PERFORMANCE OF A SIMPLE DOWNLINK BEAM SWITCHING SCHEME FOR UMTS FDD

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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 needs an 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. We found an increase in downlink capacity of up to 73% over a conventional 3-sectored system if uniform linear arrays with four antenna elements are used for beamforming. Using uniform linear arrays with six elements we obtain a capacity increase of up to 90%.

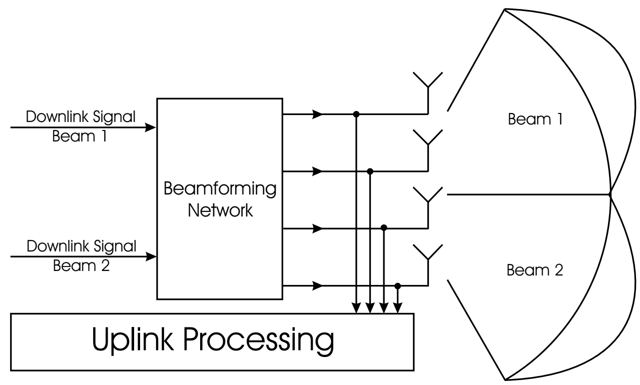


Fig. 1. Principal of downlink beam switching

1. Introduction

The Universal Mobile Telecommunication System (UMTS) brings high data rate services to the mobile user. Applications like internet browsing will cause mainly downlink traffic. Due to this traffic asymmetry the downlink will limit the overall system capacity. In W-CDMA there is a duplex distance of 190MHz which makes it very difficult to extract information for the downlink from signals received in the uplink. The reason is that the channels of the duplex frequencies are uncorrelated, cf. [1]. A method to combat this problem is to measure the downlink channel at the mobile. The channel measurements are then sent to the base station via a feedback channel, cf. [2], [3]. Release 99 of the UMTS Terrestrial Radio Access Network (UTRAN) specification does not include such abilities for the mobiles. However there are tendencies within 3GPP to extend the closed-loop transmit diversity schemes of Release 99, cf. [4], to more than two antennas, cf. [5], [6], [7]. These adaptions 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. The current standard defines that each mobile measures the power of all received pilot signals and determines the active set according to the strength of the pilots.

The big advantage of this beam switching scheme is that per equipped sector it needs only an 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. The advantage of using an antenna array for producing the beams is that this gives the possibility of using space-time processing for uplink capacity enhancement, cf. [8].

Tiirola et al [9] propose a beam switching scheme, which is similar to ours. The main difference is that in [9] 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 receive power of all users on all beams (even if the user is not served by the specific beam at the moment). They do not make system level simulations and therefore they are not able to determine the 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 for a conventional system with 3-120° sectored base stations with a downlink beam switching system with 2 beams per

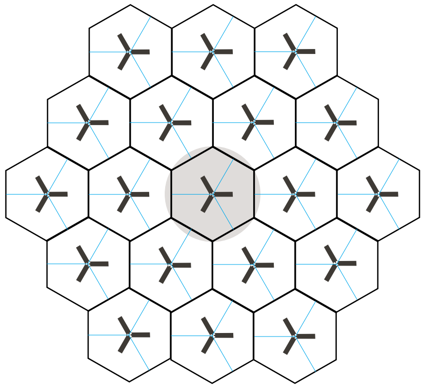


Fig. 2. Simulation area with 19 3-sectored base station sites

120° sector. In order to investigate the effect of Soft Hand Over (SHO) we do all simulations with an active set size of one (no SHO) and two (maximum two active connections per mobile).

With SHO turned off we can show a capacity increase of 73%, if 4-element ULAs are used for beamforming. Forming the beams with 6-element ULAs gives a capacity gain of 90%. Allowing SHO, results in slightly lower capacity gains.

2. Simulation

We used a static system level simulator to evaluate the performance of the suggested beam switching scheme. We simulated an area of 19 3-sectored base station sites, shown in Figure 2. This gives a total of 57 cells contributing to the inter-cell interference. The traffic of the gray shaded area in Figure 2 is evaluated for assessing the network performance. The surrounding cells serve as target cells for soft handover and contribute to the inter-cell interference. This evaluation method ensures that the interference power in the evaluation area is not under estimated, cf. [10].

