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Mobile Location using coverage information: Theoretical analysis and results

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Abstract:

This contribution addresses the location problem using coverage information in a cellular network context, particularly GSM. As it is well known, mobile location usually requires more detailed information than just coverage, due to the high variability of this kind of information. However, recent advances in propagation prediction, the availability of new tools, etc. make it coverage information a good candidate for mobile location, at least for a first approximation.

This contribution makes a preliminary analysis of the possibilities of using propagation information for location purposes, studies its requirements and limitations. In particular, several algorithms are considered and the effect of different propagation conditions is analysed.

As can be expected, location using coverage information can only be undertaken when a good knowledge of the propagation environment is available. In most cases, an "ad-hoc" measurement campaign is required. Nevertheless, when good information is available, location errors smaller than 100-150 metres are obtained for 70% of cases.

Introduction

In a previous contribution to COST [1], the use of propagation information for "hot spot" location has been reported. The basic conclusion of the report is that locating hot spots using just coverage data was indeed possible and relatively small errors are obtained.

In this contribution, a more careful analysis of the possibilities of using coverage data for location information is undertaken. The objective is to analyse what is the influence on the location error of several factors: the most important being the error on the coverage information data, but it has also been analysed the number of measurements available, the mobile speed, the correlation between measurements, different location algorithms etc.

Location algorithms

As it is well known, one of the most interesting characteristics of GSM is the fact the MS reports back to the BS (MSC) the information of the receiving level of the six BS received with greater level. This is done to facilitate the hand-over of the communication in course when the MS is leaving the serving BS coverage area. This information is not usually recorded by the network, unless specifically instructed to do so via the O&M system. Even in those cases, most O&M systems can only record the measurement reports prior to the occurrence of a call event: (Call set up, hand-over.). For that reason, MS location has to be done with a relatively small amount of measurement reports – in the region of 10-15.

Several algorithms were suggested in [1] in order to find the MS location based on that reduced amount of information. those algorithms are summarised here for reference:

In mathematical terms the objective is to find a candidate position r (x,y) for the mobile station taking into account the collection of reported measurement levels v_m to a number of bases (normally around 6). The algorithm compares those reported levels to a collection of planned or previously measured values v_p for every location of the area under study, usually of some square kilometres.

The estimated location of the MS is the position r that makes minimum the distance between the measured (reported) v_m and the planned v_p

If there is only one set of measured v_m (corresponding to one location) the usual approach is to give as candidate position with the minimum square value of the distance between the reported and planned values.

$$f(r)=\sum_{i=1}^{M}\left(v_{im}-v_{ip}\right)^2 \quad (1).$$

(being M the number of BS with reported and planned measurements)

Instead of the minimum square value, different metrics can be used: absolute value, minimax, etc.

If the number of reported measurements of a mobile is greater than one the location finding algorithm can be refined. Now v_m is a collection of k measurements to M base stations.

Several approaches can be used.

1.- The optimum approach would be using a new expression for *f(r)* that would optimise in the whole set of combinations for the components of *r*.

$$f_1(r)=\sum_{\text{all possible paths}}\sum_{i=1}^{M}\left(v_{im}-v_{ip}\right)^2$$

This approach implies first selecting all possible paths in an area of some square kilometres. The number grows exponentially with the number of measurements. Some reduction is obtained using the fact that the MS cannot move at too high speed, but even so the calculation burden is too high.

2.- A second possibility would be to use a derivative of a Viterbi-like algorithm. First a candidate starting point r is determined using (1). The following elements r_j $j=2...k$, can be determined taking into account they cannot be separated more than the maximum mobile velocity (*vel*) multiplied by the measurement interval. This implies that (1) will be evaluated only for those values v_p inside a circle of radius $vel\cdot\Delta t$.

Since those measurements with low attenuation tend to give better estimates, the best approach is to start with r_i closer to one BS.

The procedure could be generalised. Instead of just using the r_i as starting point, it could be possible to define a number l of starting points. Then there will be l different trajectories. Finally, the trajectory with smallest global error could be chosen as the selected solution.

The algorithm can be rather time consuming for large l. One possible way of reducing computing time is only to pursue the analysis of those trajectories with small accumulated error in a manner similar to the Viterbi's Algorithm.

3.- A completely different approach tries to eliminate the Rayleigh or Shadowing component in the reported measurement. That can be done performing a smoothing of the received data v_m. For example, let us consider the reported levels to station j

$v_{1j}, v_{2j}, v_{3j}, \ldots v_{kj}$

Those values usually observe a relatively large dispersion. Those values could be corrected via a "moving average" of size m $(m < k)$ procedure

$$V_{nij} = \frac{\sum_{i=n-m}^{n+m} V_{ij}}{2 \cdot m + 1}$$

4.- A collection of r can be determined using (1) independently for every v_m. Then, the estimated values (in the x-y plane) can be smoothed following a procedure suggested in [2]

The basic idea is to find a least squares approximation $r_e(t_i)$ to the collection of estimated locations $r(t_i)$: assuming they correspond to a collection of samples at taken a constant velocity vel.

