On the Optimum Number of Beams for Fixed Beam Smart Antennas in UMTS FDD

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***Abstract*— Fixed-beam smart antennas are a simple but effective method to boost the downlink capacity of UMTS FDD. In this paper we compare the two possible strategies. Using a four element uniform linear antenna array, we find the optimum number of fixed beams per 120° sector dependent on the direction of departure (DoD) spread at the base station. For the first method we find the optimum number of beams to be four for low DoD spreads and two or three for large DoD spreads. For the second method the optimum number of beams per sector is seven for small DoD spreads and goes down to four or five beams per sector for large DoD spreads depending on base station spacing. By extensive system level simulations, we show, for 1km inter base station distance, a capacity gain of more than 160% over a conventional 3-sectored reference system by both fixed beam methods.**

***Index Terms*— Universal Mobile Telecommunication System (UMTS), Wideband Code Division Multiple Access (WCDMA), smart antennas, fixed beams.**

I. INTRODUCTION

THE first Universal Mobile Telecommunication System (UMTS) networks are currently launched in Europe and Asia. These networks will bring high data rate services to the mobile user. As the number of subscribers increases there will be the need to extend the capacity of the initially deployed UMTS networks. Smart antennas are a possibility to increase the capacity of UMTS without the need of additional sites or additional spectrum. Smart antennas exploit the spatial domain of the mobile radio channel with the help of an antenna array and appropriate signal processing at the base station. In literature, there are several approaches for the implementation of such smart antennas. These approaches can be divided into two main strategies, the fixed beam methods and methods that apply user specific beam forming. In [1] to [5] fixed beam methods are studied. In [6] to [9] user specific beamforming is studied, while [10] to [12] discuss both, fixed and user specific beamforming. In this paper we focus on fixed beam methods that lay a specific number of fixed beams over the coverage area. All mobiles in the coverage area of one beam are served by this beam. Thus in the fixed beam approach, typically more than one mobile is served by a specific beam. The beams that cover a sector can be produced either with a passive (analog) beamforming network or digitally in base band. Base band beamforming requires phase coherency all the way to the antenna elements, which is not needed if a passive network is used for beamforming [13].

For the use of fixed beams in UMTS there are two possible strategies. The first method is to use the beams to increase the sectorisation of a base station site [4], which is fully compliant to Release 99 and later versions of the UMTS specification and needs no cooperation by the Radio Network Controller (RNC). The disadvantage of this method is that, due to the different scrambling codes used in the different beams, which we will call *logic cells*, the data transmitted on the different beams is not orthogonal and the interference in regions where two beams overlap is quite high. This is avoided in the second method, which we will call *switched beam method*, where the beams carry only user data and a Secondary Common Pilot Channel (S-CPICH) [14] to improve the channel estimation in the mobiles. The data channels transmitted with the different beams are typically scrambled with the same scrambling code so that their orthogonality is preserved. Therefore overlapping of neighboring beams is not as detrimental as for the first method. This method needs uplink measurements at the base station in order to determine the best beam for downlink transmission.

For a fixed antenna array size at the base station, the performance of these two systems in terms of number of served users at a certain average user satisfaction depends heavily on the number of fixed beams per 120° sector and the allocated power for the pilot and common channels. Due to the nature of the two strategies the optimum number of beams per 120° sector will be different. We think that, for a fair comparison of the performance of the two strategies, it is essential that the two systems are compared at an operational point (number of beams per sector and pilot channel power setting) that is optimum for each method. To the knowledge of the authors there is only one paper [2] that compares these two fixed beam methods. But this comparison is done with the assumption of six fixed beams per 120° sectors for both methods. These are, in fact, too many beams for the logic cell method and too few beams for the switched beam method as we will show in the following.

In this paper we evaluate by means of static system level simulation the downlink performance of the two methods for different number of beams per 120° sector over different *spreads in the Directions of Departure (DoD)*. The DoD spread in the downlink is the equivalent to the Direction of Arrival (DoA) spread in the uplink. That is, DoD spread describes multipaths that leave the base station in different directions and are captured at the mobile station after reflections and

