On the Reliability of Location based Networking

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***Abstract*—To exploit the most appropriate service at a dedicated position it is of essential interest to employ mechanisms like localization for proper position estimation. The reliability of positioning data thus is one aspect in mobile radio networks that needs to be further investigated. The present paper addresses the impreciseness of fuzzy localization and introduces respective modelling. Characteristic properties of localization techniques like accuracy and precision are considered and different underlying distribution functions are evaluated.**

1 Introduction

Location based networking is an upcoming scheme that will become more and more important in future wireless systems [1]. Serving as enabler for location based services, positioning may even be seen as one key technique in systems beyond 3G. The reliability of positioning data therefore is of essential interest. However, focus of this paper is not the localization technique itself. Instead, properties of localization techniques are investigated, expressed by their accuracy, precision and underlying distribution function.
The subsequent Section 2 introduces a general classification of localization methods. Section 3 continues by explaining existing localization techniques. Section 4 introduces the modelling of fuzzy localization followed by respective simulation. Finally, a conclusion and outlook is given in Section 5.

2 Classification of Localization Methods

Four different categories can be distinguished according to the active elements in localization.

1. Network – based
2. Mobile - based
3. Mobile - assisted
4. Foreign system - based/assisted

The first three methods rely on system inherent signal exploitation, whereas the last category applies additional non-specific mobile radio communication system techniques to perform localization.

Network-based: If all necessary measurements are performed by the network (base station) itself, this is called network-based localization. Hence, no changes to the terminal are necessary and legacy devices can be employed. Nevertheless, this procedure fails if the terminal is in idle mode and beyond that necessary signalization can bring additional load to the network.

Mobile-based: In the mobile-based localization approach the terminal holds responsible for the position determination. Therefore, base stations need to transmit on a regular basis. If no active communication is established due to very low load conditions, some kind of beacon signal in a control like channel needs to be conveyed enabling all users in the cell to perform autonomous localization at arbitrary times. Depending on the sophistication of the mobile-based localization, the base station might need to supply additional information, like its own coordinates. Disadvantages of the mobile-based localization obviously are given by increased complexity due to higher challenges on calculation power and equipment.

Mobile-assisted: The third category, called mobile-assisted localization is a hybrid solution of the two aforementioned methods. The terminal hereby measures reference signals of incoming base stations (BSs) and transmits this data back to the network. The final computation can take place in the network, e.g. a central server station. However, this burdens a lot of traffic to the network if explicit measurement signalling is triggered. Additionally, the evaluation of the position is delayed compared to the mobile-based implementation. The major advantage is the possibility to use existing GSM or already specified UMTS measurement reports [2][3]. Hence this technique can be based on specified standards and only minor changes are necessary. Besides this, if respective reports that are conveyed to the base station anyway, e.g. in the context of power control adjustment, are exploited, the aforementioned disadvantage of additionally introduced overhead is not valid anymore.

Foreign system based/assisted:
The last category, foreign system based/assisted localization, differs from the aforementioned three ones by exploiting additional metrics whose origin is not the actual mobile radio system itself. Methods to be applied here comprise radar location techniques or satellite navigation systems. Also, inter-system solutions incorporating localization based on mobile radio network techniques jointly applied with foreign system techniques belong to this category. Depending on the degree of support, a distinction in foreign system based and -assisted can be done.

3 Localization Techniques

From a physical localization point of view, in principle there are three techniques to be distinguished as mentioned in the following:

1. Triangulation: Here, trigonometric methods are used for the position determination. Within triangulation, it can be differentiated between distance-based *lateration* (example: Global Positioning System, GPS) and angle- or direction-based *angulation* (example: phase-sensitive antennas) methods. For the distance based lateration, the position of an object is computed by measuring its distance from multiple reference points. Possible methods for measuring comprise *direct* measurements by physical actions or movements, *time-of-flight* measurements by taking the time it takes to travel between the object and a certain point at a known velocity and *attenuation* measurements by exploiting certain pathloss properties.

