Performance of Downlink Beam Switching for UMTS FDD in the Presence of Angular Spread

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***Abstract*— We present a simple beam switching scheme to increase the downlink capacity of the UMTS FDD-mode. At the base station, this method only requires one additional transceiver chain, i.e. a separate one for each beam, a beamforming network and a uniform linear array. The mobiles need no changes at all. We analyze the performance of our method by means of system level simulations for different angular spreads. We found an increase in downlink capacity of more than 75% over a conventional 3-sectored system for small direction of departure spreads. Compared to a 6-sectored system our scheme gives a capacity gain of more than 25% for small direction of departure spreads.**

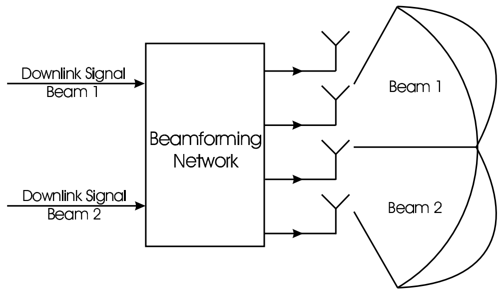


Fig. 1. Principal of downlink beam switching

I. Introduction

The Universal Mobile Telecommunication System (UMTS) brings high data rate services to the mobile user. Applications like internet browsing and multimedia, e.g. streaming video, will cause mainly downlink traffic, cf. [1]. Due to this traffic asymmetry, the downlink will limit the overall system capacity. Due to the W-CDMA duplex distance of 190MHz, the uplink and downlink channels are uncorrelated [2]. Hence, downlink channel estimation from received uplink signals is unreliable. A better choice is the downlink measurement at the mobile station. The estimates are then sent to the base station via a feedback channel, cf. [3], [4]. Release 99 of the UMTS Terrestrial Radio Access Network (UTRAN) specification does not include such capabilities for the mobiles. However, there are tendencies within 3GPP to extend the closed-loop transmit diversity schemes of Release 99, cf. [5], to more than two antennas, cf. [6], [7], [8]. These adoptions to the standard will be only applicable for future releases of UTRAN. However, operators are now starting to roll out their networks. As their number of subscribers increases, there will be need for increased downlink capacity. The methods used for increasing the capacity will have to be both, simple and compatible to Release 99 of UTRAN.

In this paper, we propose a beam switching scheme, which fulfills both of these requirements. We lay 2 fixed beams formed by a Uniform Linear Array (ULA) in each 120° sector of a base station site. The beams are formed by a beamforming network, where appropriate antenna weights are applied to the downlink signals. Figure 1 illustrates this concept. Each beam acts like an ordinary base station. This means that each beam uses its own scrambling code and transmits all necessary common channels like pilot, synchronization and paging channels, i.e. we increase the sectorization to six 60° sectors per base station site. In order to make a fair comparison between a conventional 3-sectored system, we limit the maximum transmit power per 120° sector, i.e. two beams, covering together a 120° sector, share the maximum allowed transmit power.

The big advantage of this beam switching scheme is that per equipped sector it needs only one additional transceiver chain, i.e. a separate one for each beam, a beamforming network and a uniform linear array. The beamforming can also be done digitally in the base band. The mobiles need no changes at all. The advantage of using an antenna array for producing the beams is that the beam pattern, formed with the antenna array, has a better side lobe suppression than a sector antenna with 33° 3dB beam width, which are typically used at 6-sectored base stations. Therefore, there is less inter-cell interference and a higher capacity.

Tiirola et al [10] propose a beam switching scheme, which is similar to ours. The main difference is that in [10] the decision on which beam to send is based on received power measurements at the base station. This implies that the base station has to measure the received power of all users on all beams (even if the user is not served by the specific beam at the moment). Also the authors restrict themselves to link level simulations and do not state a gain in overall system capacity.