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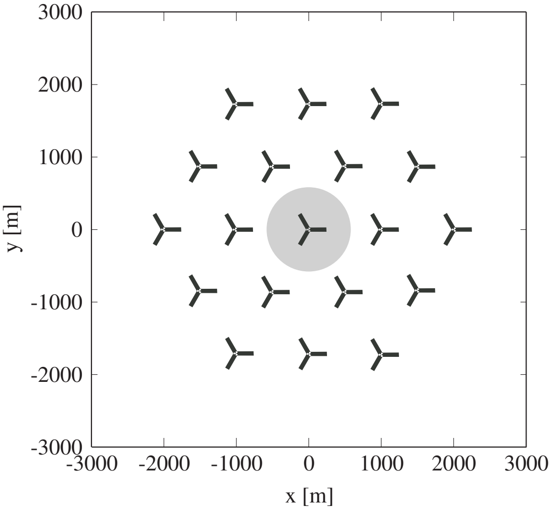

Fig. 1. Simulation area with 19 3-sectored base station sites; the direction of the main lobes of the sector antennas is indicated by the thick lines.

scattering. Using a uniform linear array consisting of four patch antennas in azimuth, we find that the optimum number of beams per 120° sector for the first method is four for low DoD spreads and two or three for large DoD spreads. For the second method the optimum number of beams is seven for low DoD spreads and goes down to four or five beams per sector for large DoD spreads depending on base station spacing. However due to the relatively flat gain curves an operator that uses always three beams for the first method or five beams for the second method independent of the actual DoD spread will not lose more than 8% of the capacity achieved with the optimum beam number.

II. The Two Fixed Beam Methods for UMTS FDD

A. Logic Cell Method

The first possible strategy for smart antenna systems using fixed beams in the downlink of UMTS FDD is to use the beams to increase the sectorisation of a base station site. Each beam forms a *logic cell* and behaves like an ordinary cell of a base station [4] that uses its own scrambling code set [15] and transmits all necessary common channels like Primary Common Pilot Channel (P-CPICH), Synchronization Channels (SCH), Primary Common Control Physical Channels (PCCPCH), etc. [14]. For a mobile in the system there is no difference between a logic cell formed by a fixed beam or a conventional cell served by a sector antenna. So the serving beam can be selected using the standardized cell search algorithm, for the initial cell search, and the standardized handover algorithm for handovers between beams, which are both based on the received P-CPICH power at the mobile [16]. In order to adapt to an unequal user distribution between the beams it is beneficial to share the power that is available to serve a sector dynamically between the logic cells of a sector. The advantage of the logic cell method is that it is fully compliant to Release 99 and later versions of the UMTS specification [17]. This method needs one transceiver chain per beam, a beamforming network, and an antenna array per equipped sector. The disadvantage of this method is that the signals

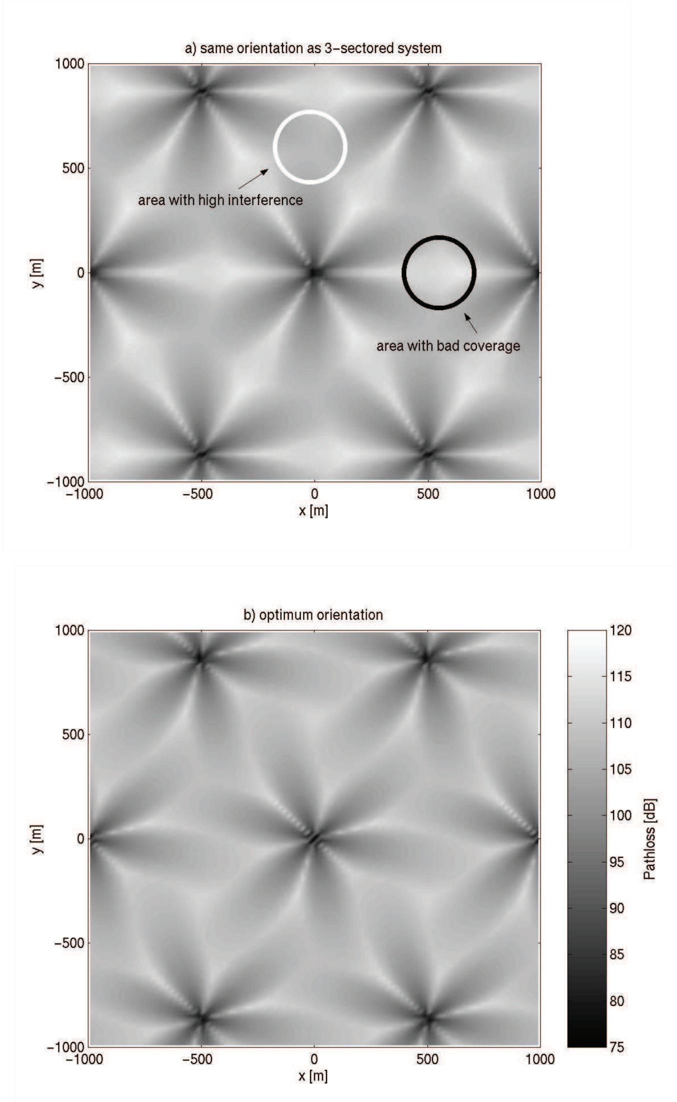

Fig. 2. Pathloss (without shadow fading) for the beam with the minimum pathloss for a system with two logic cells per 120° sector. Orientation of the antenna array broadside is the same as in a 3-sectored system (a); and optimum (b).

