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SHAPING COVERAGE USING ANTENNA ARRAYS FOR LOAD-BALANCING IN CELLULAR NETWORKS

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Abstract

In this article the authors investigate shaping coverage cooperatively in a macro-cell environment and evaluate the benefits using real antenna models. Each antenna in this proposed scheme is an adaptive array equipped with the capability to re-configure and shape power patterns through power pattern synthesis. Patterns are formed cooperatively to control coverage and balance and maximize overall network capacity. A range of antenna models are tested in this paper using an ideal optimal synthesizer and verified using a system-level WCDMA simulator. The results are

Keywords: Antenna arrays, wireless networks, pattern synthesis, adaptive cellular coverage analyzed to show the requirements and desired features of the antenna system.

1. INTRODUCTION

In the event of uniform user traffic and site distribution, omni-directional coverage shapes in theory yield the best service probability in cellular communication. In reality, traffic distributions are never that balanced and cooperative coverage through cell shaping was proposed to balance traffic load and maximize overall network resource utilization [1]. The system is designed to be an Adaptive Coverage System (ACS) that is able to maintain radio resource utilization maximization.

Initial work [1] on geographic load balancing used real-encoded genetic algorithm to solve the global optimization problem. Later a much more efficient optimization method called the Bubble Oscillation Algorithm (BOA) was proposed [2], and is efficient in terms of both speed and solution soundness.

The desired patterns generated by BOA serve as approximation targets for antenna arrays using radiation pattern (RP) synthesis. For this coverage shaping problem an optimal way to solve it as a minimization problem was proposed in [4]. It is strongly believed that this minimization-based pattern synthesis approach is optimal in the minimization sense because it has been observed that roots found with this scheme, gives the same smallest minimum square error (MSE) in more than 98% cases.

This optimal synthesis scheme has been used in system-level simulations and it has been found that the results agree with that using only the desired pattern [4]. However, only ideal antennas were tested with the synthesizer. Realistic antenna models have not been verified in terms of delivering acceptable results. Hence, this paper is intending to answer two questions here. Firstly, what kind of antennas would suit the task of shaping using the optimal synthesizer; secondly, what kind of impact would realistic antenna models have on system performance. The paper is organized as follows. The optimal synthesizer and coverage shaping are discussed in Section 2. Realistic antenna models to be used by the synthesizer are examined in Section 3 and then tested using system-level simulations, with results and discussion given in Section 4. Conclusion follows to serve as answers to the questions asked earlier.

2. OPTIMAL SYNTHESIZER & ARRAY

Since the linear arrangement of antenna elements is easiest and most viable for the construction of an array, a linear array is used throughout our study. The complex weight W_i of an array is composed of the phase shift β_i and the amplitude of the signal A_i, which is controlled by an ideal linear amplifier. The power pattern $F(\theta)$ of the array in relation to the azimuth θ is given by the following expression (neglecting the effect of mutual coupling)

$$F(\theta) = \left|\sum_{n=1}^{N} A_n e^{-j[n\frac{2\pi d}{\lambda}\cos(\theta)+\beta_n]}\right|^2 \qquad (1)$$

where d is the inter-element spacing. The excitation parameter vector is $\underline{w} = [\beta_1, \beta_2 \dots \beta_n, A_1, A_2 \dots A_n]$ contains 2*N. The ultimate pattern of the array is the product of the power patterns of an element $E(\theta)$ and the array

$$S(\theta) = E(\theta)F(\theta) \qquad (2)$$

The desired pattern $D($ is calculated by the BOA and the optimal synthesizer minimizes the following MSE to approximate the radiation pattern to a desired shape:

$$MSE\left(\varepsilon\left(\underline{w}\right)\right) = \frac{1}{181}\mu\sum_{\theta=0}^{180}\left[S\left(\theta,\underline{w}\right) - D\left(\theta\right)\right]^2 \quad (3)$$

Samples of $S(\theta,$ and $D($ are evaluated on every integer degree and the square power of their difference is averaged throughout an azimuth domain spans , which is enough to cover angles of interest for a directional sector antenna. is a penalty function:

$$\begin{cases}\mu = 1 & S\left(\theta,\underline{w}\right) - D\left(\theta\right) < 0\\ \mu < 1 & S\left(\theta,\underline{w}\right) - D\left(\theta\right) > 0\end{cases} \quad (4)$$

The resulting MSE is a function of variables and can be minimized using minimization technique. Only omnidirectional antenna was evaluated in [3] but conveniently, since (3) only depends on fixed samples of $E($ at each azimuth angle as polynomial parameters, the MSE can be minimized using whatever element patterns.