We evaluate the performance of our beam switching scheme by means of static system level simulations. We compare the maximum number of 144kbit/s data users of conventional systems with 3-120° and 6-60° sectored base stations with our downlink beam switching system with 2 beams per 120° sec-

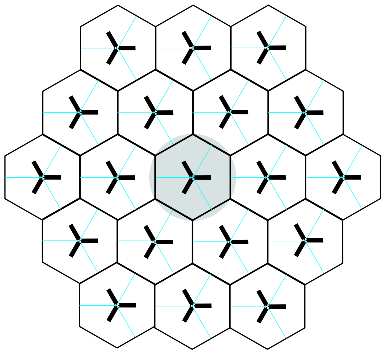


Fig. 2. Simulation area with 19 3-sectored base station sites

tor. We investigate the performance of each system in the presence of *angular spreads in the Directions of Departure* (DoD). This means that the multipath components, while leaving the base station in different directions, experience another attenuation/amplification through the antenna pattern.

Using downlink beam switching, we can show a capacity increase of more than 75% over a conventional 3-sectored system and more than 25% over a conventional 6-sectored system for small DoD spreads. An rms DoD spread of more than ten degrees results in a rapid decrease of the capacity gain over the 3-sectored system. The gain over the 6-sectored system settles at a level of around 17% for rms DoD spreads of more than 15°.

The conventional 3-sectored system with its broad antenna patterns is more robust against DoD spread than the beam switching and the 6-sectored system. Therefore, the influence of the DoD spread on the gain over the conventional 3-sectored system is larger.

II. SIMULATION

We used a static system level simulator to evaluate the performance of the suggested beam switching scheme. We simulated an area of 19 base station sites, shown in Figure 2. The traffic of the gray shaded area in Figure 2 is evaluated for assessing the network performance. The surrounding cells contribute to the inter-cell interference. This environment ensures that the interference power in the evaluation area is not underestimated, cf. [11].

The static simulator produces trustworthy results by averaging over 50 snapshots for each business case, i.e. each number of 144kbit/s data users in the evaluation area. In each snapshot, the users are equally distributed over all cells.

The pathloss is modeled based on the proposed macro cell model for UMTS system simulations presented in [12]. The pathloss $L_{m,b}$ [dB] between mobile m and base station b is given by

$$L_{m,b} = 128.1 + 37.6Log_{10}(R_{m,b}) + F_{m,b,s}\,. \quad \text{[dB]} \tag{1}$$

$R_{m,b}$ is the distance between mobile m and base station b in km. $F_{m,b,s}$ is a log-normally distributed random variable with a standard deviation of $\sigma_{ln} = 10$dB. According to [13], $F_{m,b,s}$ is chosen in such a way, that the pathloss correlation between two paths from one mobile to two different base stations is considered by a correlation coefficient of 0.5. The total pathloss $L^{tot}_{m,b,s}$ including the antenna pattern is given by

$$L^{tot}_{m,b,s} = L_{m,b} - \bar{A}_{m,b,s}\,. \quad \text{[dB]} \tag{2}$$

Indices m, b, s specify the path between mobile m and beam s (if beam switching is used) or sector antenna s (in the reference case) of base station site b. $\bar{A}_{m,b,s}$ is the expected pattern gain of antenna/beam s of base station site b in the direction towards mobile m. We assume that waves, received at the mobile station, origin from azimuthal Laplacian distributed DoDs at the base station. The exact way of modeling the DoD spread is to generate a certain number of random paths according to a Laplacian distribution for each combination of base station site and mobile. This method is computationally very costly. In order to reduce the run-time, we model the DoD spread in the following way. Instead of generating a certain number of random by Laplacian distributed DoDs for each user in runtime, we use the expected pattern gain. We define the expected pattern gain as the expectation value of the antenna pattern over the angle θ with its Laplacian distribution. The expected pattern gain of antenna/beam s of base station b towards user m at the geometrical angel $\theta_{m,b,s}$ seen from the base station is therefore given by