transmitted on different beams are scrambled with different scrambling codes and therefore they are not orthogonal to each other.

What is the optimum orientation of the antenna array that produces the logic cells in order to maximize the system capacity, measured as the number of users that can be served by the system? Consider base station sites that are placed on a regular hexagonal grid (Fig. 1) and, for the time being, a system with an even number of logic cells per 120° sector. Then, the optimum orientation of the antenna array broadside is shifted by τ degrees compared to the optimum orientation of the sector antennas in a conventional 3-sectored system. The bold lines in Fig. 1 indicate the optimum direction for sector antennas in a 3-sectored system. This angle τ is given by

$$\tau = \frac{120^\circ}{4N_B}, \tag{1}$$

where N_B is the number of logic cells per 120° sector. The

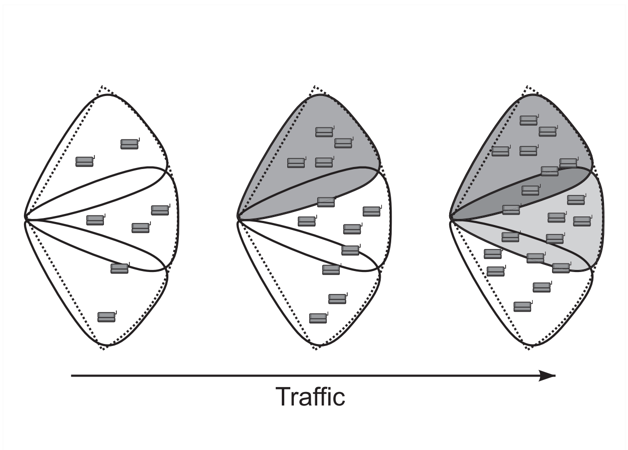

Fig. 3. Scrambling code assignment for a switched beam system with 3 beams per 120° sector and increasing load (different gray scales correspond to different scrambling codes; beams that use the primary scrambling code, which is also used for the common channels transmitted into the entire cell are white).

reason for the performance improvement due to the orientation shift can be seen in Fig. 2. It compares the pathloss (without shadow fading) to the beam with the lowest pathloss over the area for a system with two logic cells per 120° sector for two cases: on the left side (a), with the same orientation of the broadside of the antenna arrays as the optimum orientation of the sectors in a 3-sectored system; and, on the right side (b), the optimum orientation of the antenna array broadside. It can be seen that, with the sub-optimum orientation, there are areas between the beams with a very large pathloss, e.g. the area marked with a black circle. In order to serve users in these areas a high power for the common channels and data channels is necessary. On the other hand there are areas where three beams of different base station sites have quite a low pathloss, e.g. the area marked with the white circle in Fig. 2. In these areas the interference will be very high. With the optimum orientation of the antenna array the coverage areas of the logic cells intertwine as shown on the right part of Fig. 2 so that there are no coverage holes as in the sub-optimum case. The benefit due to the optimum orientation of the logic cells is largest for two logic cells per 120° sector and no DoD spread. With increasing number of logic cells per 120° sector and increasing DoD spread the benefit due to the better orientation vanishes. Note that, for an odd number of beams per sector, the optimum orientation is different. It is the same orientation as for the 3-sectored case; the worst orientation is given by a turn as calculated in (1).

B. Switched Beam Method

As just discussed, the logic cell method suffers from high interference from neighboring beams as different scrambling codes are used on each beam. This problem is avoided in the *switched beam method*. In this method the fixed beams transmit only channels carrying user specific data, while the common channels like P-CPICH, SCH, PCCPCH, etc. are transmitted into the entire sector using e.g. a single antenna element of the antenna array used for beamforming. Like in a conventional UMTS system, the receive power of the P-CPICH at the mobile determines the serving sectors [18]. The mobile will be served with the beam of the sector with the highest uplink receive power.

