Direction of Arrival Estimation: Overview and Prospectives

Roald Goossens

Supervisor(s): Hendrik Rogier

Abstract— **This article discusses the direction-of-arrival estimation of plane waves impinging on an antenna array. Special attention is devoted to the incorporation of mutual coupling between the antenna elements of the array into the estimation algorithm. More complex antenna array configurations are considered, which have a better performance for direction-of-arrival estimation.**

Keywords—**Direction-of-arrival, array configuration, signal processing**

I. Introduction

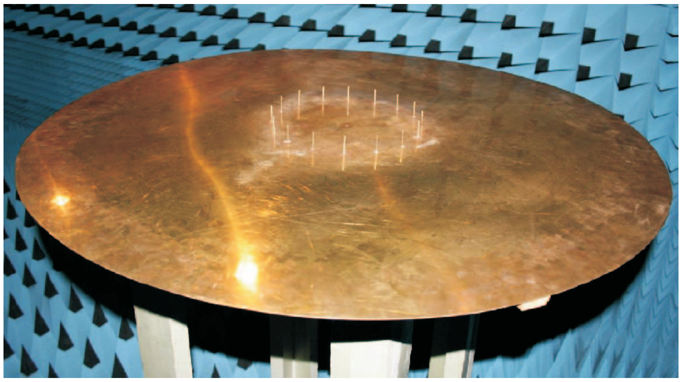
IN the last decades wireless communication is one of the most expanding technologies. The applications to communicate without wires are almost unrestricted. Besides the increasing number of mobile users, every wireless application requires more and more bandwidth. All these requirements tax the mobile communication system to the limit. One of the vital components of the mobile communication system is the antenna. In a first step a single antenna was replaced by an antenna array to increase the performance of the communication system. By means of an antenna array it is also possible to estimate the directions-of-arrival (DOAs) of plane waves, which impinge on the antenna array. The knowledge of the direction of the different mobile users enables us to adapt the radiation pattern of the antenna array such that interference between the mobile users is mitigated.

Several DOA estimation algorithms were already developed relying on basic array configurations, such as uniform linear antenna arrays (ULAS) [1] and uniform circular antenna arrays (UCAs) [2]. In most algorithms the effects of mutual coupling between antenna elements is not considered. When antenna elements are placed in an array structure, where the antenna elements are situated in the near-field region of the other antennas, the radiation characteristics of the antennas differ from the stand-alone radiation characteristics. Compensating for these mutual coupling effects in DOA estimation algorithms is a real challenge.

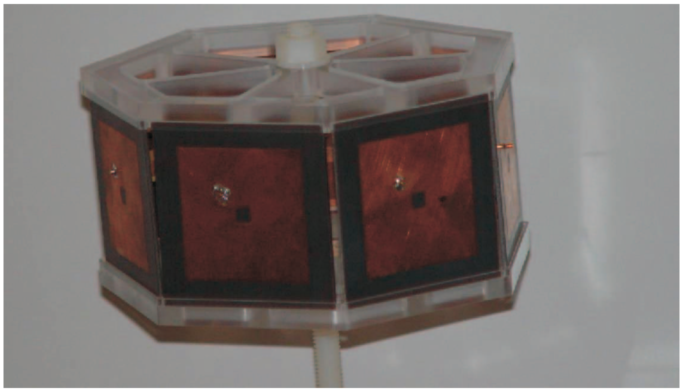
II. Uniform circular array

Uniform circular arrays have a prominent position in DOA estimation. Thanks to their circular symmetry, UCAs provide 360° azimuthal coverage and it is possible to develop DOA estimation algorithms which are numerical efficient. In Fig. 1 two examples of UCAs are shown, which were designed and built in our research group. The first UCA consists of 15 monopole elements, designed for the ISM-band covering the 2.4GHz - 2.483GHz range, and a circular ground plane. This antenna array is a uniformly polarized array and only detects signals that are vertically polarized. On the other hand, the second array is a diversely polarized array. It consists of 7 patch antennas and it is able to detect vertically as well as horizontally polarized plane waves. For both configurations we have developed DOA estimation algorithms which can deal with the mutual coupling effects.

R. Goossens is with the Department of Information Technology, Ghent University (UGent), Gent, Belgium. E-mail: Roald.Goossens@intec.UGent.be .



(a) UCA constructed by monopole elements in the presence of a circular ground plane



(b) UCA constructed by patch antennas

Fig. 1. Illustrations of the considered antenna array configurations.

