Application of Adaptive Beamforming for UMTS FDD Mode for Macro-cell Environment

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Abstract – **The work presented in this paper explores utilisation of adaptive beamforming using uniform linear array and uniform circular array with conjugate gradient algorithm applied in UMTS FDD mode in macro-cell environment. For modelling of the propagation medium geometrically based single bounce circlular model has been used. The simulation environment has been prepared in MATLAB® for UMTS FDD mode, and a number of simulations has been performed. Terminal placement has been identified as being the most important issue for beamforming performance.**

Keywords – **beamforming, adaptive antennas, UMTS, conjugate gradient.**

I. Introduction

The aim of this work was to apply and simulate adaptive beamforming system for UMTS FDD mode, while this technology brings a number of advantages for communications systems. To reach this objective, one has to study each part of the system, decide how important it is, and how to model it. The most important issue of this work was to identify channel model parameters that have a major influence on the system's performance. There is a number of channel models which take into account various parameters. Statistical models such as e.g. gaussian wide sense stationary uncorrelated scattering model [1], or GSM simulation models [1] are quite simple and suitable for simulations while geometrically based models e.g. ray tracing models are much more precise but also more complex. Geometrically Based Single Bounced Circular Model (GBSBCM) [1] with some modifications widely described in [2] and [3] used in this work is a hybrid one giving the advantages of being quite precise as geometrical models are, remaining quite simple and useful for simulations. Several parameters, such as Mobile Terminals' (MTs) placement, distance between base station (BS) and mobile terminal (MT), the number of MTs or radius of the circle within the scattering occurs, has been extensively investigated.

Unlike in UMTS TDD mode described in e.g. [4], in FDD mode scrambling and spreading codes are not totally orthogonal [5]. It has been taken into account while it could have an impact on the overall system performance.

Moreover the differences between the uniform linear array (ULA) and uniform circular array (UCA) configurations have been examined aiming mainly at finding possible benefits of the latter as a result of its 360°- radiation pattern while the former can operate only in 180° range. This paper describes the main issues of the problem, analysis that has been performed and ends with overall conclusions.

II. Antenna Arrays

An adaptive antenna is an array of antennas, with patterns dynamically adjusted in terms of noise, interference, and multipath [1]. Such antenna can adjust its antenna pattern to enhance the desired signal, null or reduce interference, and collect correlated multipath power. Two different array configurations have been used in simulations and examined: Uniform Linear Array, and Uniform Circular Array. After preliminary calculations some parameter values have been identified to obtain similar pattern shapes. It has been verified that the pattern corresponding to 8 element ULA with ½ lambda element spacing is 12-element UCA with ¾ lambda element spacing.

III. Channel Model

The model used in simulations is based on GBSBCM [1], with some modifications described in more detail in [2], and veified by measurement campaign [3]. It consists of a set of clusters of scatterers, uniformly distributed in a circular area centred at each MT in a horizontal plane. It is assumed that there are no scatterers near the BS vicinity, according to fact that BS is placed higher than any MT in macro-cell scenario.

Furthermore, all scatterers and incoming waves are assumed to be at the horizontal level, hence no information on elevation angle is considered. Such approximation is considered valid , considering that a large spatial discrimination exists in the horisontal plane, while at the vertical plane is very small.

Clusters, comprising a group of scatterers, follow a uniform spatial distribution, and scatterers within each cluster following a Gaussian distribution around the central point. The number of scatterers within each cluster follows Poisson distribution. Scatterers are assumed to be omnidirectional re-radiating elements and assigned random complex scattering coefficients. It is also assumed that, when multipath signals

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travel between MT and BS, only single scatterer reflection occurs, therefore, no other effects such as rough surface scattering, diffraction, and multiple bounce by surfaces and volumes are accounted for.

Propagation channels are independent among all links. The DCIR (Directional Channel Impulse Response) is kept the same for all links at the same BS-MT distance, and independency is assured by generation of uniformly distributed phases for each link. In case of several MTs existing in the same scenario position, a few metres' separation is assumed and independent generation of phases is also performed to account for fast fading effects.

