of streets (Manhattan grid) is considered where 72 BSs are distributed in streets as shown in Fig. 4. The performance statistics are collected only over the central core of 3 x 3 building blocks, so as to reduce the edge effects. The antennas are mounted below the rooftop and an effective antenna is a linear half wavelength array of 4 elements. The half power beamwidth of the array 32.3° in the broadside and the front-to-back ratio of antenna gain is 20 dB.

Outdoor MSs uniformly distributed in the streets and moving with a constant velocity of 5 km/h are considered. Two beams per BS, with the main lobes pointing towards the street direction with an angle of 180° between them are considered. Indoor MSs are not considered for the study because of high penetration losses due to the walls at high frequency as a result of which they are better suited to be served by femto-cell deployments, which is beyond the scope of this paper. Therefore, the beams pointing towards the buildings are ignored. On average \( U = 10 \) MSs are served by one cell. The MSs are connected to the BS on the same street on the basis of least distance because of the favourable path loss in line-of-sight (LOS) condition in the street canyon.

B1-LOS and B1-NLOS models [17] are used to model the LOS and non-LOS (NLOS) channels respectively. A full buffer traffic model [18] and a network synchronised in time and frequency is assumed. No upper limit is placed on the number of available chunks that may be assigned to one user. The simulation parameters are summarised in Table I.

VI. RESULTS AND DISCUSSIONS

The impact of the interference threshold, \( I_{th} \), on mean user throughput as a function of distance from the intended BS is examined in Fig. 5(a-b) for the downlink. In Fig. 5(a), the SINR target is \( \Gamma = 11.3 dB \) which corresponds to 16-QAM (quadrature amplitude modulation) with rate 3/4 convolutional FEC (forward error correction) coding and a packet error ratio of \( 10^{-2} \) [19]. This plot demonstrates the interference awareness capabilities of the BB protocol. For example, for the lowest interference threshold of \( I_{th} = -100 dBm \), the system is most ‘cautious’. A user would only be served, if no other MS in the network would suffer. As a consequence, the network exhibits a high level of fairness which is clearly illustrated.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total symbol length</td>
<td>22.45 µs</td>
</tr>
<tr>
<td>Carrier centre frequency</td>
<td>3.95 GHz</td>
</tr>
<tr>
<td>System bandwidth ( B )</td>
<td>89.84 MHz</td>
</tr>
<tr>
<td>Number of subcarriers (SC)</td>
<td>1840</td>
</tr>
<tr>
<td>Frame duration</td>
<td>0.6912 ms</td>
</tr>
<tr>
<td>OFDM symbols/frame</td>
<td>30</td>
</tr>
<tr>
<td>Chunk size</td>
<td>15 (time) \times 8 (frequency) = 120</td>
</tr>
<tr>
<td>Number of chunks/frame</td>
<td>2 (time) \times 230 (frequency)</td>
</tr>
<tr>
<td>Access probability</td>
<td>0.3</td>
</tr>
<tr>
<td>Bits/symbol ( m )</td>
<td>4 and 8</td>
</tr>
<tr>
<td>SINR target ( \Gamma )</td>
<td>11.3 dB and 22.5 dB</td>
</tr>
<tr>
<td>Number of sectors/cell</td>
<td>2</td>
</tr>
<tr>
<td>Number of antenna elements/sector</td>
<td>4</td>
</tr>
<tr>
<td>Average number of users/cell ( U )</td>
<td>10</td>
</tr>
<tr>
<td>Transmit power per chunk ( T^d )</td>
<td>16.4 dBm</td>
</tr>
<tr>
<td>Elevation antenna gain ( A_e )</td>
<td>14 dB</td>
</tr>
<tr>
<td>Azimuth antenna element gain</td>
<td>(- \min \left{ 12 \left( \frac{\pi}{2\theta} \right)^2, A_m \right} [dB] )</td>
</tr>
<tr>
<td>where,</td>
<td>( A_m = 20 ) and ( \theta_{3dB} = 70° )</td>
</tr>
<tr>
<td>Noise level ( N )</td>
<td>-117.8 dBm/chunk</td>
</tr>
<tr>
<td>Number of snapshots</td>
<td>50</td>
</tr>
<tr>
<td>Simulation duration per snapshot</td>
<td>50 ms</td>
</tr>
</tbody>
</table>
Throughput [Mbps]

![Graph](image)

**Fig. 5.** Comparison of performance of the proposed hybrid BB+GoB scheme for different thresholds against the state-of-the-art GoB switching. Comparisons are made using 16-QAM with $\Gamma = 11.3$ dB and 64-QAM with $\Gamma = 22.5$ dB. At 115 m and 330 m are the street crossings of the Manhattan structure, due to which drop in throughput is observed.