The static simulator produces trustworthy results by averaging over 50 snapshots for each business case. In each snapshot the users are equally distributed over the simulated area.

The path loss 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

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

$R_{m,b}$ is the distance between mobile m and base station b in km. $LogF$ represents the log-normal distributed shadowing with standard deviation of $\sigma_{ln} = 10$dB. According to [11] $LogF$ is calculated 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 gain is given by

$$L^{tot}_{m,b,s} = A_{m,b,s} + L_{m,b}\,. \quad \text{[dB]} \quad (2)$$

Sub m, b, s specifies the path between mobile m and beam (if beam switching is used) or sector antenna (in the reference case) s of base station site b. $A_{m,b,s}$ is the antenna gain of antenna/beam s of base station site b in the direction towards mobile m. Figure 3a shows the antenna pattern of the sector antenna used for reference simulations. Figure 3b and 3c illustrate the pattern of the beams formed by a 4-element ULA and a 6-element ULA, respectively.

For simplicity reasons we assume equal pilot power for the sectors (beams in the case of beam switching) of all base stations. The active set AS_m (base station antennas/beams which serve the mobile m) is therefore determined by

$$AS_m = (b, s) \,|\, L^{tot}_{m,b,s} \le \min_{(b,s)} \left(L^{tot}_{m,b,s} + ASW \right)\,. \quad (3)$$

ASW is the active set window which determines the maximum allowed difference between the lowest and the highest pathloss of two links in the active set. In case that AS_m - as determined in equation 3 - contains more links than the maximum active set size max_ass, AS_m is limited to the max_ass links corresponding to the lowest total pathloss.

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

$$\left(\frac{E_b}{N_0 + I_0} \right)_m = \sum_{(b,s)\in AS_m} \frac{P_{m,b,s} L^{tot}_{m,b,s} PG}{N_0 + \alpha I^{Intra}_{m,b,s} + I^{Inter}_{b,s}} \quad (4)$$

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. PG is the processing gain given by

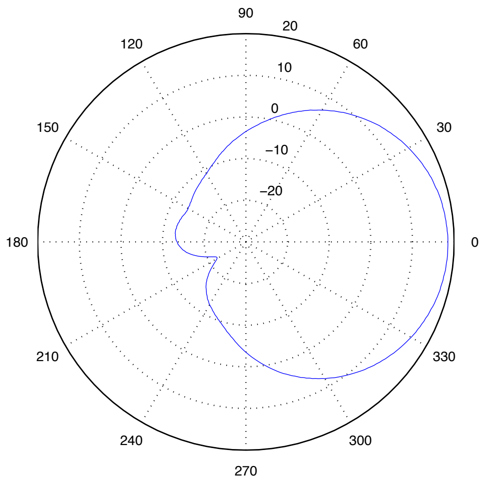
$$PG = \frac{chip\ rate}{data\ rate\ of\ service}\,. \quad (5)$$

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

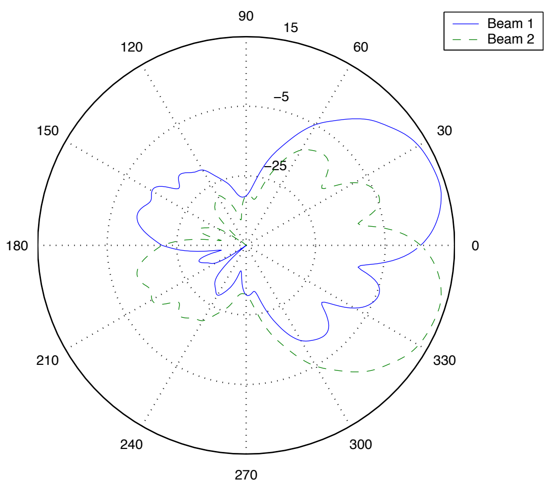
$$I^{Intra}_{m,b,s} = L^{tot}_{m,b,s} \left(P^c_{b,s} + \sum_{\mu \ne m} P_{\mu,b,s} \right)\,. \quad (6)$$