If v is assumed constant, it can be estimated using the least squares criteria as

$$vel = \frac{\sum_{j=1}^{k} (t_j - \bar{t})\left[r(t_j) - \bar{r}\right]}{\sum_{j=1}^{k} (t_j - \bar{t})^2}$$

Being

$$\bar{t} = (1/k)\sum_{k=1}^{k} t_j \text{ and } \bar{r} = (1/k)\sum_{k=1}^{k} r(t_j)$$

Then, the estimated positions are

$r_e(t_i) = r_e(0) + v\, t_i$

Note the smoothing procedure used in 4 can be also be applied to 1-3.

Simulation results

In the following, the results of using algorithms 2-4 are compared. A simulated area of 4 x 6 km with seven trisect BS is assumed. The coverage is simulated using Hata model (no shadowing). Measured values are evaluated from the actual values adding a lognormal random variable. BS are indicated in the map by a 'o' symbol. Those BS are trisectorial (120 degrees)

In the first set of simulations, the probability location function is obtained.

To obtain it, a MS at a given location and with a given speed is simulated. The MS, located originally at x= 30,20 and moving along the vector (1,1) sends 10 sets of 5 measurement reports, each set is sent every 28 meters. Then, the MS is located, using one of the algorithms described in the previous section and the estimated location saved. The process is then repeated 500 times and a collection of estimated locations obtained. Then we represent the locus of those locations, normally the estimated locations are close to the "true" location, but the "spread" gives an indication of the form and value of the expected error

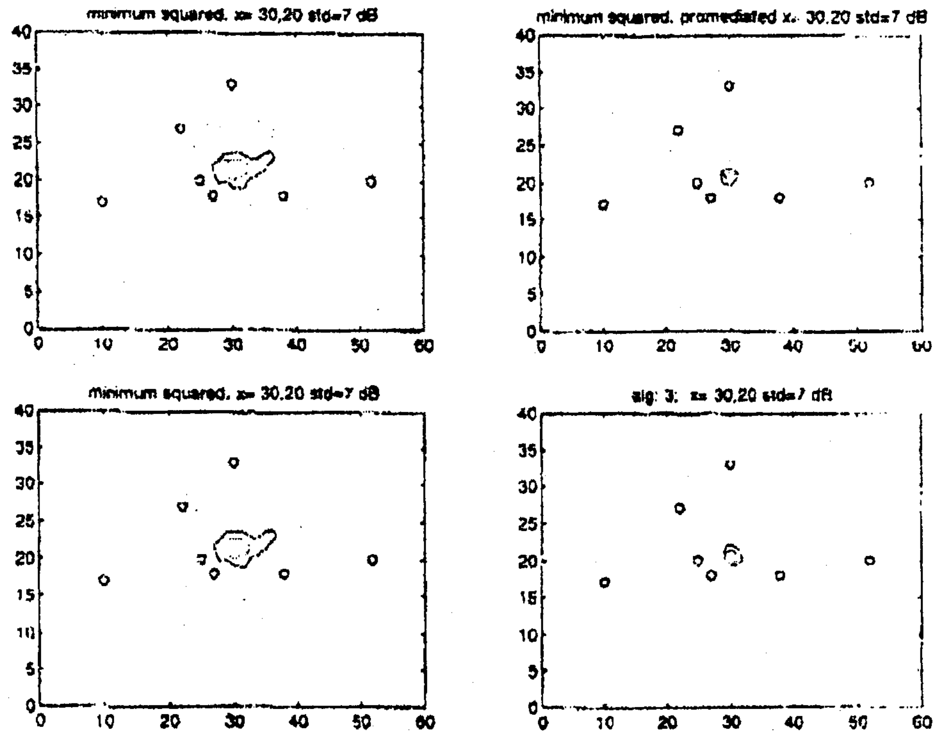

Figure 1. Probability location function. Comparison between different algorithms.

a) Direct algorithm
b) Direct algorithm with averaging (assumed at speed zero)
c) Algorithm number 2
d) Algorithm number 3

The results, shown in figure 1 (a-d) show the probability location function. The first area (light grey) is the 99% location area, the second corresponds to a 66% and the third to 33%.

It can be seen that different algorithms tend to behave rather similarly, however, algorithm 2 gives the best results, but possibly not enough for the added complexity. Promediate is always a good solution, reducing significantly the indetermination area, which can be as small as 50 m for 66% of cases. If the number of measurements is small, the mobile cannot be too away from the original location and it is not necessary to estimate speed.