Typically the data sent on the different beams is scrambled with the same scrambling code and therefore the different channels are orthogonal to each other. Of course the orthogonality between the channels will be partially lost due to multipath propagation. If there are so many users in the system that the number of required orthogonal codes exceeds the codes offered by a single Orthogonal Variable Spreading Factor (OVSF) code tree then a new code tree is used and the corresponding channels are scrambled with another so called secondary scrambling code [15]. If the second OVSF code tree is also used up, additional secondary scrambling codes can be used for scrambling. UMTS allows up to 15 secondary scrambling codes [15]. These secondary scrambling codes are not orthogonal to each other and to the primary scrambling code, so it is beneficial if all data channels transmitted with one beam are scrambled with the same scrambling code. In order to reduce the interference from the P-CPICH and the control channels that are sent into the whole sector and are always scrambled with the primary scrambling code, as many beams as possible should use the primary scrambling code. If a secondary scrambling code has to be used it is beneficial to start with the beam that is next to the border of a sector as the neighboring sector uses always different scrambling codes. Figure 3 shows schematically a possible scrambling code assignment for a switched beam system with three fixed beams per sector and increasing load.

Mobiles in a UMTS system use the P-CPICH for channel estimation by default [14]. In the switched beam method the P-CPICH is transmitted into the entire sector using a single antenna element of the antenna array, while the user data is sent on a beam. Hence P-CPICH and user data experience different radio channels, and the P-CPICH cannot be used to estimate the radio channel experienced by the user data.

The UMTS specification [19] offers two solutions for this problem. Either the mobiles use a Secondary Common Pilot Channel (S-CPICH) that is transmitted on each beam or the mobiles use the dedicated pilot bits for channel estimation that are time multiplexed with the user data. The method to use is signalled via higher layer protocols [19]. The S-CPICH has the same structure as the P-CPICH but is spread with a different channelization code and in order to reduce the interference it is scrambled with the same scrambling code as the data channels on the beam [14].

As the switched beam method uses fixed beams that serve typically several mobiles, we suggest to transmit a S-CPICH for channel estimation. The reason for this is that the energy contained in the dedicated pilot bits is lower than the energy of the S-CPICH. Therefore using the S-CPICH for channel estimation will result in a smaller estimation error and the mobile will need less receive power for achieving the same bit error rate than a mobile that estimates the channel using the dedicated pilot bits (even if the power ratio between user data and pilot bits is optimized) [20], [21]. If a beam serves several mobiles, the power reduction due to the better channel estimation will compensate for the power spent for the S-CPICH. The advantages of dedicated pilot bits come along with flexible beamforming. The advantages of flexible beamforming are that individual beams can be steered to each user and no higher level signaling is required for beam switching. However such solutions require additional signal processing for DoA estimation. In this paper we want to discuss explicitly only fixed beam solutions.

The disadvantage of the switched beam method is that, in contrast to the logic cell method, it requires measurements at the base station in order to determine the best beam for downlink transmission. Additionally, the RNC that manages the radio resources needs to be aware that a certain base station uses switched beams and needs to allocate the data channels to the different beams according to the measurements done at the base station. This is necessary as the messages that command the mobile to use a certain S-CPICH for channel estimation are generated in the RNC. The position of the mobiles is also needed in the RNC in order to implement the scrambling code assignment described above.

The optimum orientation of the antenna array, described above for the logic cell method, does not give a capacity improvement for the switched beam method. The reason for this is that the switched beam method transmits the common channels with a single antenna element into the entire 120° sector. For these common channels the optimum orientation is the same orientation as the optimum orientation in a conventional 3-sectored system. If the orientation of the antenna array would be changed, the power of the common channels would have to be increased in order to close the coverage holes produced by the orientation change. This increase in power for the common channels will eat up the benefit of reduced interference and better coverage for the beams.

III. Simulator

We used a static Monte Carlo system-level simulator to evaluate the system capacity as a function of the chosen fixed beam strategy and the number of beams per 120° sector. We simulated an area of 19 3-sectored base station sites, shown in Fig. 1. The traffic of the gray shaded area in Fig. 1 is evaluated for assessing the network performance. The surrounding cells contribute to the inter-cell interference. This evaluation method ensures that the interference power in the evaluation area is not underestimated [22]. The static simulator produces trustworthy results by averaging over 50 independent realizations of the user distribution, called "snapshots" for each user density. In each snapshot the users are uniformly, but randomly distributed over the simulated network area.