$P^c_{b,s}$ is the power of all control channels transmitted by sector/beam b, s. $\sum_{\mu \ne m} P_{\mu,b,s}$ represents the sum of the code power 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

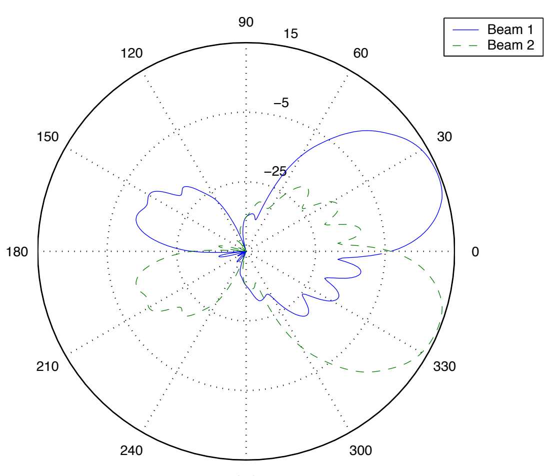
$$I^{Inter}_{m,b,s} = \sum_{(\beta,\sigma)\ne(b,s)} L^{tot}_{m,\beta,\sigma} \left(P^c_{\beta,\sigma} + \sum_{\mu} P_{\mu,\beta,\sigma} \right)\,. \quad (7)$$



a) Sector antenna



b) Beams formed by 4 element ULA



c) Beams formed by 6 element ULA

Fig. 3. Antenna pattern of sector antenna (a), beam patterns formed by 4 element ULA (b) and 6 element ULA (c). Radial unit is dBi.

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

If there are too many users in the simulation area, the maximum allowed transmit power of one ore more sectors is exceeded and therefore it is not possible to serve them all. 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 1.

Number of cells	57
Inter-BS distance	1000m
Background noise floor	-105dBm [13]
Pathloss model	Macro cell [12]
Log-normal large-scale fading	$\mu_{ln} = 0, \sigma_{ln} = 10dB$
Pathloss correlation	0.5
Max. TX power per sector	43dBm
Max. code power	40dBm
Min. code power	15dBm
Active set window	3dB
Active set size	1, 2
Service mix	100% 144kbit/s data users
Activity	100%
Target $\frac{E_b}{N_0+I_0}$	4.5dB
No. of antenna elements	1,4 and 6
Inter-element spacing	$d = \frac{\lambda}{2}$
No. of snapshots	50

Table 1. Main system parameters

3. Results

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

Figure 4 shows the simulation results for a maximum acitve set size of one and two. Evaluating the 95% level of the cdf in case of SHO, we see a capacity increase over the three sectored reference case of 69%, through downlink beam switching with 4-element ULAs. This capacity gain can be further increased up to 82% if we apply the same scheme to 6-element ULAs. Our scheme shows slightly higher gains of 73% and 90% over the 3-sectored case, for 4-element and 6-element ULA respectively, if SHO is turned off.

The higher capacity gain of the 6-element ULA is due to the better supression of emissions towards neighbouring

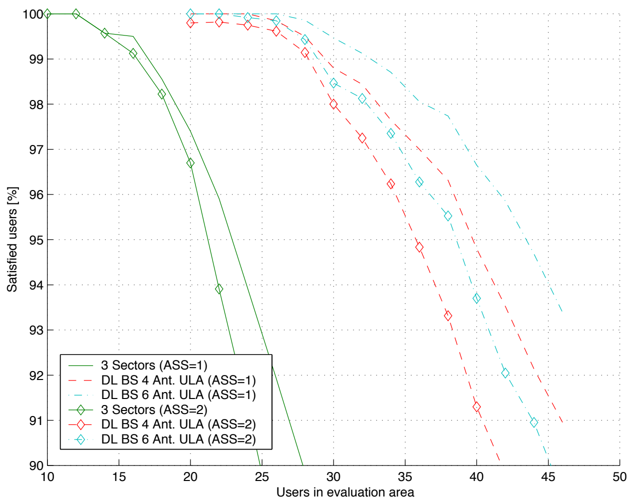


Fig. 4. Percentage of satisfied users versus number of users in the center area for the reference system using sector antennas (solid line), a system using downlink beam switching with 4-element ULAs (dashed line) and a system using downlink beam switching with 6-element ULAs (dash dotted line). The curves for systems allowing a maximum active set size of two have diamond markers where systems not allowing SHO (max_ass=1) have no markers.