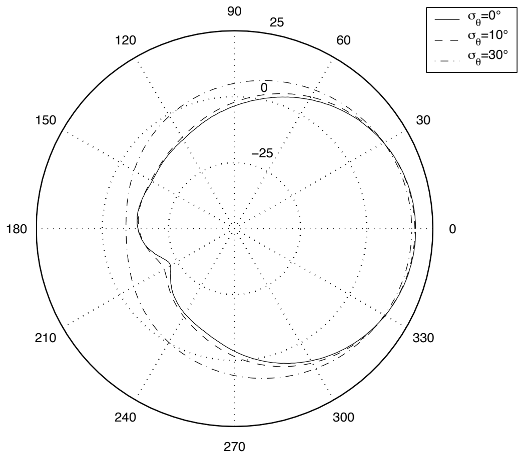
$$\begin{aligned}\bar{A}_{m,b,s}\left(\theta_{m,b,s}\right) &= E_\theta\left\{A_{b,s}\left(\theta_{m,b,s} - \theta\right)\right\} \\ &= c\int_{-\pi}^{\pi} A_{b,s}\left(\theta_{m,b,s} - \theta\right) e^{-\frac{\sqrt{2}|\theta|}{\sigma_\theta}}\, d\theta\,.\end{aligned} \tag{3}$$

$A_{b,s}(\cdot)$ describes the pattern of antenna/beam s of base station b. θ is a Laplacian distributed random variable, which represents the possible DoDs. σ_θ is the rms angular spread of the DoDs in radiants. The constant factor c is given by

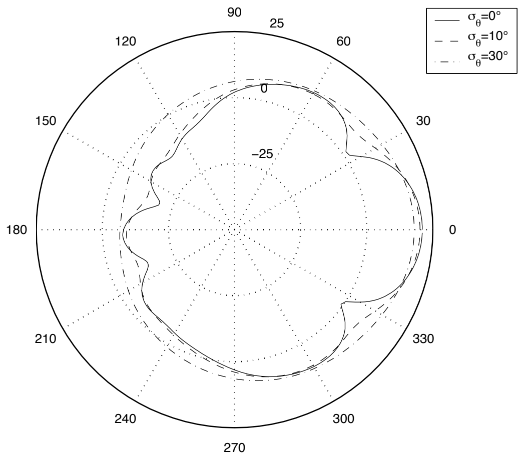
$$c = \frac{\sqrt{2}}{\sigma_\theta\left(1 - e^{-\pi\frac{\sqrt{2}}{\sigma_\theta}}\right)}\,. \tag{4}$$

Examples of expected patterns for the sector antenna used in the 3- and 6-sectored reference system are plotted in Figure 3a and 3b. In the case of downlink beam switching, the beams are formed by a ULA. Figure 3c illustrates the expected patterns for a beam intended to cover the angular range from 0 to 60° for different DoD spreads. It can be seen that the antenna gain in the main direction decreases slightly with increasing DoD spread. But the power leakage into surrounding areas increases enormous with increasing DoD spread.

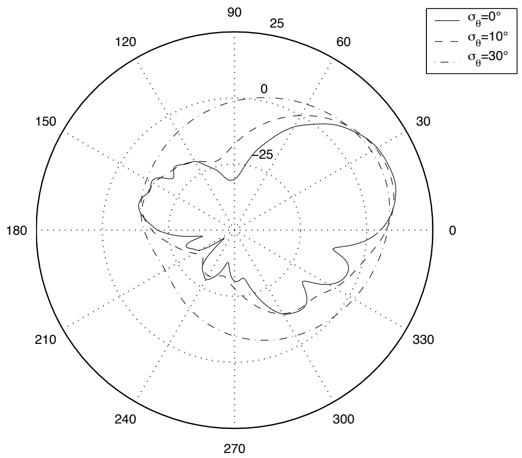
After calculating the pathlosses for each combination of base station antennas/beams and users, the active set AS_m (base station antennas/beams which serve the user m) is determined according to the received pilot powers. For simplicity



a) Sector antenna used in 3-sectored reference system



b) Sector antenna used in 6-sectored reference system



c) Beam formed by 4 element ULA (intended to cover the angular area from 0 to 60°)