A. Creation of a Snapshot

Our pathloss model is based on the macrocell model proposed for UMTS system simulations [23]. We designate each beam of a 120° sector as a "transmission branch". For the switched beam method we designate an additional transmission branch to the single antenna element that transmits the common channels into the entire sector. For the 3-sectored reference case there is only one transmission branch per 120° sector, the sector antenna that serves the sector. The pathloss $L_{m,s,b}$ [dB] between mobile m and transmission branch b of sector s is given by

$$L_{m,s,b} = L^{d}_{m,s,b} + L^{f}_{m,s,b}\,, \quad \text{[dB]} \tag{2}$$

where $L^{f}_{m,s,b}$ represents the log-normal distributed shadowing with standard deviation of $\sigma_{ln} = 10$dB. According to [24] we calculate $L^{f}_{m,s,b}$ by considering a correlation coefficient of 0.5 between two paths from one mobile to two different base stations.

Static system simulators include fast fading and the fast power control only implicitly through the required quality target of the radio links. The quality targets are determined by link level simulations that include these effects. Laiho et al. show in [20] that, when simulating circuit switched services, the predictions done with a static system simulator are comparable with the result of a dynamic simulator that includes fast fading and the fast power control at the cost of significant longer runtime.

In (2), $L^{d}_{m,s,b}$ represents the deterministic part of the pathloss which depends on the distance $R_{m,s}$ in km between sector s and mobile m and the pattern/antenna gain toward mobile m

$$L^{d}_{m,s,b} = 128.1 + 37.6\log_{10}(R_{m,s}) - \bar{A}_{m,s,b}\,, \quad \text{[dB]} \tag{3}$$

where $\bar{A}_{m,s,b}$ represents the expected pattern gain of transmission branch b of sector s toward mobile m. We assume that waves, received at the mobile station, originate from azimuthal Laplacian distributed DoDs at the base station [25]. 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 transmission branch b of sector s toward user m at the geometrical angle $\theta_{m,s,b}$ seen from the base station is therefore given by

$$\begin{aligned} \bar{A}_{m,s,b} &= E_{\theta}\left\{A_{s,b}\left(\theta_{m,s,b} - \theta\right)\right\} \\ &= c\int_{-\pi}^{\pi} A_{s,b}\left(\theta_{m,s,b} - \theta\right) e^{-\frac{\sqrt{2}|\theta|}{\sigma_\theta}}\, d\theta\,, \end{aligned} \tag{4}$$

where $A_{s,b}(\cdot)$ describes the pattern of antenna/beam b of sector s and 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

$$c = \frac{\sqrt{2}}{\sigma_\theta\left(1 - e^{-\pi\frac{\sqrt{2}}{\sigma_\theta}}\right)}\,. \tag{5}$$

The active set AS_m (sector and transmission branch that serve user m) is determined according to the received P-CPICH powers

$$\hat{P}^{P-CPICH}_{m,s,b} = \frac{P^{P-CPICH}_{s,b}}{L_{m,s,b}}\,, \tag{6}$$

TABLE I
SOFT HANDOVER GAIN FOR 144KBIT/S DATA SERVICE IN ITU VEHICULAR A ENVIRONMENT WITH 3KM/H MOBILE SPEED [20]

pathloss difference [dB]	0	3	6	10
SHO gain [dB]	1.4	1	0.9	0.4

where $P_{s,b}^{P-CPICH}$ is the transmit power of the P-CPICH at transmission branch b of sector s. For the 3-sectored reference case and systems using the logic cell method, the active set AS_m (antennas/beams which serve the mobile m) is determined by

$$AS_m = \left\{(s,b) \,|\, \hat{P}_{m,s,b}^{P-CPICH} \geq \max_{(s,b)} \left(\hat{P}_{m,s,b}^{P-CPICH} - \mathrm{ASW}\right)\right\}, \quad (7)$$

where ASW is the active set window, which determines the maximum allowed P-CPICH power difference between two links in the active set. In the switched beam method the received P-CPICH power determines only the serving sector as the beams do not transmit a P-CPICH. In a real network using the switched beam method, the beam for transmitting the downlink data has to be determined by uplink measurements. We assume that this method works perfectly so that always the beams of a sector with the lowest pathloss toward mobile m are in the active set. In case that AS_m contains more links than the maximum active set size max_ass, AS_m is limited to the max_ass links corresponding to the highest received P-CPICH power.

