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Blind Localization of Mobile Terminals in Urban Scenarios

ABSTRACT

Locating mobile terminals in cellular radio networks offers a variety of new applications in everyday live and, moreover, is very valuable in emergency cases. We consider to tackle the localization task with help of a smart antenna at the base station. We propose a blind localization approach in multipath scenarios which needs only further information about the locations of the main scattering objects, e.g. buildings. We use the additional information from a 2-D electronic data base of the environment and combine it with simple ray-tracing elements.

1. INTRODUCTION AND BOUNDARY CONDITIONS

Our research aims at estimating the locations of individual mobile users. For the problem of geolocating mobile units within a cellular infrastructure a number of position location algorithms are presented in [1],[2],[5]. However, here we focus on the blind case, i.e. we do not exploit mobile system specific information contained in the signals. The localization task will be carried out with one observation station which is equipped with an antenna array, e.g. described in detail in [3], allowing to estimate the Directions of Arrival (DoA) and the relative delays of the incoming signals from the mobile terminals. The urban scenario affected by the multipath propagation and the blind observation complicates the localization task. This results in the following boundary conditions:

- The transmitted signals (as well as training sequences) are unknown. This leads to a blind estimation problem concerning the channel parameters.
- The blind case implies no synchronization between the observation and mobile stations. Therefore, we have no information about the absolute delay and range respectively.
- The considered mobile communication system uses CDMA as multiple access technology [4]. This causes an unknown multi-user interference.
- The signal amplitudes of different mobile stations differ at the observation station due to the power management.

The treatment of the blind estimation problem is not the topic of our discussion. We assume to receive the estimated multipath parameters from some kind of blind estimator. In the following we limit ourselves to the discussion of only one mobile station, i.e. we assume some kind of preprocessing in order to separate the individual signals. In [17] we have shown that the information included in the measured multipath parameters is not sufficient to solve the blind localization task. Therefore we have proposed to use additional sources of information like aerial photos and urban maps. In the second section we will discuss the proposed localization algorithm briefly and in the third section we will test it on the measured data. In the fourth section we will summarize the test results and give an outlook of our future research.

2. LOCALIZATION ALGORITHM

The algorithm proposed in [17] consists of two processing steps. In the first step we simulate the environment by 2D-objects representing buildings which allows us to generate the path parameters for arbitrary mobile station positions. As a generating mechanism we use a ray-optical wave propagation tool herein after referred to as geometrical modeling approach. The basic principle of the implemented geometrical modeling approach was taken from [7]. However it was simplified and adjusted to our problem.

In the second step we define the likelihood function which incorporates the proximity between the generated path parameters within the geometrical modeling approach from an arbitrary transmitter position and the measured path parameters from measurements with the antenna array. In the calculation of the proximity between the calculated and measured path parameters we consider on the one hand errors in the measured path parameters and on the other hand modeling errors within the geometrical modelling approach which may produce a different number of multipath components depending on the accuracy of modeling the environment.

We arrange the measured path parameters in a parameter vector which has the following form:

$$\mathbf{z} = \left[\tau_1 \ldots \tau_P \quad \varphi_1 \ldots \varphi_P\right]^{\mathrm{T}}, \tag{1}$$

where $P \in \mathrm{N}$ is the number of estimated multipaths. Each multipath $p = 1 \ldots P$ is characterized by its relative delay $\tau_p \in \left[0 \quad \ldots \quad \tau_{\max}\right]$ and the azimuthal direction of arrival $\varphi_p \in [-\pi \quad \dots \quad \pi]$. Each estimated parameter has a corresponding standard deviation which implies the uncertainties due to the finite sampling rate, the calibration errors at the receiver, the given signal-to-noise ratio, and due to the errors of the blind estimation algorithm. We collect the standard deviations in the vector:

$$\boldsymbol{\sigma} = \left[\sigma_{\tau_1} \dots \sigma_{\tau_P} \quad \sigma_{\varphi_1} \dots \sigma_{\varphi_P}\right]^{\mathrm{T}}, \tag{2}$$

whereby σ_{τ_p} corresponds to τ_p and σ_{φ_p} corresponds to φ_p respectively. Now we assume a transmitter position:

$$\mathbf{s} = [x \quad y]^{\mathrm{T}}, \tag{3}$$

specified by two Cartesian coordinates. For the assumed transmitter position $\mathbf{s}$ we generate the corresponding parameter vector:

$$\tilde{\mathbf{g}}(\mathbf{s}) = \left[\tilde{\tau}_1 \dots \tilde{\tau}_M \quad \varphi_1^* \dots \varphi_M^*\right]^{\mathrm{T}}, \tag{4}$$