2. Proximity: Determination of the place of an object, which is 'close' to a well-known place. Here, again one distinguishes three fundamental sub-methods:

- Recordation of a physical contact, for example piezoelectric pressure or contact sensors, capacitive transducers etc.
- Monitoring of access points of a WLAN. Here it is indicated if a terminal is in the range of one or several APs.
- Monitoring of automatic authentication systems such as credit card terminals, access systems, bar-code scanner, system logins etc.

3. Pattern Recognition: Within methods that apply pattern recognition, a further separation into optical pattern recognition (scene analysis) and non-optical pattern recognition can be done.
With the scene analysis, simplified views of an observed scene are used for the representation and the comparison of pictures, for example the horizon line captured with a camera.
Non-optical pattern recognition techniques apply mapping techniques of dedicated parameters to well known samples stored in a database. Contrary to the scene analysis, the input usually does not consist of pictures taken by a camera, but any arbitrary other physical quantity is evaluated.

Accuracy and Precision
The aim of localization is to determine locations accurately and precisely. Having a look at manufacturers' instructions of e.g. GPS devices, one will find statements on both accuracy and precision, e.g. receivers can locate positions to within 10 meters (accuracy) for approximately 99 percent of measurements (precision, reliability) or accuracies of 1m-3m for 95% of the time. Thus, accuracy as used here means the granularity with which objects may be located while precision means the reliability that a located object really resides at the determined position.

Obviously, accuracy and precision are closely dependent on each other and one will intuitively agree that if applied for the same system less accuracy may result in increased precision and vice versa. This is also expressed with the help of Figure 1. The abscissa depicts the relative location of an object while the ordinate shows the probability that the object really is located at the respective position.

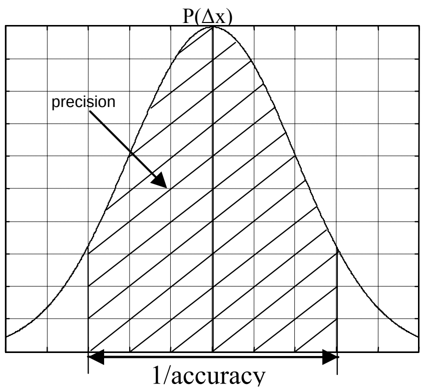

Figure 1: Dependency of accuracy and precision [4]

Accuracy of localization increases if delta x decreases, which means the granularity is increased (e.g. location resolution of 5m instead of 10m).
The precision of the localization corresponds to the integrated surface as hatched in Figure 1. Thus, one can see that if - for the same system - accuracy is increased, precision usually decreases.
To arrive at a concise quantitative summary of accuracy and precision actually these terms need to be mentioned including a remaining unsteadiness expressed by an error distribution incurred when locating objects. Further on, additional parameters need to be considered such as the necessary density of infrastructural elements.

4 Modelling of Fuzzy Localization

Localization can be carried out by the network as well as the mobile itself. Depending on that certain pairs of accuracy and precision can be achieved. From field trials and preliminary evaluations for UMTS a positioning of 20m accuracy with an according precision of 67% is predicted [5].
Modelling of fuzzy localization is performed in the following way: At the centre of the circuit in Figure 2, the mobile is shown at its real position (A). The accuracy is modelled by a radius for the estimated position (B) and varies between 0-20m (according to e.g. UMTS but also WLAN). Such, mobile (A) represents the *real* position, whereas mobile (B) represents the *estimated* position due to localization imprecision. As no distribution function for the accuracy is provided from operators and tests a Gaussian normal distribution is assumed. For the angle between real and estimated position, a distribution is chosen which implies that there is no preferred direction and no correlation between two test values. Hence for the complete circuit this results in a two-dimensional normal distribution and a corresponding correlation factor between the x and the y axis of 0. A precision of 67% in this context means that for this percentage the discrepancy between both positions is less or equal 20m. The stated pair of accuracy and precision corresponds to a variance of 400. Hence the distribution depicted in the lower part of the figure is a (0, 400) normal distribution. Summarized, one can state that accuracy expresses the granularity with which terminals may be localized while precision is a measurement for the reliability that the alleged located mobile really resides in the respective area.