A link is released if the quality of the corresponding pilot (P-CPICH or P-CPICH of the sector antenna and S-CPICH of the serving beam in the switched beam method), given by

$$\gamma_{m,s,b}^{CPICH} = \frac{\hat{P}_{m,s,b}^{CPICH}}{\hat{P}_m^{tot}}, \quad (8)$$

is below -18dB. In (8) $CPICH$ stands for either primary or secondary CPICH and $\hat{P}_m^{tot}$ is the total received power plus noise of mobile m.

The simulator adjusts the code power of all links until all served users are satisfied. A user is satisfied if

$$\left(\frac{E_S}{N_0}\right)_m = \sum_{(s,b)\in AS_m} \frac{P_{m,s,b}G_p}{L_{m,s,b}\left(N_w + (1-\alpha)\hat{P}_{m,s,b}^{SSC} + \hat{P}_{m,s,b}^{OSC}\right)} \quad (9)$$

is within 0.5dB of its predefined quality target [23]. For mobiles with more than one link in the active set the quality target is reduced according to the soft handover gain (Table I) that depends on the pathloss difference between the two links in the mobiles active set with the lowest pathloss. The soft handover gain for pathloss differences not tabulated in Table I are linearly interpolated. The sum is taken over $(s,b) \in AS_m$, representing all links in the active set of mobile m. The power $P_{m,s,b}$ is the code power used by transmission branch b of sector s to serve mobile m and G_p is the processing gain that is equal to the used spreading factor. The terms N_w, α, $\hat{P}_{m,s,b}^{SSC}$, and $\hat{P}_{m,s,b}^{OSC}$ represent the background noise, the orthogonality factor [20] for channels that are spread with the same scrambling code, the aggregated receive power of all channels that are scrambled with the same scrambling code as the link (m,s,b) and the aggregated received power of all channels that are scrambled with another scrambling code than the link (m,s,b).

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 any more possible to serve all users. Then, the link that consumes most power is dismissed. This is repeated until all remaining users are satisfied, and no sector exceeds the maximum-power criterion.

The main simulation parameters are summarized in Table II. For all simulations we took the total power for all common channels, other than P-CPICH and S-CPICH, equal to the power of the P-CPICH. Figure 4 shows the antenna pattern of a single patch antenna used in the antenna array. Using elements with a broader pattern would decrease the system capacity as the isolation between neighboring sectors is decreased. However small pattern changes will not change the optimum *number* of beams.

TABLE II
MAIN SYSTEM PARAMETERS

Number of BS sites	19
Inter-BS distance	1000m
Background noise floor	-105dBm [28]
Pathloss model	3GPP Macro cell [23]
Log-normal large-scale fading	$\mu_{ln} = 0$, $\sigma_{ln} = 10$dB
Pathloss correlation	0.5
Max. TX power per 120° sector P^{max}	43dBm
Max. code power	40dBm
Min. code power	15dBm
Common-channel power	equal to P-CPICH power
Max. active set size	4
Active set window ASW	3dB
Service mix	100% 144kbit/s data users
Activity	100%
Target $\frac{E_S}{N_0}$	6.1dB
Orthogonality factor α	0.5
Minimum pilot quality	-18dB
No. of antenna elements	4
Inter-element spacing	$d = \frac{\lambda}{2}$
No. of snapshots	50

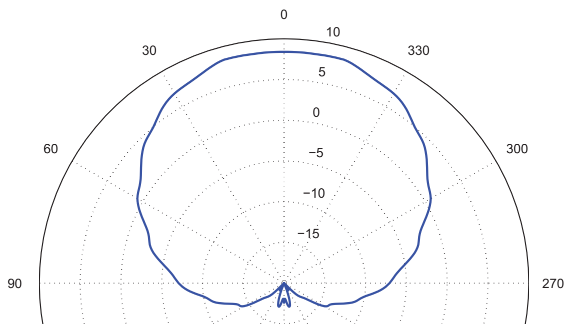

Fig. 4. Antenna pattern of a single patch antenna used in the antenna array [27]; radial unit is dBi.

