A NEW TRILATERATION METHOD TO MITIGATE THE IMPACT OF SOME NON–LINE–OF–SIGHT ERRORS IN TOA MEASUREMENTS FOR MOBILE LOCALIZATION.

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ABSTRACT

In this contribution, a new Mobile Station (MS) localization method is provided using Time Of Arrival (TOA) measurements, in the UMTS-FDD downlink [5]. Contrary to the usual trilateration algorithms, the proposed method takes into account possible large TOA error measurements caused by Non-Line-Of-Sight (NLOS) and Near-Far-Effect (NFE). To this end, the new method measures the 'coherence' between the TOA estimates and allows the mobile to select the three most reliable measures among the whole available TOA measurements. Realistic simulations show the accuracy improvement provided by the proposed algorithm over a simple trilateration.

1. INTRODUCTION

Mobile localization is a growing practice in cellular communication systems and many applications are already forecasted: localizing traffic in order to balance the network, emergency interventions, etc. The main approaches proposed to locate a mobile are based on either Time-Of-Arrival (TOA) or Angle-Of-Arrival (AOA) [1]. In this paper, we are interested in localization based on TOA measurements as mobile operators are still, for the moment, reluctant to install antennae with several sensors (necessary for location based on AOA). The basic idea behind TOAs is to measure the time of flight of a signal propagating between a Mobile–Station (MS) and at least three Base-Station (BS) in order to obtain the mobile position. The performance of this approach depends strongly on:

- the accuracy of the estimation of time of arrivals obtained from at least three BS. This remark is particularly problematic for UMTS-FDD systems. Indeed, as all BSs (resp. MSs) transmit during all the time and on the whole bandwidth, power control algorithms are used in order to minimize the signal strength emitted and therefore to limit the interference level. Some TOA estimates, in particular those related to far-located BS, can therefore suffer from the so-called Near-Far-Effect (NFE).
- the existence of a Line Of Sight (LOS) path, which is not always verified in radio-mobile environments where obstacles can hide the LOS between the considered mobile and the BS.

To obtain a precise localization, it is therefore important to take into account these two problems (NFE and NLOS).
As far as NFE is concerned, a solution based on a robust channel estimation has already been proposed in [2] which reduces the influence of the NFE on TOA measurements, particularly those related to far-located BSs.
Concerning the NLOS, the problem is much more complex as it is difficult to detect and therefore to model this phenomenon. The classical solution to this problem consists in trying to have more measures than necessary, in order to mitigate the effect of some wrong measures using trilateration. However, if for example, only one of all the measures is erroneous, the trilateration will reduce the mobile location performances, as shown by the simulation examples in this paper. As a consequence, we propose a new solution which, in addition to keeping a very simple implementation architecture of usual trilateration techniques, enables us to identify some strongly erroneous TOA measurements. The mobile position is then obtained only from the three most reliable TOA among the set of all TOA estimates.
The paper is organized as follow: In section 2, the TOA estimation algorithm is presented. Then, in section 3, the principles of the new selection algorithm complying with the UMTS–FDD standard constraints are described. Finally, in section 4, some simulations, using an implemented UMTS-FDD simulator, will show the improvement in mobile location performances brought by the new algorithm compared with a traditional trilateration, in particular in situations when NLOS or NFE problems appear.

2. TOA ESTIMATION

In this section, the model of the UMTS–FDD downlink signals is recalled. Note that the TOA approach works also for

This work was done when the first author was working at ENST Paris.

the uplink. However, the downlink scenario is particularly attractive as a common pilot channel is transmitted continuously with a relatively high power.

2.1. Downlink received Signals

A UMTS network is divided into cells, each of them (denoted c) contains a BS c which communicates with K^c mobile stations. According to the UMTS–FDD standard [4], for each slot l, a BS c emits simultaneously:

- a QPSK sequence $b^c_{l,0}$ of N_s symbols ($N_s = 10$) as a pilot sequence common for all users of the cell.
- K^c other QPSK sequences $b^c_{l,k}$ sent respectively to each user k of the cell.