IV. ALGORITHMS AND CALCULATIONS

The choice of adaptive algorithm for deriving adaptive weights is highly important, in that it determines both the speed of convergence and hardware complexity required to implement the algorithm [6]. Non-blind adaptive algorithm is highly suitable for a WCDMA system, because the combination of spreading and channelisation code can be used as a reference for beamforming. For this work Conjugate Gradients (CG) algorithm has been chosen as it converges fast, has good numerical stability, is easy to implement and simulate and converges towards MMSE criterion [7]. CG implementation follows [8].

For each array element, for all active BS-MT links, and for each time and angle sample of the DCIR, each element of the channel matrix,**U,** is a product of: scrambling code, DCIR moduli, DCIR phase antenna AF. As a result matrices for all active links are obtained and are added with antenna thermal noise.

For each link *l*, the CG is applied to minimise the quadratic form:

$$\mathbf{f}_l(\mathbf{w}_l) = \frac{1}{2}\mathbf{w}_l^{H}\mathbf{R}\mathbf{w}_l - \mathbf{d}_l^{H}\mathbf{w}_l \qquad (1)$$

where $\mathbf{R} = \mathbf{U}^H\mathbf{U}$ ($M\times M$) is the correlation matrix, $\mathbf{d}_l = \mathbf{U}^H\mathbf{c}_l$ ($M\times 1$), and $\mathbf{c}_l$ ($N_s\times 1$) is the *l*th DesS code or sequence, whose elements correspond to each chip. All the *L* cost functions are minimised independently. The CG Normal Equation Residual (CGNR) problem:

$$\mathbf{U}^H\mathbf{U}\mathbf{w}_l = \mathbf{U}^H\mathbf{c}_l \qquad (2)$$

leads to a solution $\mathbf{w}_l$, minimising the residual error, $\left\|\mathbf{U}\mathbf{w}_l - \mathbf{c}_l\right\|$, i.e., towards MMSE [9], [10]. The rank *M* **R** matrix is symmetric and positive-definite, guaranteeing the CG convergence to the minimum residual error in at most *M* steps, theoretically. The calculation of Signal-to-Interference-plus-Noise-Ratio (SINR) for the *l*th link follows [8]:

$$SINR^{(l)} = \frac{P_{DesS}^{\ (l)}}{\dfrac{1}{G_p}\left(\sum_{l_T=1}^{L_T} P_{NDesI}^{\ (l)} + N_{th}\right)} \qquad (3)$$

where: G_p - CDMA processing gain (equal to the spreading factor, in this case, 128), P_{DesS} - DesS power, P_{NDesI} - NDesI power, N_{th} - total thermal noise power.

The Beamforming Gain (BG), G_{bf}, is defined as the SINR gain relative to the SINR achieved with a single omnidirectional antenna at the BS, for each of the *L* active links:

$$G_{bf}^{(l)} = SINR^{(l)}\Big|_{\text{beamformer}} - SINR^{(l)}\Big|_{\text{single}} \quad [dB] \qquad (4)$$

Due to the size of the matrices **R** and vectors **d**, leading to large computational time, most of the average calculations involve 100 totally independent DCIRs, with spatial cluster/scatterer distributions and reflection coefitients being independent between each DCIR concretisation. After preliminary simulations it was verified that increasing number of averaged calculations above this value does not affect results much. Averaging 100 concretisations wsa considered to be the lower limit in the sense of statistics, but also the upper limit in the sense of acceptable time of simulations.

