ADAPTATION OF THE ELEMENT RADIATION PATTERN IN THE SAGE ALGORITHM FOR A CUBICAL AND A DODECAHEDRAL RECEIVING ANTENNA ARRAY

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ABSTRACT

For measurement purposes, not only the type of antenna but also the position and the polarisation of the antenna in the antenna array are very important. In most simulations and measurements, the antennas are having all the same polarisation and a nearly omnidirectional radiation pattern. In this paper, the radiation pattern of an antenna array will be included in the SAGE algorithm. By applying this algorithm on simulated or measured data, the time domain values of the Direction of Arrival (DOA) parameters can be determined very accurately. Here, the extracted parameters are the time delay or the distance, the azimuth angle, the elevation angle and the complex amplitude or the power for every significant path. The simulations are based on a previously described hexahedral and dodecahedral antenna array with monopole antennas in different polarisations. The simulation results show the influence of the element pattern on the performance of the SAGE algorithm.

INTRODUCTION

Increasing the performance and the accuracy of the telecommunication system is a very important issue in the booming world of wireless communication. One possible solution is taking into account the type of antenna, the position and the polarisation of the antenna in the antenna array and by including them in the radiation pattern, which is a part of the steering vector in high resolution Direction of Arrival (DOA) techniques. Hence the performance can be improved.

In a first part of this paper, the Space Alternating Generalised Expectation maximisation (SAGE) algorithm (described in [1]) will be explained. This SAGE algorithm is implemented in the time domain using training sequences and is used to replace the highly dimensional optimisation procedure necessary to compute the joint maximum likelihood estimate of all the parameters by several separate maximisation processes, which can be performed sequentially. By applying the described algorithm on simulated or measured data, the DOA parameters can be determined.

After this theoretical explanation, the at our university available ray-tracing tool ”Enhanced Propagation for Indoor Communication Systems (EPICS)”(described in [2]) will be used to generate the necessary simulation data. This EPICS software is able to calculate the received power or signal in a point or a trajectory of points in different indoor and outdoor environments by taking into account electromagnetic phenomena such as penetrations, reflections, diffractions, etc. and combinations of those phenomena. The resulting simulated data in the frequency domain, is transformed to the time domain and a training sequence is included, necessary for the time domain SAGE algorithm.

SAGE ALGORITHM

The Direction of Arrival (DOA) parameters to be estimated, can be limited to the time delay $\hat{\tau}_l$, the azimuth angle $\hat{\phi}_l$ of the incident wave, the elevation angle $\hat{\theta}_l$ of the incident wave and the complex amplitude $\hat{\gamma}_l$. These parameters are placed together in a vector $\hat{\zeta}_l$. The different incident waves form L different $\hat{\zeta}_l$, because the number of paths is L. These vectors are all stacked together in the matrix $\hat{\zeta}$. Each step of the SAGE algorithm is an estimate of a subset of the components of $\hat{\zeta}$, while keeping the estimates of the other components fixed.

The main part of the algorithm is the correlation function $z(\hat{\tau}_l, \hat{\phi}_l, \hat{\theta}_l, \hat{x}_l(t;\hat{\zeta}))$, which is defined as follows:

$$z(\hat{\tau}_l, \hat{\phi}_l, \hat{\theta}_l, \hat{x}_l(t;\hat{\zeta})) = [c(\hat{\phi}_l, \hat{\theta}_l)]^H \int u^*(t' - \hat{\tau}_l)\hat{x}_l(t';\hat{\zeta})dt' \tag{1}$$

with $u(t)$ the desired signal (based on the training sequence), corrected with an estimate of the time delay $\hat{\tau}_l$. This correlation function between the calculated and received signal, is the cost function that has to be maximised:

$$\hat{\tau}_l^{'} = \arg\max_{\tau}\{|z(\tau, \hat{\phi}_l, \hat{\theta}_l, \hat{x}_l(t;\hat{\zeta}))|^2\} \quad (2)$$

$$\hat{\phi}_l^{'} = \arg\max_{\phi}\{|z(\hat{\tau}_l^{'}, \phi, \hat{\theta}_l, \hat{x}_l(t;\hat{\zeta}))|^2\} \quad (3)$$

$$\hat{\theta}_l^{'} = \arg\max_{\theta}\{|z(\hat{\tau}_l^{'}, \phi_l^{'}, \theta, \hat{x}_l(t;\hat{\zeta}))|^2\} \quad (4)$$

$$\hat{\gamma}_l^{'} = \frac{1}{N_a T_a} z(\hat{\tau}_l^{'}, \hat{\phi}_l^{'}, \hat{\theta}_l^{'}, \hat{x}_l(t;\hat{\zeta})) \quad (5)$$

where the prime variables denote the new values after the iteration. After each step the estimation vector $\hat{\zeta}$ is updated with the last calculation. The received signal $\hat{x}_l(t;\hat{\zeta})$ of one user is calculated based on the received global signal $y(t)$ and based on the estimates of the signals $s(t;\hat{\zeta}_{l'})$ of the other interfering sources:

$$\hat{x}_l(t;\hat{\zeta}) = y(t) - \sum_{\substack{l'=1 \\ l' \neq l}}^{L} s(t;\hat{\zeta}_{l'}) \quad (6)$$

$$s(t;\hat{\zeta}_l) = \hat{\gamma}_l \cdot c(\hat{\phi}_l, \hat{\theta}_l) \cdot u(t - \hat{\tau}_l) \quad (7)$$