Fig. 3. Expected pattern of sector antenna used in the 3-sectored (a) and 6-sectored (b) reference system and for a beam formed by the 4 element ULA (c). The expected patterns for rms DoD spreads of 0° (no DoD spread), 10° and 30° are plotted with solid, dashed and dashed-dotted line, respectively. Radial unit is dBi.

reasons we assume equal pilot power for the sectors (beams in the case of beam switching) of all base stations. So the received pilot signals from different sectors/beams are indirect proportional to their pathlosses. In order to further decrease the complexity of the simulator, we prevent soft handover, i.e. we set the maximum active set size to unity. The serving sector/beam for user m is then the one with the minimum total pathloss $L^{tot}_{m,b,s}$.

Having determined the active sets, the simulator adjusts the code power of all links until all served users are satisfied. A user is satisfied if

$$\left(\frac{E_b}{N_0+I_0}\right)_m = \sum_{(b,s)\in AS_m} \frac{P_{m,b,s} L^{tot}_{m,b,s} G_p}{N_0 + \alpha I^{Intra}_{m,b,s} + I^{Inter}_{b,s}} \quad (5)$$

is within 0.5dB of its predefined quality target [12]. $(b,s) \in AS_m$ represents all combinations of antennas/beams s and base station sites b that are in the active set of mobile m. $P_{m,b,s}$ is the code power used by sector/beam s of base station site b to serve mobile m. Note that, if the sector antenna/beam s of the base station site b is not within the active set of mobile m, $P_{m,b,s}$ is zero. G_p is the processing gain given by

$$G_p = \frac{chip\ rate}{data\ rate\ of\ service}. \quad (6)$$

N_0, α, $I^{Intra}_{m,b,s}$ and $I^{Inter}_{b,s}$ represent the background noise, the orthogonality factor for intra-cell interference, the intra-cell interference and the inter-cell interference, respectively. The intra-cell interference $I^{Intra}_{m,b,s}$ for the link between mobile m and sector/beam s of base station site b is given by

$$I^{Intra}_{m,b,s} = L^{tot}_{m,b,s}\left(P^c_{b,s} + \sum_{\mu\neq m} P_{\mu,b,s}\right). \quad (7)$$

$P^c_{b,s}$ is the power of all control channels transmitted by sector/beam b,s. $\sum_{\mu\neq m} P_{\mu,b,s}$ represents the sum of the code powers for all mobiles (except the desired mobile m) served by sector/beam s of base station site b. The inter-cell interference at mobile m for a link of sector/beam s of base station site b is given by

$$I^{Inter}_{m,b,s} = \sum_{(\beta,\xi)\neq(b,s)} L^{tot}_{m,\beta,\xi}\left(P^c_{\beta,\xi} + \sum_{\mu} P_{\mu,\beta,\xi}\right). \quad (8)$$

$\sum_{(\beta,\xi)\neq(b,s)}$ stands for the sum over all sectors/beams of all base station sites despite the desired sector/beam s of base station site b. $L^{tot}_{m,\beta,\xi}$ represents the total pathloss between sector/beam ξ of base station site β and mobile m given by (2). $P^c_{\beta,\xi}$ represents the power of all control channels transmitted by sector/beam β,ξ. $\sum_\mu P_{\mu,\beta,\xi}$ is the total power used for serving mobiles at sector/beam ξ of base station β.

If there are too many users in the simulation area, the maximum allowed transmit power of one or more sectors is exceeded and therefore it is not possible to serve all users. Then the user causing most interference is dismissed. This is repeated until all remaining users are satisfied and all sectors fulfill the maximum power criteria.

The main simulation parameters are summarized in Table I.

III. Results

We investigated a 3- and 6-sectored system using off-the-shelf sector antennas with 65° and 33° 3dB beamwidth, respectively. And compared the percentage of satisfied users over the number of users in the evaluation area (gray shaded area in Figure 2) with a system, using downlink beam switching where the 2 beams per 120° sector were formed with a 4-element ULA.