A. UCA-RARE + Root-MUSIC

MUSIC [3] is a traditional superresolution eigenstructure technique for DOA estimation, which relies on the estimation of the signal subspace by performing a singular value decomposition of the data covariance matrix. To estimate the azimuth angle as well as the elevation angle of the impinging signals a computationally hard two-dimensional search over the MUSIC spectrum is required. We have developed a combined UCA-RARE / Root-MUSIC algorithm [4] that estimates the DOAs in two dimension where mutual coupling is incorporated. Although mutual coupling complicates the receiving antenna characteristics, a UCA is still attractive because a UCA can be designed such that all mutual coupling effects maintain the circular symmetry. In a first step the azimuth angles of the impinging signals are estimated by the UCA-RARE algorithm. The UCA-RARE algorithm is most appropriate for 2-D DOA estimation because it allows to estimate the azimuth angles without any knowledge of the elevation angles. Given these azimuth estimates, it is possible to estimate the elevation angles by a modified Root-MUSIC algorithm in elevation direction. Important to notice is that this algorithm is the only algorithm that is able to estimate the DOAs in two dimensions by calculating the roots of a polynomial, which is of course numerically easy. Moreover, it accounts for all mutual coupling effects.

B. Polarization

Using an array with diversely polarized antennas complicates the estimation of DOAs. Besides the azimuth and elevation angle, the polarization parameters of the impinging signals are unknown. The MUSIC algorithm transforms into a four-dimensional search over the MUSIC spectrum. For an arbitrary array configuration it is not evident to estimate the DOAs and the polarization parameters of the signals numerically efficient. In [5] we developed a rooting algorithm that estimates the azimuth angle and the polarization parameters considering a uniform circular array. Once more, special attention is devoted to the correct incorporation of all mutual coupling effects such that the algorithm stays applicable for future array configurations. There is the general trend to increase the number of antenna elements and reduce the size of antenna arrays, such that mutual coupling effects are more significant.

III. Complex antenna arrays

The research on DOA estimation using uniform circular arrays has resulted in several efficient estimation algorithms. However, some drawbacks of UCAs are detected. A UCA is not able to estimate the elevation angle of signals with high accuracy. In order that antenna arrays meet all the requirements of future applications, it is necessary to study more complex antenna array configurations. A first straightforward extension is a cylindrical array. This array exists of two UCAs placed above each other. In this configuration the circular symmetry is maintained and the algorithms developed for UCAs can be extended for cylindrical arrays. A cylindrical array collects more information about the elevation angle of the impinging signals, such that the elevation angle can be estimated with a higher accuracy.

Another configuration, which has a high degree of symmetry, is a spherical array [6]. While a UCA provides a 360° azimuthal coverage, a spherical array (see Fig. 2) provides full spherical coverage. The spherical symmetry in this array enables us to develop 2-D DOA estimation algorithms, where the accuracy of the DOA estimates does not depend on the DOA. A challenge, concerning spherical arrays, is the incorporation of all mutual coupling effects which is more complicated in this array configuration.

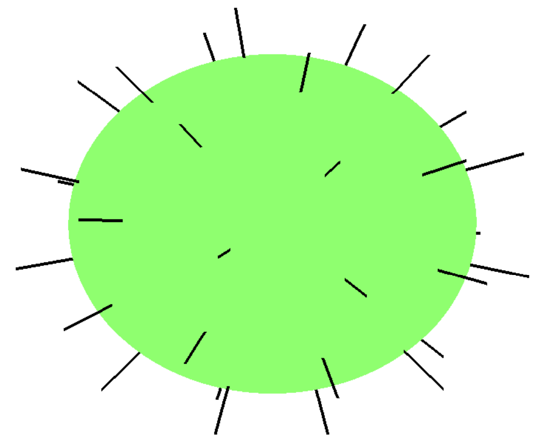


Fig. 2. Spherical antenna constructed by monopole elements.

IV. Conclusions

An overview is given about some aspects of DOA estimation. More in particular, the correct incorporation of mutual coupling effects in DOA estimation algorithms is discussed. This enables us to develop two algorithms for DOA estimation using uniform circular arrays. The combined UCA-RARE/Root-MUSIC algorithm is a root-based 2-D estimation algorithm, while the other proposed algorithm deal with the polarization of the impinging signals. The challenge for ongoing research is the development of DOA estimation algorithms for more complex antenna array configuration, which enable us to estimate the DOAs with a higher accuracy.

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Roald Goossens
Supervisor(s): Hendrik Rogier

Estimating the directions of arrival of plane waves impinging on an antenna array is an important issue in mobile communication systems. The knowledge of the directions of arrival can tremendously improve the performance of the communication system. To obtain accurate estimates several computationally efficient algorithms are developed in recent years. The detailed electromagnetic character of the antenna array in receive mode, including mutual coupling between the antenna elements of the array, is often neglected. A method to incorporate a full detailed electromagnetic description into the estimation algorithm is proposed considering a uniform circular antenna array. Furthermore special attention is given to more complex antenna array configurations, which have the possibility to still deliver estimates of the directions of arrival in a numerically efficient way and with a higher accuracy than uniform circular arrays.

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