3. Antenna Element Models

The antenna elements used for the linear array can be of diverse forms. The omnidirectional dipole is a classic form with a uniform gain distribution across the $(0, 2\pi)$ azimuth domain. A more directional sine wave gain function (5) is another simple example.

$$G(\theta) = \sin\left(\theta + \frac{\pi}{2}\right), \quad \theta \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right] \quad (5)$$

Real antennas and related models have more complicated forms. The azimuth RP of the 3GPP antenna model [5] is described by several parameters: maximum azimuth gain, half-power beam width (HPBW), and front-back ratio (FBR):

$$G_h(\theta) = -\min\left(12 \cdot \left(\frac{\theta}{HPBW_h}\right)^2, FBR_h\right) + G_m \quad (6)$$

where G_m is the maximum gain of the antenna, and subscript *h* signifies the horizontal (azimuth) plane .

In reality, the antennas widely deployed by mobile communication operators are mostly sector antenna array panels with a typical maximum gain of 10-20 dBi and the half-power beam width (HPBW) usually lies between 60 and 90 degrees. This is in accordance with the common practice of using three sector antennas to form a complete cell. For example, two base station antennas Type 741989 and Type 80010426 (frequency range: 1920…2200 MHz for both; max azimuth gain: 16.7 and 17.7 dBi; FBR: >24 and >28 dB; max power per input: 300W for both) from major antenna equipment vendor Kathrein-Werke KG conform to this sector antenna requirement.

Let $HPBW_h =$ (, $FBR_h =$, $G_m = 18$c, the 3GPP model approximates the pattern of both Kathrein antennas in the azimuth plane (Fig.1). The ideal pattern has nearly equal gains of 18 dBi on every azimuth angle within 120-degree range and gives least overlap between intra-cell sectors. This makes the ideal pattern a very good benchmark for antenna performance comparison.

Sector antenna patterns are optimally synthesized using the antennas and models discussed above as array elements. 4 elements are chosen as a trade-off between performance and cost and a half-wavelength inter-element spacing is used. Sector shapes are only controlled and synthesized on the azimuth plane. All theoretical antenna models are given the 3GPP pencil beam-like elevation patterns with vertical HPBW of 7 degrees [5]. For both Kathrein models, their data sheets are directly used to produce an elevation pattern [6].

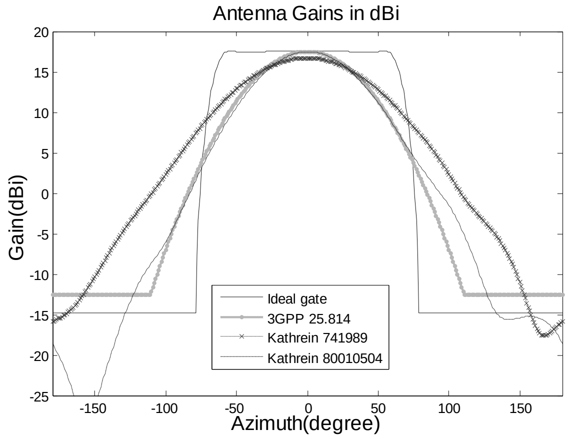

Fig. 1. Azimuth RP of Kathrein and 3GPP antennas

4. Macro-Cell Simulation

A system level WCDMA network simulator is used to examine the performance of the proposed shaping scheme. For comparison reasons antenna tilt angles are fixed to be 3.5° and the same traffic scenario is used for all antennas.

To model unbalanced traffic distributions, scenarios where User Equipments (UE) move and gather to form traffic hotspots are generated. The scenarios test adaptability of traffic load balancing techniques at increasing levels of traffic load and heterogeneity. Throughout each scenario, 100 snapshots of traffic distribution are taken (one minute apart) and discrete event simulation is carried out at the time of each snapshot. It is engineered that each snapshot represents the position to the previous one after an interval of 60 seconds. More precisely, the traffic model's configuration is:

- 16 Node-BS within the network, each has 3 sectors, cell radius = 0.5km.
- 8,000 UE uniformly geographically distributed in the network at the start of the simulation. 75% mobiles move and cluster and at the end of the simulation these UEs will end up in one of the traffic hotspots.
- 6 hotspots are being formed during the simulation and each has a population of 1,000 subscribers. The relative location of each MS within a hotspot is a sample from a normal distribution with a standard deviation of half the cell radius.

