Position Assignment in Digital Cellular Mobile Radio Networks (e.g. GSM) derived from Measurements at the Protocol Interface

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Abstract - Measurements are carried out at the protocol interface between base transceiver station and base station controller unit for optimization of the base station subsystem in an existing digital mobile network. At this interface it is possible - in contrast to measurements at the air interface - to gain mass data (e.g. received power, BER, signaling information) with low expenditure. The collected data allow however, only for a very rough estimation of the terminals' positions.

In this paper a method is presented to assign measurement data from protocol interface to the related location of the mobile with the aid of field strength prediction. The application of the position assignment method is demonstrated within the GSM network.

To validate this approach measurements were taken from the German GSM D1 net and were compared with exact position assignments by means of GPS.

On the base of location assignment methods there are new experimental possibilities available, e.g. identification of traffic hot spots or areas of bad interference conditions.

I. INTRODUCTION

In today's digital cellular mobile radio networks, features like power control and handover are related to periodic measurements of level and quality at the mobile (downlink/forward) and at the base station (uplink/reverse) receiver. The measurement values and corresponding signaling events of all customer's calls in a specific cell under investigation could be observed by the network operator at the protocol interface between base transceiver station and base station controller unit. Statistical evaluation of such mass data produced by customer calls and collected at the protocol interface is an important aid to optimize the base station subsystem parameters in an operating network. The almost only drawback is that there is no exact information available about the position of the mobile. Position determination is limited to the statement 'lies in' or 'lies out' of the coverage bounderies - which are also known only roughly - of the cell under investigation.

If the performance along routes or at selected points has to be examined, there are carried out field test runs by special cars equipped with GPS for exact position assignment of downlink measurement values. In comparison to protocol interface measurements this procedure implies some disadvantages like no availability of uplink data, very time consuming and costly test runs, no mass data for statistical evaluation available.

By collection of data from several test runs and some postprocessing for visualization an impression of the real coverage of the network can be achieved. In Fig. 1 a part of the coverage of the German D1 GSM network based on measurement runs in the area of Bonn, Germany, is shown. In this figure different gray shades along the routes correspond to coverage by different base station transceivers which are indicated by small circles.

In section II the applied algorithms for position assignment of protocol data are presented. All position assignment methods are based on a comparison of values measured by the mobiles with the values predicted by a typical network planning tool. A simulation example shows the influence of prediction errors on the accuracy of position assignment.

Section III shows the application of one of the proposed position assignment methods to the German D1 net as an example for a GSM net in operation. The results are compared with GPS based position assignment. It can be seen that the proposed position assignment is of sufficient accuracy to be useful e.g. in traffic hot spot detection in macro cells.

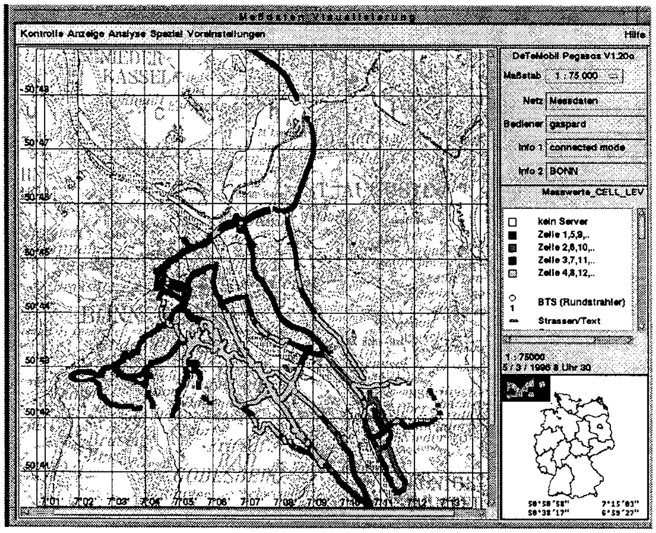

Fig. 1: Visualization example of coverage evaluated by test runs in the area of Bonn of the German D1 GSM network