Through a discrete multipath channel, the signal corresponding to the slot l received by the MS from the BS c is thus given by:

$$x^c_l(t) = \sum_{k=0}^{K^c} G^c_k \sum_{r=1}^{R^c} \sum_{i=0}^{N_s N-1} \alpha^c_{r,l} b^c_{l,k}(i) g(t - iT_c - \tau^c_r)$$

where G^c_k represents the gain factor of the k–th signal of the c–th cell. For each cell, R^c paths are considered characterized by their delays τ^c_r and their fading coefficients $\alpha^c_{r,l}$. g represents the global filter, (*i.e.* pulse shaping filter (square root raised cosine of roll–off 0.22) + receiver filter). If the considered MS receives signals from C BS's, the global received signal (corrupted by additive noise w_l) is given by: $x_l(t) = \sum_{c=1}^{C} x^c_l(t) + w_l(t)$.
At the receiving end, the signal is sampled at the rate T_c and we denote $x_l(n) \stackrel{\text{def}}{=} x_l(nT_c)$.

2.2. TOA estimation

For each cell, under the assumption of a LOS, the considered TOA can be obtained as the position of the first peak of the autocorrelation function of the channel coefficients. In practice, the latter are classically obtained by the RAKE estimator which carries out correlations of the received signal with delayed versions of the pilot sequence. For example, the channel estimate of the c–th cell, corresponding to the received signal during the slot l, is given by:

$$\hat{h}^c_l(k) = \frac{1}{N_s N} \sum_{i=0}^{N_s N-k} x_l(i+k) b^{c^*}_{l,0}(i).$$

To determine the TOA, averaging the channel coefficient estimates over several slots, supposing the delays constant during this observation period, provides a better accuracy. In this case, it is possible to determine the TOA by estimating the peaks of the following function $\frac{1}{J}\sum_{l=1}^{J} |\hat{h}^c_l(k)|$, $k = 0 \ldots L-1$, where the channel coefficients have been averaged over J snapshots.
However, even with this new function, the peak estimation requires the use of a threshold γ to get rid of the noise peaks and to retain only peaks corresponding to effective channel paths. Usually, this thresholding is done in an ad–hoc way[1] which may affect the performance of mobile localization. Indeed, a high threshold might hide the first path if the latter is of relatively low power and a low threshold would lead to a false (noise) peak detection. In fact, the performance of the thresholding depends essentially on the robustness of the used channel estimation to the NFE (*i.e.* on the effect of the noise terms in the channel estimates). As the RAKE estimator is known to be non robust to the NFE, the use of the "RAKE-SP estimator" has been proposed in [2] which consists in carrying out a projection of the RAKE channel coefficient vector on the signal subspace of the channel covariance matrix. It was shown in [2] that in the context of the UMTS-FDD downlink, the RAKE-SP reduces significantly the false peak detection probability. Note that the accuracy of the presented RAKE-SP estimator can not be lower than $T_c/2$ (*i.e.* half of the sampling interval). A better precision could be obtained with an oversampling or a high resolution method (like a MUSIC–type algorithm) but the resulting increase of the complexity might not be supported by the MS.

3. MOBILE POSITION FROM TOA ESTIMATES

3.1. Trilateration algorithms

Assuming a homogenous propagation environnement and the existence of a line of sight, the propagation delay is related to the mobile position according to:

$$v(t_i - t_0) = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (1)$$

where t_i represents the TOA associated to the BS i, t_0 the reference time of transmission of the BS signals, v the propagation speed, (x, y) the mobile position and (x_i, y_i) the coordinates of the BS i. In practice, the TOA measurement is corrupted by estimation errors and possible NLOS effect leading to :

$$\hat{t}_i = t_i + w_i + u_i$$

where w_i represents the estimation noise, usually of zero mean and a variance depending on the NFE and u_i a possible 'large' bias due to the NLOS effect. Classical trilateration methods take into account only the estimation noise w_i (often modelled as a gaussian noise) by solving the non-linear equation system (1) in the least squares sense or using a properly chosen statistical criterion.
Two algorithm classes exist in the literature using:

- an iterative resolution (ML or MSE) [6],
- an explicit solution [3].