However, these good results are not obtained when a MS far from a BS is located. The following set of pictures show the results for a location x=45,30

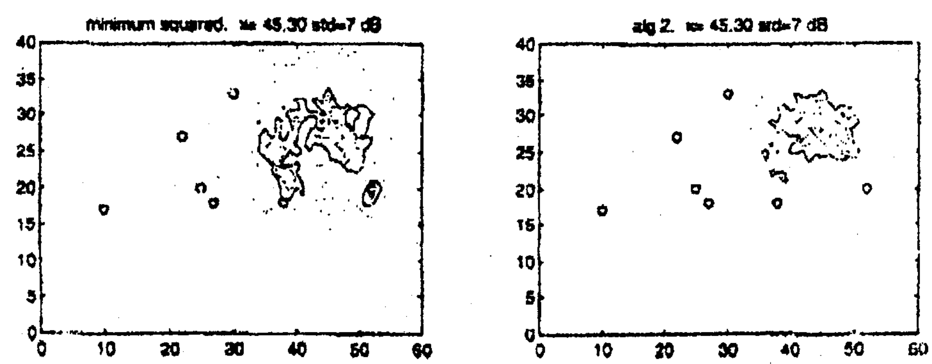

Figure 2. Probability location function. Situation for far locations
a) Direct algorithm
b) Algorithm number 2

In this set of results becomes apparent how those locations are not correctly reported. The variability is very large and this explains the erratic behaviour of the location function that seems scattered around.

Next, the mean value of the error is investigated over the whole area of interest. The following set of figures (3 onwards) is obtained repeating the previous process at every location. The mean error value (and its dispersion) is obtained and represented in a 3-D graph.

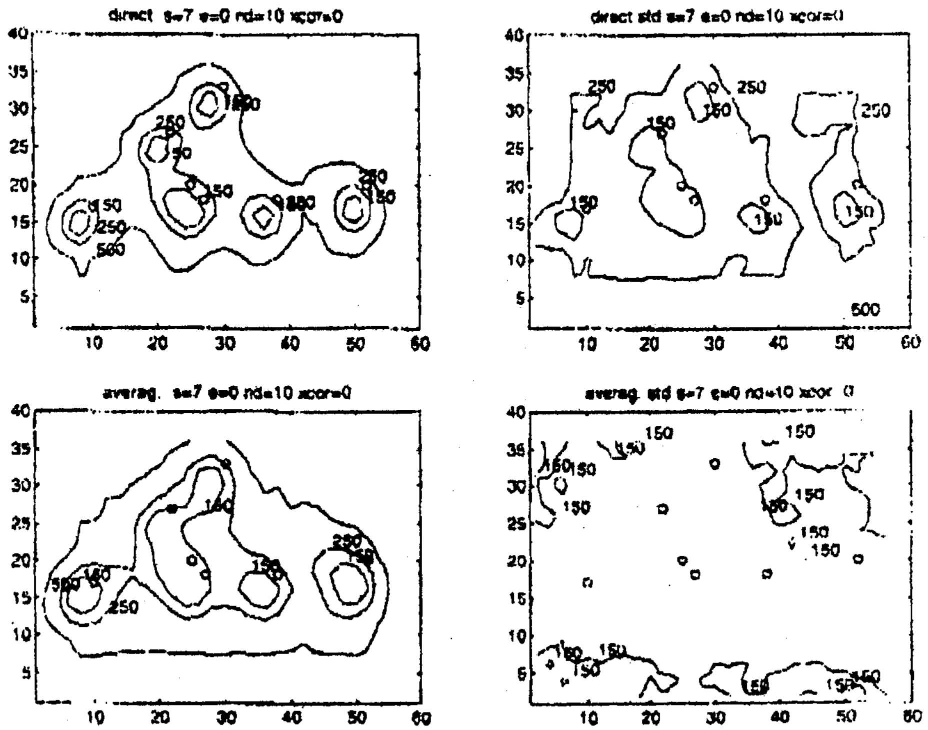

Figure 3. Location squared error. Mean and dispersion
a) Direct algorithm
b) Dispersion for a)
c) Direct algorithm averaged
d) Dispersion for c)

First, the error at every position is represented in fig 3-a with standard conditions (lognormal std. =7 dB, no extra errors, e=0, 10 reports assumed no correlated). It can be seen that only areas close to a BS are acceptable. In this set of results, the averaging effect appears clear. Fig. 3 a shows the average error (with algorithm 1). It can be seen that most areas have an average error smaller than 500 m. However, the dispersion (shown in 3-b), is also around 250, leading to a very bad accuracy. When averaging is used (3 c) the mean error improves but, most significant, there is a large decrease in dispersion (less than 150 m). Location errors in the central area can be in the region of 250m for that lognormal standard deviation of 7 dB.

Next, an study of different parameters is undertaken and briefly reported in Figure 4.

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