II. POSITION ASSIGNMENT ALGORITHMS

During a call each mobile station monitors signal powers of surrounding neighboring cells to assist e.g. features like handoff [1],[2].These measurements are available at the cell site and can be monitored and stored for further evaluation by the network operator with the aid of commonly used protocol analyzers. Besides the powers received from neighboring cells a measurement of the delay for the signals propagating between serving base station and mobile station is performed. In GSM this quantity is called 'Timing Advance' (TA). It ranges from 0 to 63 times half of the bit duration of 3.9 μs, i.e. one step corresponds to 553m [1]. By these measurements an experimental vector $\vec{m}(t_i)$ is formed for each time step t_i. Its components are the powers received from the serving cell and from the neighboring cells supplemented by one component which represents the delay measurement. The received power can be reduced by power control of the base station transmitter, so the measured received power of the serving cell has to be corrected by the actual power control reduction step which is also available at the interface A_{bis}. It is assumed in the following that $\vec{m}(t_i)$ is characteristic for the mobile's position with a resolution defined by the time step t_i. Because of averaging in the receiver fast fading of the measured power is eliminated. In Fig. 2 an example of a real measurement taken at the protocol interface A_{bis} of the German D1 net is shown. The maximum number of monitored neighboring cells in GSM is equal to 6 what will limit the maximum available information for further processing.

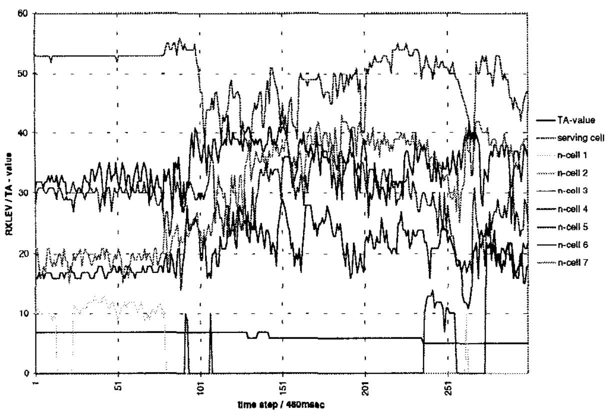

Fig. 2: Measurement example taken from A_{bis}

Measurement values are repeated in the GSM every 480msec. Fluctuations of the measured quantities resulting from this fine time resolution make a further averaging expedient. This averaging is dependent on the maximum assumed speed of the mobile and of the spatial resolution of the used prediction tool. The resolution of the topographical data base used for prediction was 5'' which is equal in Germany to about 150m in north-south and 100m in east-west direction, respectively. If we assume maximum average speeds of 150km/h a mobile stays within an element of the meshed grid at least for 2.4sec. Hence, it is reasonable to do the further averaging of the measured $\vec{m}(t_i)$ data by sliding averaging over at least 5 successive measurement points. In Fig. 3 the result of the sliding averaging of the measurement data from Fig. 2 is shown as an example.

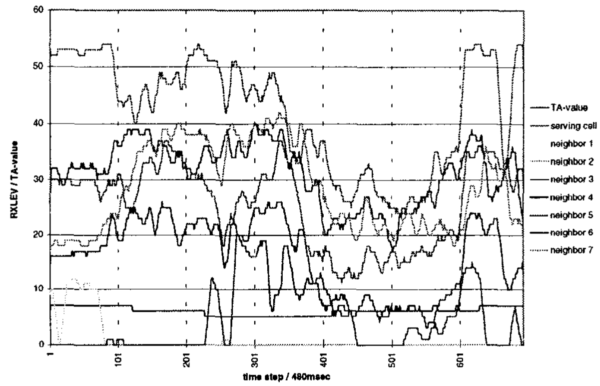

Fig. 3: Measurement example from A_{bis} after sliding average

In parallel to the evaluation of the measurement vectors $\vec{m}(t_i)$ a set of prediction vectors $v(x,y)$ is established once for a given cell. This set is generated by prediction of received median power as a function of position (x,y) in the area of interest, which is at least as large as the coverage area of the observed serving cell. At each point of the grid of longitude and latitude the predicted powers for serving and neighboring base stations are considered as the components of the prediction vectors $v(x,y)$. In general, in GSM the number of neighboring cells to be considered is limited to 32. Thus the maximum number of components for each prediction vector is 32 plus one component for the serving cell's power. In Fig. 4 a visualization example for the predicted received power of the serving cell in a suburban area of about 15kmx10km evaluated in the following is shown (dark gray = high power, light gray = low power).