The second approach has been chosen here as it represents a better trade-off complexity-precision than the first one. Indeed, in the first case, the accuracy of the solution strongly depends on the initialization and eventually on the number

[1] It can be taken equal to a percentage of the strength of the received signal.

of iterations.
In this work, we propose a new approach to deal with the NLOS noise (bias) u_i. A major problem here is the difficulty to simply predict or model the NLOS phenomenon. For this reason, most existing solutions to the localization problem do not take the NLOS noise into consideration. We handle that problem by considering the situation where multiple (more than three) TOA measurements are available and only one or few of them are affected by the NLOS noise. More precisely, we propose a suboptimal (but yet simple and efficient) new trilateration algorithm which enables us to identify the incoherent TOA measurements and to only select the three most reliable TOAs among the set of all TOA estimates from which the mobile position is calculated. The proposed selection algorithm, based on a coherence criterion, has the advantage to be easy to implement and not to require any change in the UMTS-FDD standard.

3.2. Selection algorithm : coherence criterion

In this section, we present the selection algorithm based on the following coherence criterion applied on the set of all TOA estimates corresponding to a same mobile position:

- For a reference BS k (t_k), by supposing known the time t_0, we propose to identify the three TOAs (t_i, t_j, t_l) (associated to the BSs i, j, l, respectively) corresponding to a same mobile position which minimize the following expression :

$$\xi^k_{i,j,l}(t_0) = \|\sqrt{(x_{i,j,l} - x_k)^2 + (y_{i,j,l} - y_k)^2} - v(t_k - t_0)\|^2.$$

  $(x_{i,j,l}, y_{i,j,l})$ represents the coordinates of the mobile position estimated from (t_i, t_j, t_l). This quadratic criterion measures the gap between the distance (BS k – MS) estimated via the TOA t_k and via the mobile position given by the TOAs (t_i, t_j, t_l). It is used here as an indicator of the coherence between the TOA measure at the reference BS k and any 3-tuple (i, j, l) of TOA measures[2]. It is clear that in the noiseless case the criterion value is minimum, equal to zero.

- In order not to privilege one BS (the reference BS) with respect to the others, we propose to evaluate the criterion by considering successively each BS k as a reference one:

$$\hat{i}, \hat{j}, \hat{\ell} = \arg \min_{i,j,l,k} \xi^k_{i,j,l}(t_0).$$

- Actually, the reference time t_0 is not known in the UMTS-FDD standard, we propose to determine it as follows:

$$\hat{i}, \hat{j}, \hat{\ell}, \hat{t_0} = \arg \min_{i,j,l,k,t_0} \xi^k_{i,j,l}(t_0). \tag{2}$$

  This minimization is performed by enumeration in terms of (i, j, l, k) and a line-search numerical optimization for the reference time parameter t_0.

[2]Note that k can be member of a given 3-tuple (i, j, l).

Remark: In order to reduce the computational cost, we have chosen to estimate the mobile position from (t_i, t_j, t_l) by using an approach giving an explicit solution. Unfortunately, in the case of three BSs, the explicit solution of [3] does not always exist. We propose here to estimate first the mobile position as function of the reference time t_0 which is computed later using (2). The solution corresponds to:

$$\begin{pmatrix} x_{i,j,l} \\ y_{i,j,l} \end{pmatrix} = -\begin{pmatrix} 2x_{j,i} & 2y_{j,i} \\ 2x_{l,i} & 2y_{l,i} \end{pmatrix}^{-1} \begin{pmatrix} v^2 e_{j,i} - k_j + k_i \\ \\ v^2 e_{l,i} - k_l + k_i \end{pmatrix}$$

with $k_i = x_i^2 + y_i^2$, $x_{m,n} = x_m - x_n$, $y_{m,n} = y_m - y_n$ and $e_{m,n} = t_m^2 - t_n^2 - 2(t_m - t_n)t_0$.

4. SIMULATIONS

In order to illustrate the new method in a realistic scenario, a microcell environment, similar to the Manhattan model [5], has been simulated. $C = 8$ cells have been considered, each of them containing a BS communicating with $K^c = 20$ interfering mobiles randomly distributed. The radio-channel has been represented by three paths with complex amplitude and time–delay characteristics as given in [5]. By adding a background noise representing 10% of the maximum signal power received by the 4th BS[3], the considered mobile is supposed to be able to estimate the TOAs of the 4 closest BSs[4]. The TOAs have been estimated from the received signals, by using the RAKE-SP estimator (cf section 2.2) and the threshold γ has been taken equal to 20% of the strength of the received signal. During the observation period (chosen equal to 120 slots), the channel fading coefficients $\alpha^c_{r,l}$ are supposed to vary at each slot whereas delays τ^c_r are supposed to be constant.
For the simulations carried out, the corresponding sets of curves represent the circular error cumulative probability density function (CDF) versus the mobile location error. The latter is given in meters and evaluated over 100 Monte–Carlo runs. Note that, in order to show that the efficiency of the algorithm does not depend on a particular mobile position (i.e. on a particular BSs configuration with respect to the mobile), a random mobile position is considered at each Monte–Carlo run. Different scenarios have been simulated to illustrate the impact of the proposed selection algorithm in the case of some NLOS and NFE errors, with comparison with the classical trilateration [3].

