APPLICATION ASPECTS AND PERFORMANCE OF
ADAPTIVE ANTENNA BASE STATIONS IN A GSM NETWORK

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Abstract Base stations with adaptive antennas are now available as first generation products for capacity improvement of cellular systems like GSM. This paper describes the pre-development steps which have been made by a joint project of Ericsson and Mannesmann Mobilfunk to show experimentally in a public GSM system the advantages and capabilities of this new technology. Based on basic measurements verifying the principles and limits of the adaptive antenna technology, prototype base stations with this new technology were integrated into the commercial GSM infrastructure of Mannesmann Mobilfunk’s German D2-network in Giessen. The high potential of the adaptive antenna technology has been verified by reduction of the frequency re-use distance and measurement of the accompanied network quality.

1. Introduction and Background
GSM with its international roaming feature in most countries of the world results in mobile subscriber penetration rates increasing continuously throughout the last years. Experts believe that this growth will continue and end in penetration rates of 80 to 100%. The GSM growth however is not only characterised by increasing subscriber numbers but also by increase of new services, e.g. especially circuit switched or packet switched data services. Both effects end in an increased demand in radio network capacity. Within the standardised GSM 900 MHz or 1800 MHz frequency bands a certain number of network operators have got a piece of spectrum to cover their country including the metropolitan areas with millions of inhabitants. The must popular ways to increase the capacity of a cellular system are cell splitting and the overlay of a microcell system on a macrocell layer. Thus, the number of cells and therefore the possibility to re-use the frequencies more often are increased. This technology controls interference very effectively but is unfortunately very expensive.

The way to control interference in a cellular network, which is considered in this paper, is based on adaptive antenna technology in which narrow beams are controlled by base stations during movement of subscribers. Goal of the paper is not to describe deeply the theory behind adaptive antennas; goal is to describe the steps, which have been made by a GSM operator to incorporate a new powerful technology quickly in its radio network, and to learn about the advantages and disadvantages of this new technology in a life mobile radio network [1],[2],[3].

The experimental work was divided into two phases: In phase 1 dedicated measurements have been carried out to verify principles, to select information on different algorithms, and to describe the uplink and the downlink separately.

Fig.1: Basic structure of the testbed
In phase 2 three prototype base stations with adaptive antennas have been implemented into the German GSM network of Mannesmann Mobilfunk and measured in terms of quality behaviour and capacity growth.

2. Phase 1: Dedicated Measurements

2.1 Test system
Goal of phase 1 was to carry out dedicated measurements in order to verify the principles of array antennas. Field trials were made at 1800 MHz. The basic structure of the testbed is shown in Fig. 1. For comparison reasons a two branch dual polarised sector antenna has been used. The array antenna can be described by the following functionality:
- Eight branch diversity combining in the uplink
- Usage of the uplink data for calculation of the directional information for the downlink
- Direction of arrival (DOA) is used to determine the narrow beam radiating in the downlink.

2.2 Algorithms
Different algorithms have been used to control the uplink combining and the downlink beam forming. In the uplink Maximum Ratio Combining (MRC) is applied for the array antenna (8 branch diversity combining) and for the sector antenna (2 branch diversity combining). Alternatively, Interference Rejection Combining (IRC) is applied during tests. Other algorithms were tested using the raw data on a computer outside of the test arrangement. In the downlink the direction of arrival is estimated on the strongest signal path. For beam forming according to this DOA a Fixed Beam (FB) algorithm and a Steered Beam (SB) algorithm have been used.

2.3 Test Sites and Results
Test locations are chosen near Düsseldorf in urban, suburban, hilly rural and flat rural terrain. With a few degree separation between a mobile and possible interferers for both the uplink and the downlink the array antenna shows a considerable interference suppression or gain in C/I performance over a sector antenna. The results were so exciting that we decided to introduce array antenna technology into our GSM network as described in the following chapter.

3 Phase 2: Measurements in the German D2 Network
Phase 2 project goals include both the first implementation of GSM 900 MHz base station prototypes with adaptive antenna technology into the public D2 radio network and tests of the new technology step by step starting with functional tests (coverage tests, handover tests, and beam selection tests) and ending with performance tests (comparison between sector and array configurations, determination of capacity and quality improvements) of the system carrying public traffic.