Figure 4 shows the percentage of satisfied users versus the number of users in the evaluation area for the two reference systems and the beam switching system for DoD spreads up to 30°. The performance of the system using downlink beam switching is always better than the performance of the 6-sectored reference system which is always better than the 3-sectored system. We can observe that the system using downlink beam switching and the 6-sectored reference system are more sensitive to DoD spreads than the 3-sectored reference system. As the distances between the curves for different DoD spreads are larger for the downlink beam switching and 6-sectored reference system than for the 3-sectored reference system. This is also illustrated in Figure 5 where the number of 144kbit/s data users in the evaluation area decreases faster with increasing rms DoD spreads for the downlink beam switching and 6-sectored reference system than for the 3-sectored reference system. But even for a huge rms DoD spread of 30° performs the beam switching system better than the 3-sectored reference system without DoD spread present.

TABLE I

Main system parameters

Base station sites	19
Inter-BS distance	1000m
Background noise floor	-105dBm [14]
Pathloss model	3GPP Macro cell [12]
Log-normal large-scale fading	$\mu_{ln} = 0, \sigma_{ln} = 10dB$
Pathloss correlation	0.5
Max. TX power per 120° sector	43dBm
Max. code power	40dBm
Min. code power	15dBm
rms DoD spread	0, 1, 2, 5, 7, 10, 15, 20, 30°
Active set size	1
Service mix	100% 144kbit/s data users
Activity	100%
Target $\frac{E_b}{N_0+I_0}$	4.5dB
Antenna of 3-sectored reference system	Kathrein 741.794 65° 3dB beam width
Antenna of 6-sectored reference system	Racal 2233 33° 3dB beam width
Antennas downlink beam switching	ULA with 4 patch antennas, $\frac{\lambda}{2}$ inter-element spacing
No. of snapshots	50

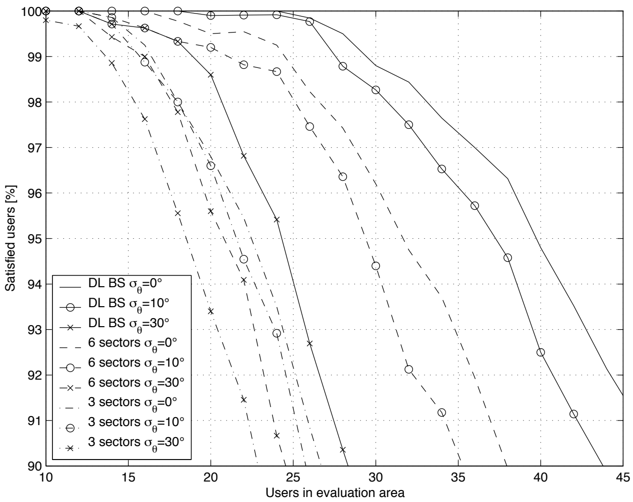


Fig. 4. Percentage of satisfied users versus number of users in the evaluation area for downlink beam switching and the 3- and 6-sectored reference systems for different rms DoD spreads. The curves for the beam switching, 3- and 6-sectored system are plotted with solid, dashed and dashed-dotted line, respectively. Curves for rms DoD spreads of 0°, 10° and 30° are indicated with no, circular and cross markers, respectively.

Figure 6 shows the relative capacity gain of downlink beam switching over the 3- and 6-sectored reference system at the 95% satisfaction level over rms DoD spread. There is a gain of more than 75% over the 3-sectored reference system until the rms DoD spread reaches five degrees and more than 70% up to a rms DoD spread of ten degrees. A further increase of the DoD spread results in significant decrease in capacity gain. But even for a huge rms DoD spread of 30° a capacity gain of more than 30% can be achieved. The gain of the downlink beam switching system over the 6-sectored reference system remains 25% to 30% until a rms DoD spread of about ten degrees.