Evaluation Criteria

For the evaluation of localization effects and to assess the similarity of radio condition, say reception power, between real (A) and estimated (B) location, an objective measure is needed. This can be provided by a cross correlation of respective measurement reports as taken at both positions. For the cross correlation of such measures, equation 1 is employed whereby f_1 denotes the observed Rx values at position (A) and f_2 respective Rx values at position (B). The calculated cross correlation value *C* represents the similarity of Rx levels for both positions.

$$C_n = \frac{\sum_{n=0}^{\infty} f_1(n) f_2(n)}{\sqrt{\sum_{n=0}^{\infty} f_1^2(n) \sum_{n=0}^{\infty} f_2^2(n)}} \tag{1}$$

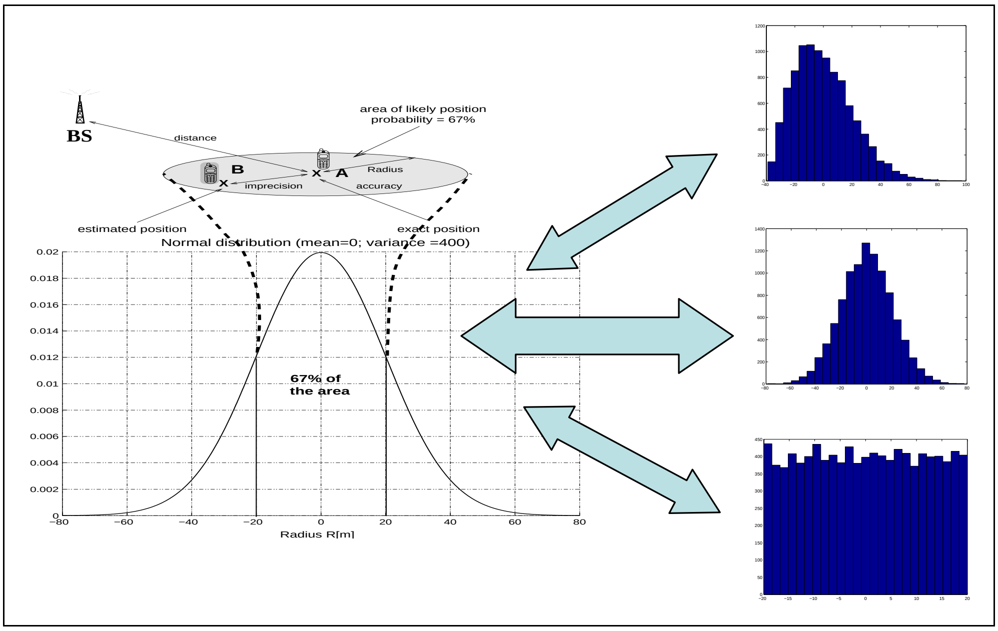

Figure 2: Scenario and modelling of fuzzy localization using different distribution functions

Correlation Analysis

To enquire the influence of the distance between BS and terminal on the correlation value the scenario in Figure 2 was examined. Initially placed close to a fixed BS, a terminal starts to depart until coverage of the BS is exceeded. For the chosen scenario, an upper limit of 200m was chosen, whereby a simple one slope pathloss model with an exponential attenuation factor of γ=2,4 was applied. Further system related properties, especially the determination of measurement reports in terms of RPI levels (Received Power Indicator = quantized measure of received power) follow the recommendation of WLAN 802.11a,h [6]. Every meter the terminal has moved away from the BS a new estimated position is drawn out of the mentioned normal distribution with an accuracy value of 20m and a corresponding precision of 67%. The distant dependent correlation of real and estimated position is shown in Figure 3. Besides simulations, the same scenario has also been addressed by analytical investigations. The solid curve in Figure 3 corresponds to analysis, while the single spots refer to the results of the simulations.

As a first result it can be seen that both approaches match quite well, since the single simulation points are grouped around the graph. Furthermore the correlation increases with ascending distance. This can be explained with the employed attenuation characteristic which is negative exponential. Close to the sender the imprecision of localization has a higher impact than far away. For real networking this means, that location data based decision algorithms the better can rely on respective data, the more the terminals are located at the cell edge. This is of special interest for handover support if a terminal is to enter another cell's coverage.