by means of the geometrical modeling approach. M is the number of generated multipaths, $\varphi_m^* \in [-\pi \quad \dots \quad \pi]$ with $m = 1 \dots M$ is the generated azimuthal direction of arrival, and $\tilde{\tau}_m \in [\tilde{\tau}_{\min} \quad \dots \quad \tilde{\tau}_{\max}]$ is the generated absolute delay since we obtain the whole path length from the geometrical modeling approach. In order to obtain the relative delays we subtract the absolute delay of the first incoming generated multipath component from the multipath delays in (4) in the following way:

$$\tau_m^* = \tilde{\tau}_m - \tilde{\tau}_{\min}, \tag{5}$$

and define the vector with generated parameters corresponding to the transmitter position $\mathbf{s}$:

$$\mathbf{g}^*(\mathbf{s}) = \left[\tau_1^* \dots \tau_M^* \quad \varphi_1^* \dots \varphi_M^*\right]^{\mathrm{T}} \tag{6}$$

with $\tau_m^* \in [0 \dots \tau_{\max}^*]$.

Now we want to derive the statistical weight which expresses the probability that the measured multipath components have been radiated from the assumed transmitter position $\mathbf{s}$. Therefore we compare the generated parameter vector $\mathbf{g}^*(\mathbf{s})$ with the measured parameter vector $\mathbf{z}$. Since their dimensions can be different we propose to match them “path wise”. Therefore we define the following bivariate Gaussian distribution to describe the proximity between the measured multipath p and the generated path m:

$$N\left(\boldsymbol{\mu}_m^*(\mathbf{s});\boldsymbol{\mu}_p,\mathbf{C}_p\right)=\frac{1}{\sqrt{|2\pi\mathbf{C}_p|}}\exp\left\{-\frac{1}{2}\left(\boldsymbol{\mu}_p-\boldsymbol{\mu}_m^*(\mathbf{s})\right)^{\mathrm{T}}\mathbf{C}_p^{-1}\left(\boldsymbol{\mu}_p-\boldsymbol{\mu}_m^*(\mathbf{s})\right)\right\}, \tag{7}$$

$\boldsymbol{\mu}_p=\begin{bmatrix}\varphi_p & \tau_p\end{bmatrix}^{\mathrm{T}}$ is the mean value, which contains the measured DoA and the relative delay of the p-th multipath. The related covariance matrix $\mathbf{C}_p=\begin{bmatrix}\sigma_{\varphi_p}^2 & 0\\ 0 & \sigma_{\tau_p}^2\end{bmatrix}$ contains the estimated standard deviations of the DoA and the relative delay related to the p-th multipath defined in (2). $\boldsymbol{\mu}_m^*(\mathbf{s})=\begin{bmatrix}\varphi_m^* & \tau_m^*\end{bmatrix}^{\mathrm{T}}$ is the parameter pair of the m-th generated multipath.

Ideally there is exactly one generated multipath m which corresponds to the measured multipath p. It is obvious that the maximum value of (7) indicates the most probable combination of the measured and generated multipath. We propose the following method in order to find the unique and most probable association between the estimated and generated paths. We calculate:

$$\nu_{m,p}=N\left(\boldsymbol{\mu}_m^*(\mathbf{s});\boldsymbol{\mu}_p,\mathbf{C}_p\right), \tag{8}$$

for all index values of m and p and define the matrix:

$$\mathbf{W}=\begin{bmatrix}\nu_{1,1} & \cdots & \nu_{1,P}\\ \vdots & \ddots & \vdots\\ \nu_{M,1} & \cdots & \nu_{M,P}\end{bmatrix}, \tag{9}$$

In the next step we search for the maximum value of all matrix elements in $\mathbf{W}$:

$$\eta_1=\nu_{m,p}=\max(\mathbf{W}). \tag{10}$$

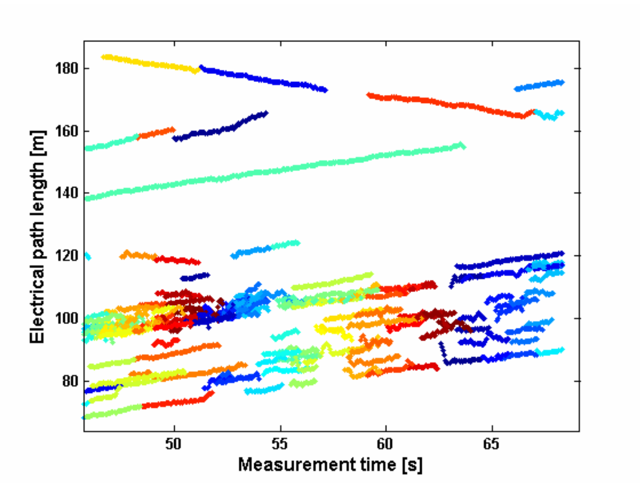
We store the individual weight η_1 of the estimated multipath p and eliminate the m-th row and the p-th column from $\mathbf{W}$ in order to achieve the unique association between the measured and generated parameter pairs. Then we repeat the maximum search with the reduced matrix $\mathbf{W}$ in which the m-th generated multipath and the p-th measured multipath have been removed. After P search iterations we obtain P individual weights $\eta_r(\mathbf{s})$ with $r=1\ldots P$. We should mention that we can always fulfil the condition $M\geq P$ by increasing the interaction order. We define the total likelihood function as the sum over the individual multipath weights:

$$w(\mathbf{s})=\sum_{r=1}^{P}\eta_r(\mathbf{s}). \tag{11}$$

We have rejected the conventional product formulation for the complete cost function because in this case a single multipath component calculated with the geometrical modeling approach from the exact transmitter position which is wrong due to modelling errors of the environment, yields a vanishing individual weight $\eta_p(\mathbf{s})$ and hence would decrease drastically the joint weight even if the remaining individual weights are significant. In the next section we will show some measurment results.

3. MEASUREMENT RESULTS

The proposed localization algorithm is applied to measurements obtained with the multidimensional RUSK channel sounder during a measurement campaign in Ilmenau [11], [12]. The fixed receiver equipped with an 8 element dual polarized Uniform Linear Array (PULA) has collected the signal radiated by the mobile transmitter endowed with the 16 element Uniform Circular Array (UCA). A multidimensional channel sounder is the measuring device that allows the observation of the time-varying multipath channel impulse response [13], [18]. From the measured channel impulse response it is possible to extract the multipath parameters. The estimation of the multipath parameters was carried out by the RIMAX algorithm which is a high-resolution modified ML parameter estimator [14]. In order to achieve a higher accuracy of the localization result the multipath parameters have been tracked along the observation time [15], [16]. There are diverse multipaths which are not persistent and it is mostly not easy to give a plausible geometrical interpretation of their parameters. The tracking procedure decreases the number of such statistically unreliable multipaths since for the localization purposes we use only those with a certain minimum duration. Fig. 1 shows an example of a RIMAX-delay estimation subsequently processed with the linear Kalman filtering algorithm [8], [9], [10]. Hereby we plotted the delays of multipaths with a “lifetime” of at least 20 snapshots corresponding to a measurement period of approximately 0,6 seconds. A path track is labelled by a uniquely assigned path number which is indicated by different colours. In Fig. 2 we show the corresponding measurement scenario as well as the approximate trajectory of the transmitter (Tx) and the receiver position (Rx). The buildings are represented by polygons which were obtained from the city map of moderate quality. These polygons build the additional geometrical information which is essential for the localization algorithm as shown in [17].



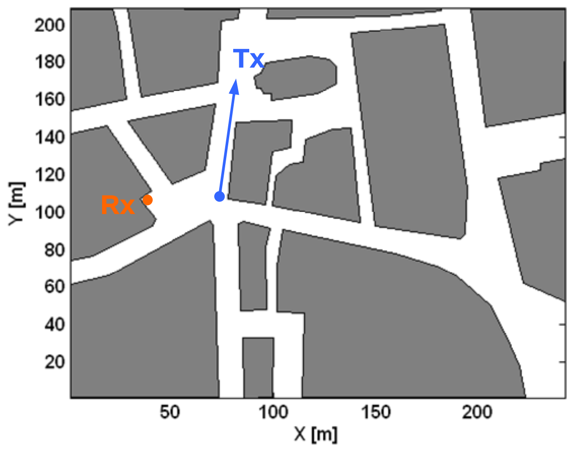


Fig. 1: RIMAX-delay estimation after Kalman filter processing

Fig. 2: Measurement scenario

The channel sounder measurements in combination with the tracking parameter estimator is an excellent experimental platform for the localization task since it enables very accurate delay and DoA estimation on the one hand and on the other hand it is possible to vary the system bandwidth and thus the accuracy of the estimated parameters. That is, it is possible to choose a constellation most similar to the real conditions; however in this paper we used the full bandwidth of 120 MHz. Moreover, the channel sounder allows the measurement of the double-directional structure of the multipath channel which includes joint DoA/DoD (Direction of Departure) estimation. Since the multipath channel is invertible, we can exchange the transmitter and receiver sides. E.g. in the following we have assumed the observation station at the transmitter side and the mobile terminal at the receiver side since we wanted to analyze a scenario with the moving observation and a static mobile station.