TABLE III

OPTIMIZED VALUES FOR THE MINIMUM SIDE LOBE RATIO OF THE DOLPH-CHEBYSHEV PATTERN AND P-CPICH POWER FOR DIFFERENT NUMBER OF LOGIC CELLS PER 120° SECTOR

Logic cells per sector	Side lobe level	P-CPICH power	
		1km BS dist.	5km BS dist.
2	19dB	0.3W	0.7W
3	16dB	0.3W	0.6W
4	13dB	0.3W	0.5W
5	13dB	0.2W	0.5W
6	13dB	0.15W	0.5W

TABLE IV

OPTIMIZED VALUES FOR THE MINIMUM SIDE LOBE RATIO OF THE DOLPH-CHEBYSHEV PATTERN AND S-CPICH POWER FOR DIFFERENT NUMBER OF FIXED BEAMS PER 120° SECTOR IF THE SWITCHED BEAM METHOD IS USED

Switched beams per sector	Side lobe level	S-CPICH power	
		1km BS dist.	5km BS dist.
2	28dB	0.3W	0.8W
3	19dB	0.3W	0.6W
4	16dB	0.3W	0.4W
5	13dB	0.2W	0.4W
6	13dB	0.2W	0.3W
7	13dB	0.15W	0.3W
8	13dB	0.15W	0.3W
9	13dB	0.15W	0.3W

We used the Dolph-Chebyshev synthesis [26] to form beams with different beam widths. The Dolph-Chebyshev synthesis allows to control the beam width with a single parameter, i.e. the minimum allowed side lobe ratio r [26]. In order to ensure a fair comparison between the different strategies, we optimized the beam width and the pilot powers for the different schemes with varying number of beams per 120° sector. For this optimization we assumed a rms DoD spread of 5°. Further for the optimization we configured the simulator in such a way that mobiles are not served if one of the links in its active set is released, e.g. because of missing pilot coverage. The idea behind that was not to favor configurations that improve the system capacity by removing soft handover links. Tables III and IV list, for the logic cell and switched beam methods, the optimized values for minimum side lobe ratio r of the Dolph-Chebyshev patterns and the CPICH powers that ensure the maximum number of served users. Using the same optimization method for the conventional 3-sectored reference system that uses off-the-shelf sector antennas with 65° 3dB beam width, we found a optimum P-CPICH power of 0.6W for 1km inter base station distance and 1W for 5km inter base station distance. For the P-CPICH in the switched beam method that is transmitted only with a single element into the entire sector we used 0.6W for 1km inter base station distance and 1.1W for 5km inter base station distance, which were the optimum pilot powers for a 3-sectored system that used a single element of the antenna array as sector antenna.

IV. RESULTS

We evaluated the network capacity of the different fixed beam strategies by comparing the average number of users in the system if 95% of the users in the evaluation area (the gray shaded area in Fig. 1) are satisfied. As reference we used the network capacity of a conventional 3-sectored system with sector antennas with 65° 3dB beam width. For an inter base station distance of 1km, Fig. 5 shows the capacity gain of the logic cell method as a function of the number of logic cells per 120° sector and the rms DoD spread. For rms DoD spreads down to 10° , *four* logic cells per 120° sector perform best. Only for an enormous DoD spread of 20° *two* and *three* logic cells per sector give a larger gain than four logic cells per sector. The maximum capacity of about 165% is achieved with four logic cells per sector if no DoD spread is present. The capacity gain decreases with increasing DoD spread but it is still more than 70% for a DoD spread of 20° and two or three logic cells per sector.

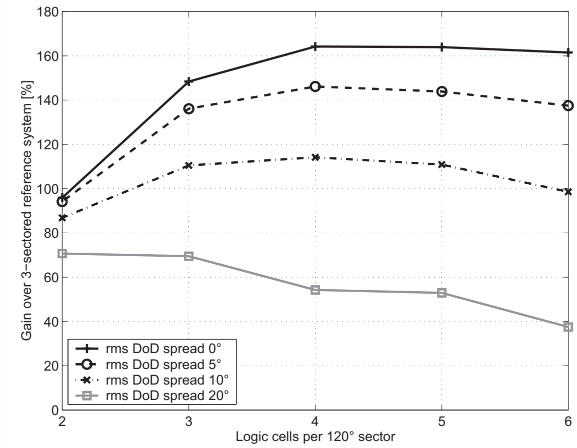

Fig. 5. Capacity gain of systems with different number of *logic cells* per 120° sector over a conventional 3-sectored system for rms DoD spreads from 0 to 20°.

The reason why the performance of systems with more logic cells is more sensitive to increased DoD spread is that the effective beam pattern of the beams is broadened by the DoD spread. So each beam produces more interference in the neighboring logic cells. This interference due to the overlapping beams decreases with increasing angular distance from the interfering beam. So systems with less logic cells per sector, where each beam covers a wider angular area, will have a lower average interference increase due to increased DoD spread than systems with many logic cells that have to serve a very narrow area.