For every significant path l, the steering vector $c(\hat{\phi}_l, \hat{\theta}_l)$ is defined as follows:

$$c(\hat{\phi}_l, \hat{\theta}_l) = e^{j\frac{2\pi}{\lambda}|r_i - r(\hat{\phi}_l, \hat{\theta}_l)|} / P(r_i - r(\hat{\phi}_l, \hat{\theta}_l)) \quad (8)$$

with $\hat{\phi}_l$ an estimate of the azimuth angle of path l, with $\hat{\theta}_l$ an estimate of the elevation angle of path l, with r_i the location of element i of the antenna array, with $r(\hat{\phi}_l, \hat{\theta}_l)$ the location of the different paths based on the estimations of the azimuth angle and elevation angle. $P(r_i - r(\hat{\phi}_l, \hat{\theta}_l))$ stands for the received incident power for path l on antenna element i. It is calculated from the received incident electromagnetic field, with the radiation pattern included. This antenna array pattern takes into account the type of antenna, the position and the polarisation of the antenna in the antenna array.

SIMULATION SET-UP

The simulation set-up is based on a real indoor measurement set-up at the University of Kassel [3]. The used bandwidth is 600 MHz at a carrier frequency of 5.2 GHz. Instead of using measurement data, the configuration set-up will be modelled with the EPICS program, a ray-tracing tool available at our university, resulting in simulated data. The size of the room is 8.17 m on 8.73 m. The floor and the ceiling do not exist in this example. The transmitter is indicated as Tx and vertically polarised; the receiving antenna array is plotted as Rx.

The 438 EPICS generated frequency points are interpolated to 4095 points, the same amount as the training sequence. After this interpolation, the frequency data is transformed to the time domain, because the SAGE algorithm is implemented as a time domain algorithm. The input consists of the received signal in the time domain, the position of each antenna and the PN-code sequence. Finally, the DOA parameters are extracted with the SAGE algorithm.

In Fig. 1(a), the simulation set-up for the cubical configuration is depicted. The receiving antenna array consists of 6 monopole antennas, where the coordinates can be found in Table 1, as described in [4]. Antenna 1 and 4 are polarised in the z-axis, antenna 2 and 5 are polarised in the y-axis and antenna 3 and 6 are polarised in the x-axis. As can be seen, the different antennas are placed slightly excentric of the centre (1.895 m, 5.815 m, 1.600 m) in order to include some phase information for the steering vector. Otherwise, the vertically (z-axis) polarised antennas, i.e. antenna 1 and 4 would have the same position in the x-y-plane, and DOA parameter estimation would have been very difficult.

	x	y	z		x	y	z
Antenna 1	1.925 m	5.845 m	1.640 m	Antenna 4	1.865 m	5.785 m	1.560 m
Antenna 2	1.925 m	5.855 m	1.630 m	Antenna 5	1.865 m	5.775 m	1.570 m
Antenna 3	1.935 m	5.845 m	1.630 m	Antenna 6	1.855 m	5.785 m	1.570 m

Table 1: Hexahedral receiving antenna array coordinates.

For the dodecahedral configuration, the simulation set-up is depicted in Fig. 1(b). The receiving antenna array is plotted as Rx and consists of 12 monopole antennas, with equal sized pentagons as ground planes. The coordinates can