Since the measurement is synchronized we obtain the absolute delay. Therefore we subtract the absolute delay of the first incoming multipath component from all multipath delays in order to extract the relative delays.

In the next step we apply the procedure described in section (2) and calculate the likelihood function for each observation. As we have mentioned above we assume a scenario with an observation station moving along the trajectory plotted in Fig. 2 and a mobile station transmitting from the fixed unknown position. It is clear that the true position corresponds to the receiver position from Fig. 2. We have assumed an identical standard deviation of the measurement noise for all multipaths of $\sigma_\varphi = 5°$ and $\frac{\sigma_\tau}{c_{light}} = 5\,\mathrm{m}$.

Then we calculate the likelihood function for each position of the observation station at

1000 random points and interpolate it. Fig. 3 shows a contour representation of the likelihood function for one observation. We can see that there is no clear maximum. There are at least 3 areas for a probable location of the receiver station. Now, we sum up the single likelihood functions. The resulting likelihood function can be seen in Fig. 4. The maximum of this function lies very close to the true position of the receiver. We can conclude that due to the motion of the observation station we achieve a concentration of the likelihood function around the true receiver position and consequently a significant improvement of the localization result.

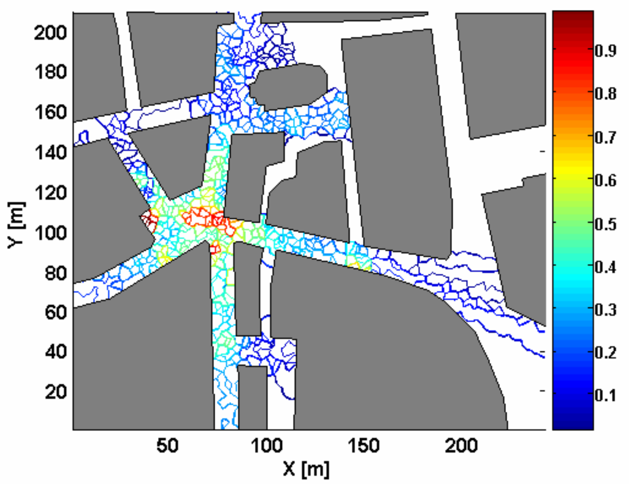


Fig. 3: Likelihood function after single observation

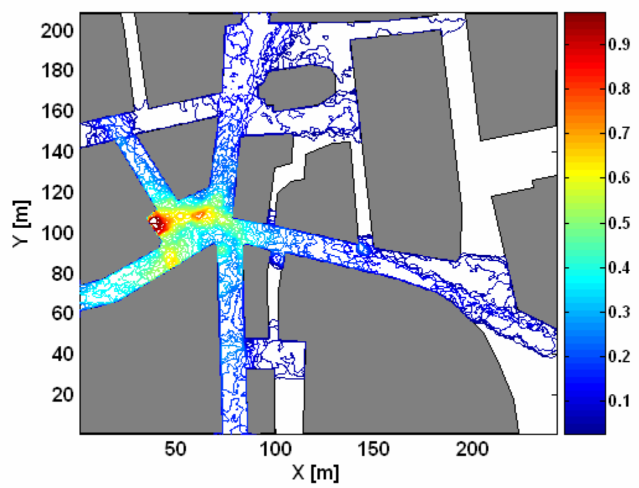


Fig. 4: Sum of the likelihood functions for the whole measurement.

4. CONCLUSIONS

In our contribution we have applied the localization algorithm proposed in [17] to the data measured by the RUSK channel sounder. In spite of the poor accuracy of the geometrical information retrieved from the urban map, the grossness of the approximation of the trajectory of the transmitter as well as the inaccurate adjustment of the antennas we have achieved a quite accurate localization result. Thus, it appears that the algorithm is applicable to real data and yields reliable and robust blind position estimations. The performance of the localization algorithm should be tested in different scenarios in order to substantiate the statement above. Furthermore, we should verify the performance of the algorithm in the case of reduced measurement bandwidth. A reduced bandwidth results in a decreased accuracy for the measured multipath parameters and, consequently, leads to harder estimation conditions. Finally, scenarios with a moving mobile station will be modeled and analyzed in future work.

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