The gain improvement by increasing the number of logic cells from two to three is significant for low DoD spreads but a further increase of the number of logic cells per sector gives only a moderate performance gain. An operator using only three logic cells per 120° sector, independent of the DoD spread, will never lose more than 8% of the capacity achieved with the optimum number of logic cells per sector. Hence from an economical point of view it might be a good solution to use three logic cells per 120° sector, independent of the actual DoD spread.

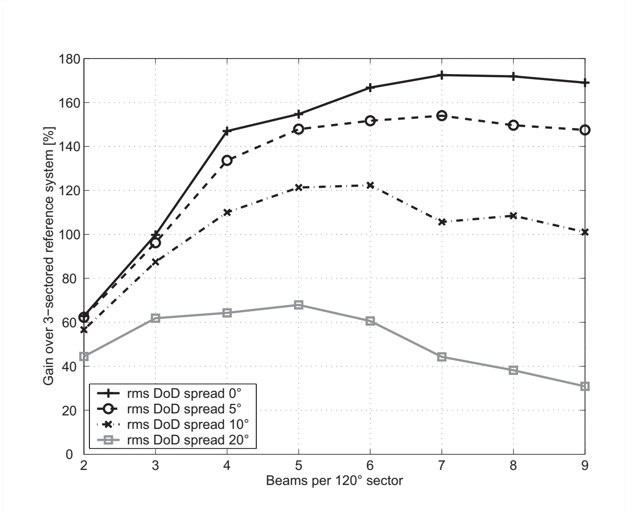

Fig. 6. Capacity gain of systems with different number of *switched beams* per 120° sector over a conventional 3-sectored system for rms DoD spreads from 0 to 20°.

We did this study also for a system with 5km inter base station distance and found the same optimum number of logic cells per sector. However due to the increased power needed for the common channels the capacity gain was lower. In the optimum case of no DoD spread and four logic cells per 120° sector this system achieved a capacity gain of 128% over the reference system.

The transmit power per 120° sector is limited and the power overhead due to the P-CPICH and other common channels increases with increasing number of logic cells per sector. Therefore the optimum beam number that maximizes the capacity might be lower if significantly more than the optimum power is used for the P-CPICH and other common channels.

Figure 6 shows the capacity gain of a switched beam system dependent on the number of beams 120° sector are best for rms DoD spreads of 0 or 5°. An environment with no DoD spread at all gives the maximum capacity gain of 170% . For a rms DoD spread of 10° *six* beams per 120° sector are best and for a rms DoD spread of 20° *five* beams are optimal. However the gain curves are very flat so that the actual number of beams does not matter much. This means that the capacity achieved with five beams per sector is never more than 7% below the capacity achieved with the optimum beam number. As for the logic cell method, the capacity gain decreases with increasing DoD spread. Due to the large number of users served per sector it happened in some of the snapshots that a secondary scrambling code had to be used.

We analyzed also a switched beam system with 5km inter base station distance, which showed the same optimum beam number for DoD spreads down to 5°. For DoD spreads of 10 and 20° the optimum beam number was lower with *five* respectively *four* beams per sector. The reason for this shift in the optimum beam number is the larger amount of power used for the common channels in order to serve the larger cells. However using five beams per sector independent of the actual DoD spread gives a capacity loss of less than 7.5% compared to the optimum case.

A significant increase of the S-CPICH power above the optimum value will shift the optimum beam number toward lower values, as the price for an additional beam is the S-CPICH power that is not available for user traffic.

V. CONCLUSION

For fixed beam smart antennas there exist two possible downlink strategies in UMTS FDD. Either the beams are used to form logic cells or the switched beam method is used. For an even number of logic cells per 120° sector we found that the optimum orientation of the broadside of the antenna array is different to the optimum direction of the main beam of a conventional 3-sectored system. For an inter base station distance of 1km and no DoD spread, both fixed beam methods show a capacity gain of more than 160% over a 3-sectored reference system. The optimum number of beams per 120° sector depends on the used method and the DoD spread. In general, the logic cell method requires less beams than the switched beam method. The optimum number of logic cells per sector is four for low DoD spreads and two or three for large DoD spreads. However as there is no tremendous capacity increase if more than three logic cells per sector are used, an operator that uses three logic cells per sector independent of the actual DoD spread does not lose more than 8% of the capacity achieved with the optimum configuration. The optimum number of beams per 120° sector for the beam switching method is seven for low DoD spreads and goes down to four or five beams per sector for large DoD spreads depending on base station spacing. However using five beams per sector independent of the actual DoD spread gives a capacity loss of less than 7.5% compared to the optimum beam number.

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