3.1 Integration and Verification of Adaptive Antennas Base Stations (ABTS)
As test area the town Giessen was chosen. Giessen city has typically 2 to 5 story buildings, see Fig. 2. The three test sites form a triangle with around 2 kilometer edge length. The test sites were connected via a standard Abis interface with a standard GSM Base Station Controller (BSC). Thus, all algorithms are handled in the special ABTS, no adaptation in the BSC are required.

Our functional tests started with signal strength and signal quality measurements for both sector and array configuration in order to proof that our customer gets unchanged coverage area. The next tests look into beam selection procedures and then especially into
intercell handovers from sector to array cells and finally between array cells. Obviously standard features like frequency hopping, discontinuous transmission, etc. were also tested before public traffic was switched to the ABTS. All measurements were carried out in the uplink by controlling STS counter results. Of special interest were TCH cut-off ratio (0.2%-0.8%), HO cut-off ratio (0.2%-0.5%) and SDCCH cut-off ratio (0.4%-0.7%).

3.2 Capacity Gain using Adaptive Antenna Base Stations
In order to determine the capacity gain of the adaptive antenna technology, the frequency re-use factor applied in the test area has been reduced step by step. The frequency plans are shown in Table 1 for traffic channels. BCCH channels were transmitted only via sector antennas to guarantee the normal GSM handover measurements by mobile stations. In the final step the same frequencies were used in adjacent cells.

Performance of the test area is measured for the different frequency plans by measuring the frequency of intra-cell handovers (ICHO). An ICHO is induced when the quality is worse than a threshold and when the signal strength is higher than a threshold, see Fig. 3. This typically occurs when there is interference present. Fig. 4 shows ICHO/Erlang versus the cell traffic in Erlang for the sector antenna and the array antenna, respectively. For constant ICHO/Erl the cell load can be increased by using adaptive antennas indicating the higher system capacity.

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Table 1: Frequency plans

Due to the fact that the field trials were performed with life traffic it was important not to degrade the network quality in a way that was noticable to customers. We thought that a quality level of 12 ICHO/(Erlang*Hour) is suitable for comparison. In Fig. 5 the array versus sector performance is depicted. Intra cell handovers ICHO/Erlang*Hour are shown versus the total number of deployed frequencies in the system.
number of deployed frequencies in the field test area. Taking into account the described quality level of 12 ICHO/(Erl*h) the capacity gain reached in Giessen was about 120%. This gain can be reached for speech channels. Unfortunately, the GSM system operation requires a continuous signal on the BCCH channel for mobile orientation purposes and mobile measurements of BTS candidates for handover. This GSM specialty limits the application of adaptive antenna technology in a GSM system to only non-BCCH channels. With the better understanding of requirements, system operation should be specified in such a manner that this powerful technology can be used for all channels. This is especially important for the current specification of the 3rd generation UMTS system.

4 Capacity Gain Simulations for a Metropolitan Area
The experimental results so far described give a first indication of the achievable capacity gain in a GSM network. The test area of Giessen however was to small to get generalized results for inhomogeneous networks. Therefore a capacity gain study [4] was carried out taking into account a real base station configuration and different values of the percentage of cells equipped with adaptive antennas \( P_{\text{adapt}} \) in Fig. 6. It is known that capacity limitations do not occur in inhomogeneous mobile networks at all sites at the same time. Capacity is limited by sites having high interference potential (active or passive interferer). When these sites are equipped with adaptive antenna BTS one can reach very quickly high capacity gains. Fig. 6 shows a capacity gain of 60% when only 25% of the sites are ABTS.

![Capacity Gain using adaptive antennas for a metropolitan area of the D2 network.](image)

5 Conclusion
In the present paper steps were described to introduce adaptive antenna technology into a GSM radio network. Principles of this new technology were at first tested in special test environments. The measurement results indicate improved C/I-ratios and positively influence the decision to introduce prototype adaptive base stations into the German D2 network. These prototypes provide a quality and capacity improvement in accordance with the expectations. Compared with normal sector antennas, the adaptive antenna technology yields a 120% capacity improvement at unchanged D2 network quality.

References