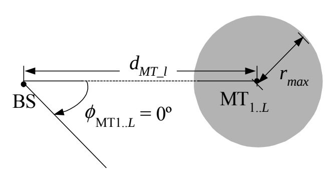
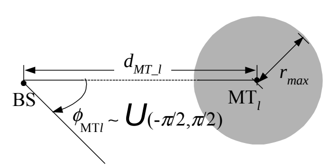
V. SCENARIOS

The macro-cell scenarios that have been chosen for simulations differ in angular positioning of MTs, their distance from BS, number of users or scattering region radius. All calculations have been performed for 4, 8, 16 and 32 users for scenarios M_a-M_f (scenarios M_b and M_e for 50 and 400 m only for 8 and 16 users), and for 16, 32 and 64 users for scenarios M_g and M_h.

Scenarios M_a-M_c (Table 1) give the opportunity to observe if the beamformer is able to work in environments of many signals arriving from common angles, very close to each other.

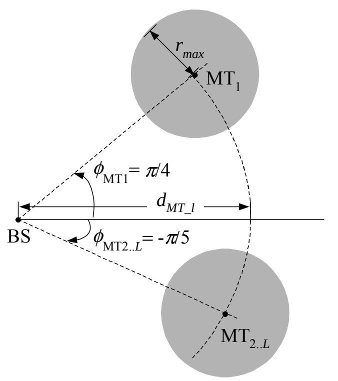
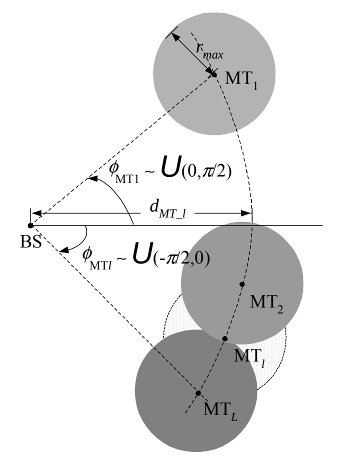
Scenarios M_d-M_f (Table 1) help to examine how an adaptive array deals with a large number of incoming signals from various directions, while the number of array elements becomes unefficient to create enough nulls for cancellation of undesired signals.

TABLE 1 – SIMULATION SCENARIOS

Sc #	d_{MT_l} [m]	r_{max} [m]	Scenario (not to scale):
M_a	1 000	200	
M_b	1 500	50 200 400	
M_c	2 000	200	
M_d	1 000	200	
M_e	1 500	50 200 400	
M_f	2 000	200	with independent ϕ_{MTl}, among links

Scenarios M_g and M_h (Table 2) aim at verifying how the beamformer performs when one of MTs is placed separately from others, i.e., DesS comes from one specific direction, and all NDesI come from one or more other directions; these can also show better if the beamformer sets weights to form a visually clear array pattern, while directions of DesS and NDesI are well distinguished. The same set of scenarios has been used for ULA and UCA simulations.

TABLE 2 – SIMULATION SCENARIOS (2)

Sc #	d_{MT_l} [m]	r_{max} [m]	Scenario (not to scale):
M_g	1 500	200	
M_h		200	

VI. ANALYSIS RESULTS

As expected, scenarios M_a-M_c showed up extremely difficult for the beamformer to solve, and it is hard to notice significant impact of smart antenna technology on receiving capability (Fig. 1 for ULA, Fig. 2 for UCA). Gain in these situations remains not larger that 5 dB, even for a very small number of users. Randomly spread scenarios bring BG to the order of 8 dB for the smallest number of users, slightly decreasing when the number of users increases (5 dB for 32 users). Moreover, they are independent of BS-MT distance, and only weakly dependent on the number of users; combined with the random nature of scenarios comprising this group it gives a more general view on the behaviour of BG when users are spread around BS, which is more likely in real world.

In scenarios M_g and M_h it is visible that gains (nearly 30 and 20 dB respectively) are well above the gains present in other groupings, which shows that having one separate MT is a big advantage, letting the beamformer to reach good performance by placing the main lobe precisely, simultanously cancelling major part of non-desired signals.