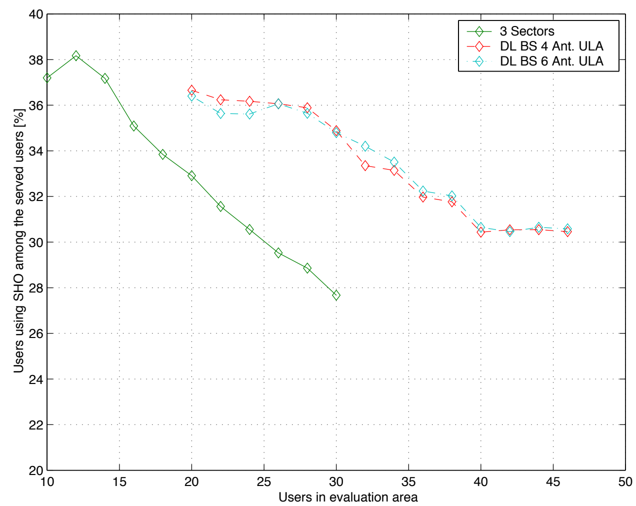


Fig. 5. Percentage of served users using SHO for 3-sector antenna (solid line), downlink beam switching with 4-element ULA (dashed line) and 6-element ULA (dashed dotted line).

beams which results in lower inter-cell interference. The advantage of the 6-element ULA over the 4-element ULA can be seen by comparing the amount of power emitted into the desired area over the amount of power emitted into the rest of the area R. For a beam intended to cover the azimuthal area from 0° to 60° R is given by

$$R = \frac{\int_0^{\frac{\pi}{3}} A(\varphi)d\varphi}{\int_{\frac{\pi}{3}}^{2\pi} A(\varphi)d\varphi}, \qquad (8)$$

where $A(\varphi)$ is the gain of the beam pattern in direction φ. For the 4-element ULA $R = 6.7$ whereas for the 6-element ULA $R = 42.2$. This means that a beam produced by a 4-element ULA causes about 6 times as much inter-cell interference to other beams of the same base station site than a 6-element ULA. As there is also intra-cell interference, the 6-element ULA is only 8% (if SHO is allowed) or 10% (if SHO is not allowed) better than the 4-element ULA.

Figure 4 shows also that the decrease in system capacity through SHO is in the order of 10%. The reason for this is that a user in SHO produces less intra-cell interference but more inter-cell interference. In contrast to inter-cell interference, intra-cell interference is weighted with an orthogonality factor $\alpha < 1$ in equation 4. Therefore a user in SHO costs more than a user with a single link.

The percentage of served users in SHO over the number of users in the evaluation area is shown in Figure 5. For system loads where 95% of the users are satisfied, the amount of served users using SHO is around 32% independent of the use of beam switching or conventional 3-sectored base stations.

The probability for SHO decreases with increasing system load. The reason for this is that the probability for a mobile to be in SHO is highest close to the borders of the coverage area of base stations and at the beam borders (sector borders in a conventional system). The inter-cell interference has also the highest value there. Therefore mobiles close to these borders need a higher code power than mobiles close to the base station. If the system is overloaded it dismisses the users demanding highest code powers, e.g. users at the beam borders which are very likely to be in SHO.

4. 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 an additional transceiver chain, a beamforming network and an antenna array per sector. The mobiles need no additional capabilities and therefore our proposal conforms to Release 99 of the UTRAN standard.

After extensive system level simulations and comparison with a classic 3-sectored reference system we conclude that

- using the proposed scheme with a 4-element ULA gives a capacity gain of up to 73% over the reference system.
- using the proposed scheme with a 6-element ULA gives a capacity gain of up to 90% over the reference system.
- allowing soft handover decreases system capacity about 10%.
- the amount of users in soft handover decreases with increasing system load.

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

For the soft handover problem we suggest that the decision to make a soft handover is not only based on the pilot strength. A more efficient way would be to allow soft handover only for remote users who would not achieve their quality target with a single link.

5. Acknowledgment

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