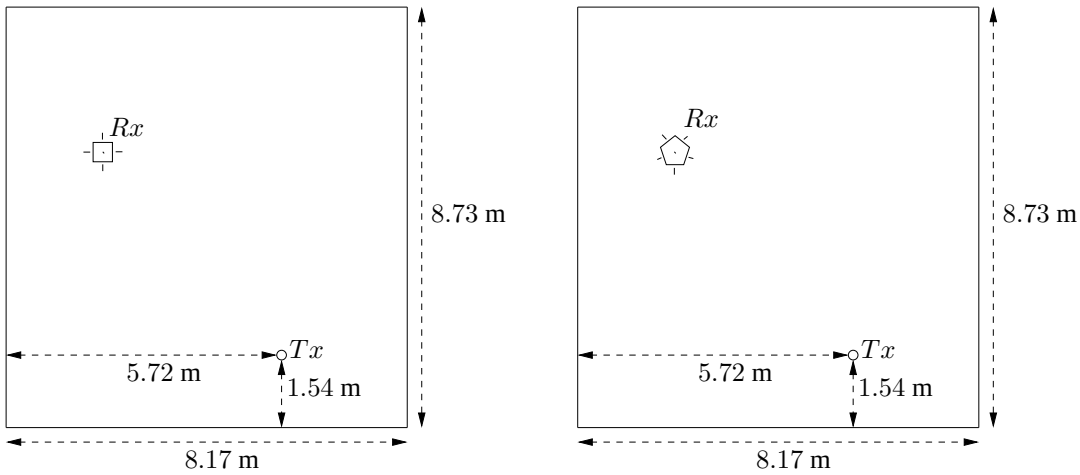

Figure 1: The simulation set-up with cubical (left) and dodecahedral (right) receiving antenna array.

be found in Table 2, as described in [4]. The centre of the antenna array is (1.895 m, 5.815 m, 1.600 m). Antenna 1 is the highest one and polarised in the z-axis. Antenna 2, 3, 4, 5 and 6 are placed slightly lower and not only polarised in x- and y-direction but also in the z-axis. Antenna 7, 8, 9, 10 and 11 are placed lower and polarised in the three main directions. The last antenna, antenna 12 is the lowest one and polarised in the (negative) z-axis.

	x	y	z		x	y	z
Antenna 1	1.8950 m	5.8150 m	1.6415 m	Antenna 7	1.9250 m	5.8368 m	1.5815 m
Antenna 2	1.9321 m	5.8150 m	1.6185 m	Antenna 8	1.8835 m	5.8503 m	1.5815 m
Antenna 3	1.9065 m	5.8503 m	1.6185 m	Antenna 9	1.8579 m	5.8150 m	1.5815 m
Antenna 4	1.8650 m	5.8368 m	1.6185 m	Antenna 10	1.8835 m	5.7797 m	1.5815 m
Antenna 5	1.8650 m	5.7932 m	1.6185 m	Antenna 11	1.9250 m	5.7932 m	1.5815 m
Antenna 6	1.9065 m	5.7797 m	1.6185 m	Antenna 12	1.8950 m	5.8150 m	1.5585 m

Table 2: Dodecahedral receiving antenna array coordinates.

SIMULATION RESULTS

In this section, the simulation results will be described. The 5 rays with the highest power are selected by the SAGE algorithm and plotted as asterisks in the following figures. Please note the grading colours: red means high received power, green is the intermediate power level and blue stands for low received power. These results have to be compared with the results (plotted in circles) of the ray tracing tool EPICS. The same colour convention is used and the results from both SAGE and EPICS are normalised to the same value. Of course, the estimation of the time delay $\hat{\tau}$ is multiplied with the speed of light, resulting in an estimation of the distance $\hat{d}$. So, the results of the SAGE algorithm can be more easily compared with the results of EPICS and with the geometrical configuration.

For the cubical receiving antenna array, the received power as a function of the azimuth angle and distance is plotted in Fig. 2(a), and as a function of the elevation angle and distance in Fig. 2(b). In contrast for the dodecahedral configuration, the received power as a function of the azimuth angle and distance is plotted in Fig. 3(a), and as a function of the elevation angle and distance in Fig. 3(a).

As one can see, the DOA parameter extraction with the SAGE algorithm matches the ray-tracing results from EPICS very accurately. The rather small differences between the estimations and the reference values can be explained by the fact that all rays (the direct ray and the single, the double and the triple reflections) are taken into account for the evaluation with EPICS and not all of them are modelled by the SAGE algorithm.

CONCLUSIONS

In this paper, we described in a first part the DOA parameter estimation with the SAGE algorithm. The radiation pattern, included in the steering vector, takes into account not only the type of the antenna but also the position and the