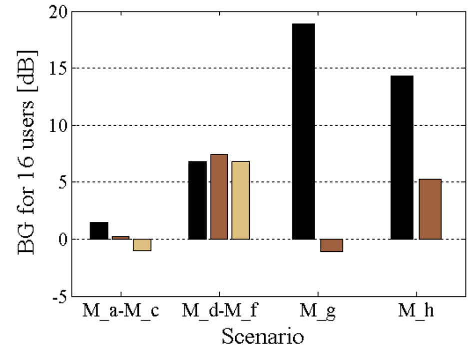


Fig. 1 – Results obtained for ULA array

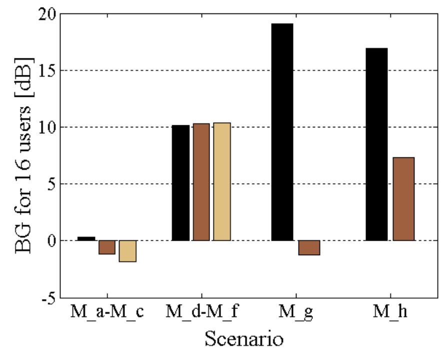


Fig. 2 - Results obtained for UCA array

The analysis shows that behaviour of ULA and UCA is very similar in each of simulated scenarios. Qualitatively both arrays behave in the same way, the only difference, in fact not that big, being in the quantitative comparison. Usually, when it happens, it is to the advantage of UCA, of which the clearest example is in scenario M_h, where the difference reaches nearly 5 dB. One should still notice that simulated scenarios does not allow to examine all capabilities of UCA in terms of main lobe placement in 360° range, thus some advantages of this array over ULA cannot be identified.

Examples of obtained radiation patterns are shown in Fig. 3 and Fig. 4 for ULA and UCA respectively. It kas been verified that for most of the situations, the best array patterns one can observe for 3rd – 4th CG iteration. This phenomenon can be explained with the difference between MMSE and optimum SINR or BG solutions. In MMSE solution, the $\mathbf{w}^H\mathbf{R}\mathbf{w}$ term in the cost function (1) involves not only the powers used in calculations of SINR, but also ones that do not contribute to the calculation of SINR. Several involved powers evolve differently, which implies that the MMSE may not lead to the best SINR and BG. Detailed analysis of the problem and composition of **R** can be found in [11].

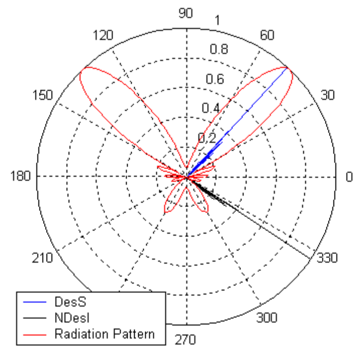


Fig. 3 – Example of a radiation pattern for ULA

The simulations have been made for the same conditions for ULA and UCA. The same DCIRs, the same random noise and phases has been used to analyse thoroughly the behaviour of both antennas. The scenario chosen for this comparison was M_g with the scattering circle radius of 50 m, since it is the most suitable and easiest for beamforming, showing capabilities of nulls and lobes placement.

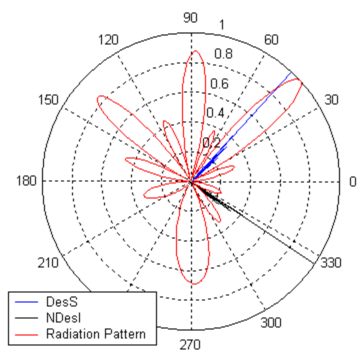


Fig. 4 – Example of a radiation pattern for UCA

VII. Conclusions

Mobile terminals' grouping has been identified as the issue being most important, and having the major impact on beamforming. Other issues, like scattering circle radius, BS-MT distance, or number of users does not have that much impact, modifying BG only by the order of magnitude of several dB. Analysis also showed that some scenarios have no or nearly no gain at all, while others have gains of 25-30 dB. These observations show that beamforming can really have very positive impact on receiving/transmitting, but one should be aware that is not always the case.

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