IV. Conclusion

We proposed a simple beam switching scheme for the downlink of the UMTS FDD-mode. The big advantage of the proposed scheme is that we need only one additional transceiver chain, a beamforming network and one antenna array per sector. The mobiles need no additional capabilities and therefore our proposal conforms to Release 99 of the UTRAN standard.

Our extensive system level simulations and comparisons with conventional 3- and 6-sectored reference systems have shown that

- our scheme provides a capacity gain of more than 75%

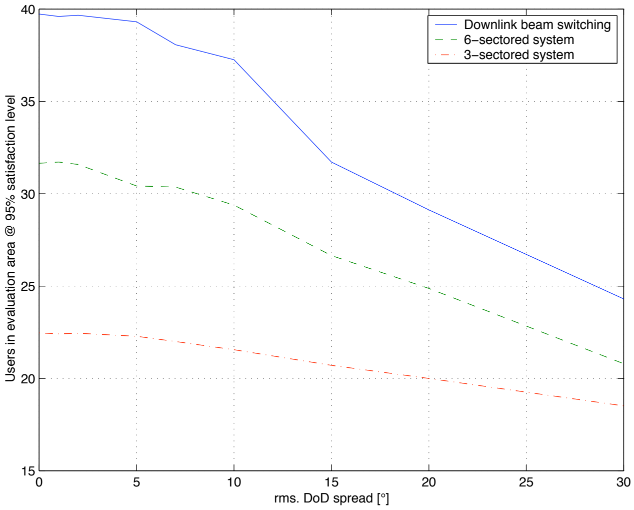


Fig. 5. Number of 144kbit/s data users in the evaluation area at the 95% satisfaction level over rms DoD spread. The curve for the system using downlink beam switching and the curves for the 3- and 6-sectored reference system are plotted with solid, dashed-dotted and dashed line, respectively.

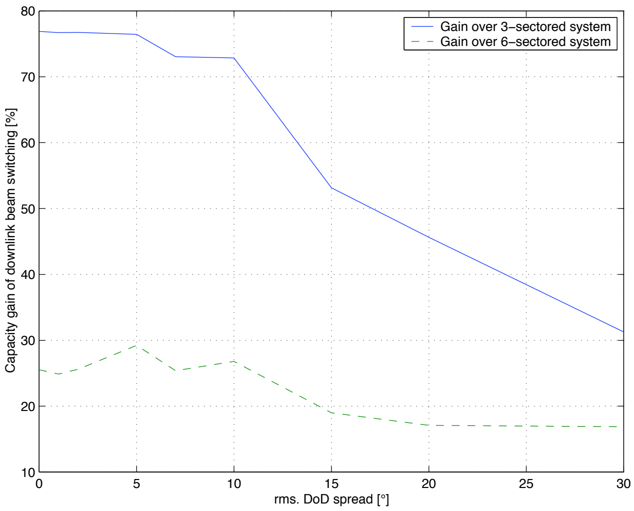


Fig. 6. Relative capacity gain of the downlink beam switching system over the 3-sectored reference system (solid line) and the 6-sectored reference system (dashed line) at the 95% satisfaction level over rms DoD spread.

over a conventional 3-sectored system for rms DoD spreads up to five degrees;

- our scheme provides a capacity gain between 25% and 30% over a conventional 6-sectored system for rms DoD spreads of up to ten degrees. The reason for the gain over the 6-sectored reference system is that the beams formed by the ULA have a better side lobe suppression than the pattern of the sector antenna with 33° 3dB beam width, which are typically used at 6-sectored base stations. Therefore, there is less inter-cell interference and a higher capacity;
- due to the broader main beam of the sector antennas used in the 3-sectored reference system, this system is more robust against DoD spread than the beam switching system and the 6-sectored reference system;
- even for a huge rms DoD spread of 30°, downlink beam switching shows a capacity gain of more than 30%.

Due to the simplicity of the proposed method, we strongly support the use of downlink beam switching for a substantial capacity increase in the downlink of UMTS FDD.

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