[3]The BSs are numbered with respect to their distance to the MS (e.g. the BS 1 represents the closest BS to the MS)

[4]Although the MS receives signals coming from more than 4 BSs (here, C is taken equal to 8), this assumption seems realistic considering the interference level in the UMTS-FDD systems [5].

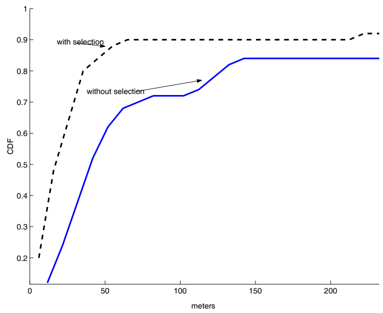

Fig. 1. Mobile localization from 4 TOAs : NFE

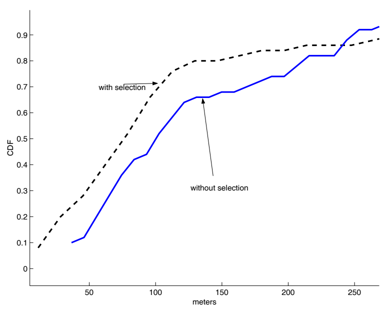

Fig. 2. NFE and NLOS for the 2 BS

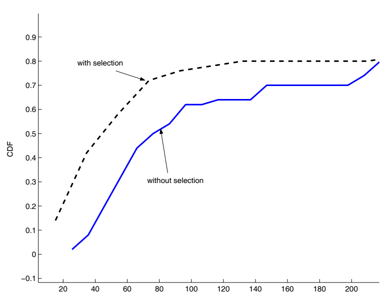

Fig. 3. NFE and NLOS for the 4 BS

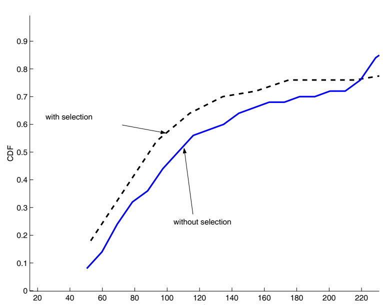

Fig. 4. NFE and NLOS for the BSs 2 and 4

Figure 1 shows the performances of the proposed algorithm in the case where TOA errors are only caused by NFE. The results clearly demonstrate the efficiency of our proposed selection algorithm in comparison with a classical trilateration method. Indeed, at a probability level of 67%, the localization error has nearly been divided by a factor 2. In figures 2 and 3, the problem of NLOS is highlighted with the case of a NLOS concerning respectively the BS 2 and 4. Note that in our simulations, the NLOS case for a BS corresponds to a strong attenuation of the first path and consequently to the detection of the second path as LOS. Our selection algorithm succeeds in eliminating the TOA measure corrupted by the NLOS bias (related to BS 2 and 4 respectively) before doing the trilateration. Moreover, one can observe that the gain obtained by the selection algorithm is more significant in the case of figure 3 where the selected TOAs (corresponding to the closest BS $1, 2, 3$) are less corrupted by the NFE. Figure 4 presents simulation results in the situation where 2 out of 4 BSs are affected by the NLOS noise. Even though, in this case, one of the three selected TOAs is affected by the NLOS noise, the proposed algorithm provides a non–negligible performance gain compared to the trilateration techniques using all measured TOAs.

5. CONCLUSION

In this paper, a new trilateration technique has been introduced in order to reduce the NFE and NLOS effects on mobile localization. The presented results clearly demonstrate the efficiency of the proposed trilateration algorithm with respect to a classical trilateration method. The proposed algorithm has the advantage of requiring no change in the UMTS-FDD standard and to keep the very simple implementation architecture of existing trilateration techniques.

6. REFERENCES

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