Applying different distribution functions

The inherent properties of accuracy, precision and distribution function of location measurements with respect to their influence on reliability within localization based networking will be discussed in the following. Additionally to the chosen Normal distribution of (B) terminals before, indicated by the largest arrow in Figure 2, Uniform- and Rayleigh distributions have been considered, too. As one can see in Figure 4, the chosen distributions do not have a noteworthy influence on the correlation (if the number of incorporated estimated positions (B) is sufficiently high as needed for statistical reliability). Such it can be concluded, that results from the previous section are transferable and in the following further properties are investigated by using normal distributions only. A further effect that can be seen in Figure 4 and that was neglected in Figure 3 is the behaviour of the correlation value for distances

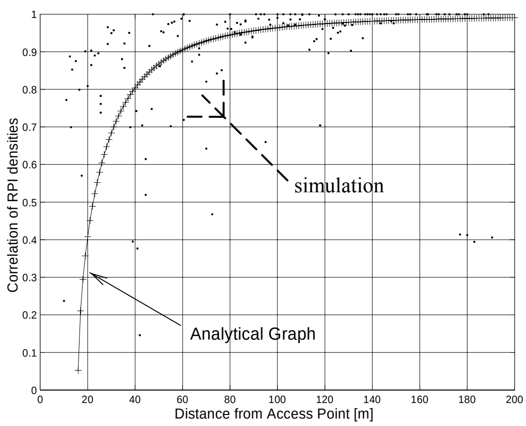

Figure 3: Distance dependent correlation [4]

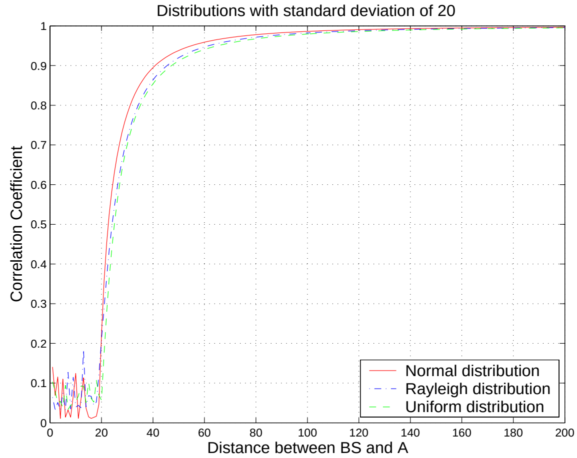

Figure 4: Correlation for different distributions

below 20m. The different curves show a rather unsteady behaviour here. This is due to the fact that within the selected scenario, the estimated position of the B terminal may be e.g. at the other side of the BS due to the assumed accuracy of 20m. Such, only distances between real positions A and the BS being sufficiently higher than the accuracy of localization may be considered for evaluation.

Localization reliability with respect to sliding standard deviation

Concerning localization the best case is of course when the correlation coefficient C is equal 1. This means, that location A and B are the same and there occurred no location errors (A second, but not very probable interpretation of C=1 would be, that there are two positions that feature exactly the same link conditions). It should also be mentioned, that in real environments, slow and fast fading as well as shadowing have to be taken into account, which was neglected here due to simplification reasons. In this simulation scenario it is further assumed, that the power sent by BS is constant no matter of the distance between BS and (A).

It was also in context of this work to investigate how the correlation curves change with respect to variation of the given distribution (see Figure 2). It was first assumed that the variation of measurements distribution is two times smaller at the end of 200 meter distance, than it is in the beginning, and decreases proportionally to the increasing distance ('decreasing' or 'smaller' case). The second time it is two times bigger at the end of 200 meter distance, than it is in the beginning, and increases proportionally to the increasing distance ('increasing' or 'bigger' case).