- A negative exponential call model is used for all the UE both for the time between connections and the duration of connections. The average connection duration is 120 seconds with an inter-call-arrival time of 720 seconds.

Using the same traffic and network setting, all 6 antenna elements are used to shape antenna power patterns. Identical power patterns are and used for transmit and reception antennas. The desired power patterns are calculated by the BOA shape-finding algorithm, and the BOA assumes that 18dBi azimuth gain is the most the antenna can output, so that the optimization only takes place within the possible search space and the shapes found are physically feasible.

The simulation results are compared with the performance of a conventional network deploying tri-sector base stations equipped with three fixed conventional antennas (Kathrein 741989), which gives each cell a circular coverage. Fig.2 illustrates the service probability of different networks, which declines for all networks as the hotspots form. All 6 schemes using optimized patterns perform better than circular coverage, and exhibit very similar performance. Overall, the choice of the element does not seem to have significant impact, although the closer the pattern is to a gate-function the better the result is. The pure desired pattern is also tested in the simulation, and its result is notably better than all synthesized patterns. Considering the results from the synthesized patterns are at most 3% worse, this is acceptable.

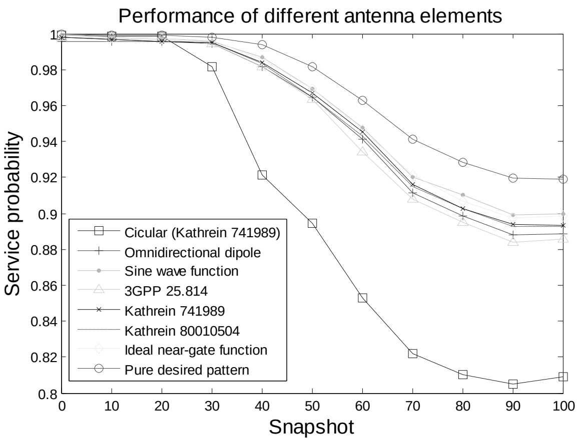

Fig. 2. Percentage of mobiles that can be served

The performance of different antennas is more or less correlated with their synthesis quality, which can be measured by the minimum MSE (MMSE) according to (3). In Fig.3, it is shown that the MMSE for all antennas are highest for the last snapshot. Indeed, the MMSE has a trend to increase with growing traffic heterogeneity. A simple guess is that the worse the performance in terms of service probability is, the higher the MMSE. This is generally correct from Fig.2 and Fig.3, but there is an exception that the ideal element has poorest MMSE in the last snapshot. This is probably because the ideal pattern rolls off to flat faster than all other patterns and has the highest FBR.

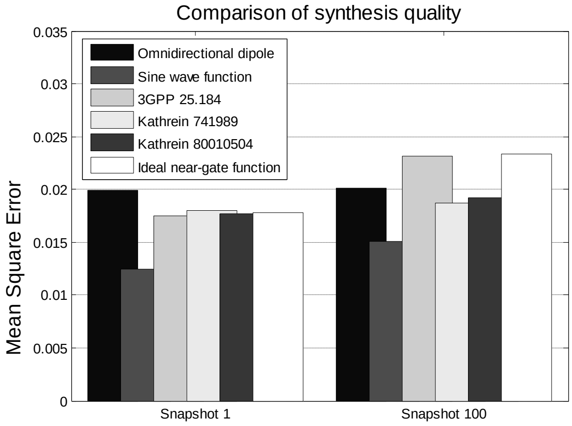

Fig. 3. MSE of shaping (averaged from 960 samples)

The greater the number of elements the better the performance. However, since even the pure desired pattern only yields 3% more capacity gain, large numbers of elements would not be necessary in practice.

5. CONCLUSIONS

A range of antennas are tested using an optimal synthesizer for their suitability and performance in shaping power patterns for a cooperative coverage scheme. The differences between the antennas was found to have little influence to what can be eventually shaped and on the service proability in a cooperative coverage scheme. The performance was within 3% of the ideal. This indicates that an adaptive coverage scheme is flexible and effective with even real antennas, and that such kind of a system is feasible.

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