in Fig. 5(a) where the user throughput for $I_{th} = -100$ dBm is almost constant regardless of the location within the cell. Note, that a uniform user distribution is assumed. As the interference threshold is increased, the system is “desensitized” which generally results in a higher throughput close to the BS and a reduction in throughput closer to the cell edge. However, for all thresholds the throughput is improved at all locations relative to the case when $I_{th} = -100$ dBm since the spatial reuse of resources is increased. The new BB+GoB techniques outperforms GoB at any location for a threshold of $I_{th} = -70$ dBm. There are two more important observations: (a) for an interference threshold of $I_{th} = -70$ dBm the BB+GoB approach achieves only slightly better throughput up to a distance of 300m, but the per user throughput at the cell edge (between around 330m and 480m) is improved by a factor of 2 or equivalently by 100%. The interference awareness property of the new BB+GoB approach clearly unfolds here, and (b) the robustness to interference is also demonstrated at the first street crossing at around 115 m where the state-of-the-art GoB faces a throughput drop of about 35% whereas the BB+GoB technique only experiences a drop of about 9%.

In Fig. 5(b), $\Gamma = 22.5$ dB corresponds to 256-QAM with rate 3/4 convolutional FEC coding and a packet error ratio of $10^{-2}$ [19]. It is recognized that the particular example is at the upper end of practical modulation orders for such systems, but it is chosen because it highlights a few more important properties of the new technique and it assists in the validation of the new approach since some of the expected behavior can indeed be observed. For instance, the spatial dependency of the throughput is increased – as expected. However, even for this modulation order and an interference threshold of $I_{th} = -100$ dBm, a fair and constant throughput independent of location of about 10 Mbps can be seen. This is about 67% higher than than achieved with 16-QAM, i.e., the doubling of the spectrum utilization, from 4 bits/symbol to 8 bits/symbol, results in 67% improved throughput for $I_{th} = -100$ dBm. User throughput achieved at the close vicinity of the serving BS is 50 Mbps/user and that at the cell-edge is 4.85 Mbps/user using $I_{th} = -70$ dBm. This is in sharp contrast to GoB which only achieves approximately 26 Mbps/user close to the BS (only about 50% of what BB+GoB achieves), and about 2.3 Mbps/user at the cell edge (approx. 47% of BB+GoB).

Fig. 6(a–b) compare performance of BB+GoB against BB with omnidirectional antennas and pure GoB. An SINR target of $\Gamma = 22.5$ dB and 8 bits per symbol are assumed. Using omnidirectional antennas, a maximum median system throughput of 238 Mbps/cell (see Fig. 6(a)) is achieved in DL using $I_{th} = -75$ dBm. However, fairness is compromised as more than 50% of all users in the system are in outage. The users having zero throughput are said to be in outage. By adjusting the threshold to $-105$ dBm, 5.16 Mbps for the 10%-ile of user throughput is feasible (see Fig. 6(b)) at the cost of 59% reduction in median system throughput compared to using a threshold of $-75$ dBm. For comparison, the benchmark system (GoB) achieves a median system throughput of 129.0 Mbps/cell and a lower 10%-ile of user throughput of 561.5 kbps. Using an interference threshold of $I_{th} = -105$ dBm, BB with omnidirectional antennas provides an 9-fold increase in the lower 10%-ile of user throughput at the cost of 25% reduction in system throughput compared to the GoB.

Using BB+GoB, a median system throughput of 238.5 Mbps/cell is achieved using a threshold of $-75$ dBm (see Fig. 6(a)) and the corresponding 10%-ile of user throughput is 4.36 Mbps (see Fig. 6(b)). This represents a 85% increase in median system throughput together with a 7.8-fold increase in the lower 10%-ile of user throughput compared to GoB. By adjusting $I_{th}$ to $-90$ dBm, the 10%-ile of user throughput improves to 8.88 Mbps. This is approximately a 16-fold increase compared to GoB while at the same time the median system throughput is 20% higher.
A new hybrid interference avoidance technique has been proposed which combines two existing powerful techniques - GoB switching and interference aware concept using BB signalling. A comparison against CCI mitigation approaches: first, solely based on GoB switching, and second, solely based on BB signalling with omnidirectional antennas has been performed in a Manhattan environment. It has been shown that the BB interference threshold can be used to balance throughput and fairness in a cellular system. In particular, it was shown that by selecting a low interference threshold, which makes the system more cautious to CCI, a constant user throughput independent of distance from the BS can be accomplished. This comes at the expense of a reduced user throughput compared to GoB switching technique alone. However, by increasing the interference threshold, the average per user throughput at any location in the cell can clearly be improved compared to pure beam switching. In particular, the mean cell edge user throughput is increased by a factor of two. Moreover, it has been demonstrated that the throughput at the 10th percentile, which is a measure for the minimum guaranteed throughput, can be improved by up to a factor of 16 for high SINR targets.

REFERENCES