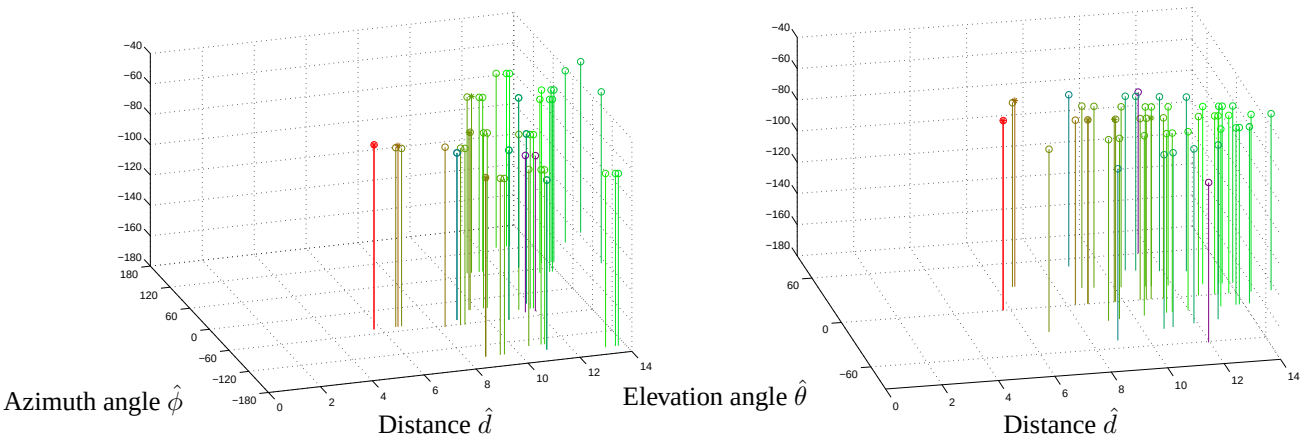

Figure 2: Azimuthal and elevation simulation results with cubical array: SAGE (asterisks) versus EPICS (circles).

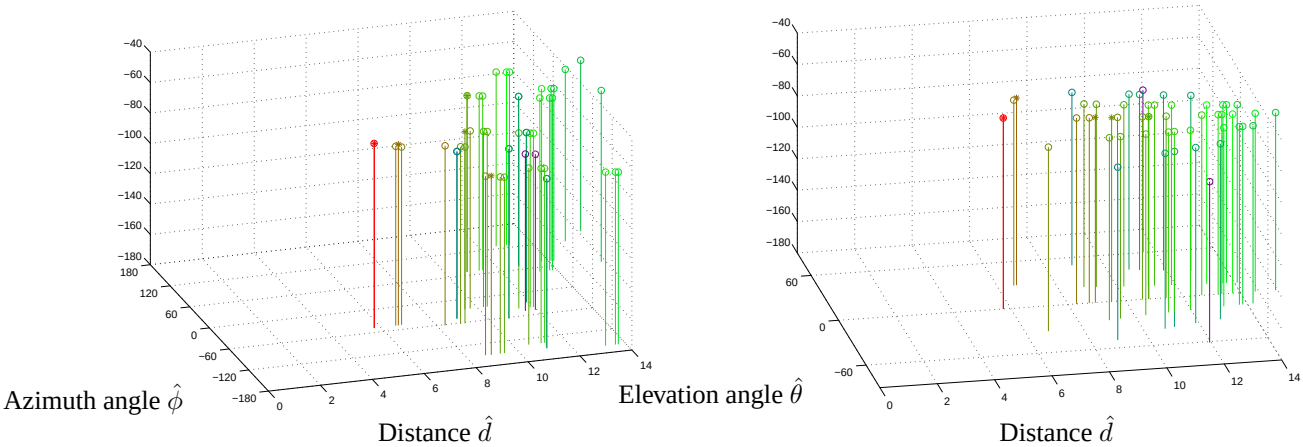

Figure 3: Azimuthal and elevation simulation results with dodecahedral array: SAGE (asterisks) versus EPICS (circles).

polarisation of the antenna in the antenna array. Instead of antennas with all the same polarisation, resulting in a nearly omnidirectional radiation pattern, a smarter antenna array design (the hexahedral and the dodecahedral configuration) was modelled. The antenna array with different polarisations and the indoor propagation channel, simulated with the ray-tracing tool EPICS, shows that everything works fine. The time delay (or the distance), the azimuth angle, the elevation angle and the complex amplitude (or the power) of the significant paths are accurately extracted. The simulation results show the high performance of the SAGE algorithm.

REFERENCES

[1] J. Verhaevert, E. Van Lil, and A. Van de Capelle, "Direction of Arrival (DOA) Parameter Estimation with the SAGE Algorithm", *Elsevier Signal Processing*, vol. 84, no. 3, pp. 619–629, March 2004.

[2] I. De Coster, G. Añon Madariaga, B. Pazos Souto, E. Van Lil, and F. Pérez-Fontán, "An Extended Propagation Software Package For Indoor Communication Systems", in 9th *International Conference on Antennas and Propagation (ICAP 1997)*. 14–17 April 1997, pp. 2.298–2.301, IEE, Edinburgh, UK.

[3] R. Kattenbach and D. Weitzel, "Wideband Channel Sounder for Time-Variant Indoor Radio Channels", in *Millennium Conference on Antennas & Propagation (AP2000)*, 9–14 April 2000, pp. P1182.1–4, Davos, Switzerland.

[4] J. Verhaevert, E. Van Lil, and A. Van de Capelle, "Three-Dimensional Monopole Antenna for Direction of Arrival Determination", *IEE Proceedings of Microwave, Antennas and Propagation*, vol. 151, no. 2, pp. 121–126, April 2004.