As it could be expected the values of the correlation coefficients are highest for the decreasing standard deviation, then values for the distribution with the constant standard deviation are next best and finally for increasing standard deviation of the distribution, the correlation is worst (see Figure 5 and Figure 6). Again, there is no significant difference with respect to the chosen kind of distribution expressed by the fact that the also shown uniform distribution performs in between the other mentioned correlations. Such, the manifestation of the distribution is less important than its distance dependency. For real networking this means that applied positioning methods should not exceed a lower standard deviation when locating mobiles at the cell edge. Otherwise, the earlier mentioned better reliability (for constant standard deviation) is not valid anymore.

5 Conclusion and Outlook

This paper addresses the incorporation of localization data in mobile networks serving as a basis for dedicated decision processes. The properties of localization have been addressed first, by classifying current localization methods and presenting shortly basic principles of localization techniques. A special issue hereby was to show up the dependency of accuracy and precision. Since localization

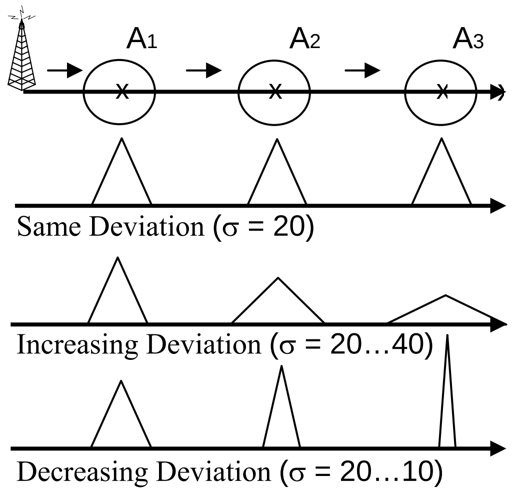

Figure 5: Distance dependent stand. deviation

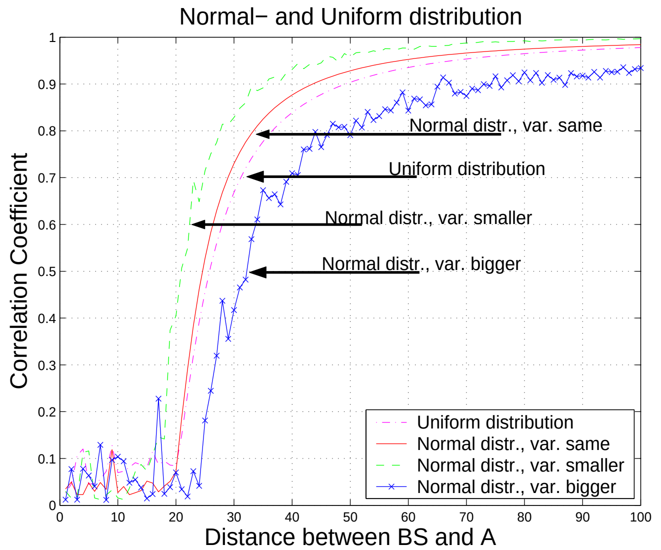

Figure 6: Correlation for distance dependent deviation

methods of today usually mention mean values of accuracy and precision, it was of interest to investigate in how far different underlying distribution functions of the localization error show an impact on actual position estimations. A method of modelling fuzzy localization was introduced and applied to a simple scenario.
Both, simulation and analysis was incorporated to determine the similarity of signal reception levels at the real and estimated position. As a measure, the correlation of the respective measurements was exploited. It was shown, that for distant independent (same) distribution localization errors are least harmful at cell edges, a fact that is important especially for handover control. Further on, it was shown that different underlying distributions of estimated location errors thereby only have a minor influence on the overall correlation value. More influence indeed has the dynamicity of the standard deviation. If the deviation is a function of the distance, its influence is not negligible.

The presents results are based on a number of simplifications in the dedicated scenario and such may be seen as a best case evaluation. Further investigations in this field need to address distance dependent exponential attenuation factors γ as well as error distribution functions being dependent not only on the distance, but also on the direction (angle). Also, shadowing and fading effects should be included. Finally, it is of essential interest to include time dependent correlation of data of position A (real) and B (estimated), for the case, that both measurements are not taken at the same time but with a short delay.

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