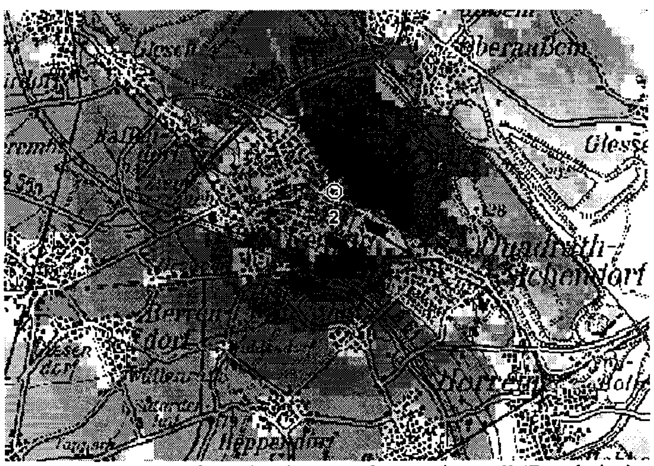

Fig. 4: Prediction of received power for serving cell 'Bergheim'

After preparing the measurement vectors and prediction vectors the position assignment is performed by searching the predicted vector which is the most similar one to the actual measurement vector $\vec{m}(t_i)$. This search has to be performed for each measurement vector. The a priori known position of the most similar prediction vector is assigned to the measurement vector in time step t_i. Three different similarity measures were evaluated:

- correlation coefficient between vectors $\vec{m}(t_i)$ and $\vec{v}(x,y)$

$$p(x,y,i)=\frac{\sum_{n=0}^{N}\left(v_n(x,y)-\overline{v(x,y)}\right)\cdot\left(m_n(i)-\overline{m(i)}\right)}{\sqrt{\sum_{n=0}^{N}\left(v_n(x,y)-\overline{v(x,y)}\right)^2\sum_{n=0}^{N}\left(m_n(i)-\overline{m(i)}\right)^2}} \quad (1),$$

where n denotes the vector component, i denotes time t_i and the overbar denotes averaging over all components of the vector.

- cosine of the angle between vectors $\vec{m}(t_i)$ and $\vec{v}(x,y)$

$$\cos\left(\angle\left(\vec{m}(i),\vec{v}(x,y)\right)\right)=\frac{\sum_{n=0}^{N}v_n(x,y)\cdot m_n(i)}{\sqrt{\sum_{n=0}^{N}v_n(x,y)^2\sum_{n=0}^{N}m_n(i)^2}} \quad (2).$$

The position of the predicted vector which yields maximum correlation coefficient or maximum cosine of the angle between measurement vector and prediction vector is assigned to the actual measurement vector.

- distance of the vectors $\vec{m}(t_i)$ and $\vec{v}(x,y)$

$$a(x,y,i)=\sqrt{\sum_{n=0}^{N}\left(m_n(i)-v_n(x,y)\right)^2} \quad (3).$$

The position of the predicted vector with minimum distance to the measured vector is assigned to the actual measurement vector.

The timing advance information is used to limit the number of prediction vectors which are compared to the actual measurement vector with the aid of the three defined similarity measures.

By repeating the steps described so far for every measurement vector of a complete call one will get the position assignments during the entire call and consequently an estimate of the mobile's run.

III. APPLICATION IN GSM

To evaluate the different methods of position assignment measurement runs were carried out. As a reference the position assignment of a GPS receiver was used, which resulted in an accuracy in the order of about 100m. The measurement runs were carried out in a suburban area in the vicinity of Cologne, Germany. The cell radius was about 10km. So the rectangular prediction area was chosen to cover the whole cell area and consisted of 210x150 prediction vectors laying on a grid of 5''x5'' with 11 components: 10 possible neighbor cells within the cell under investigation plus one component for the serving cell 'Bergheim'. In parallel, the data available at the interface A_{bis} were stored. It was found out that most exact position assignment was obtained by calculation of the second similarity measure between measurement and prediction vectors. The reason is that this similarity measure is not dependent on the absolute measurement or prediction accuracy but only on the relation of the different components. For instance, if the gain of the real receiver antenna is not equal to the assumed value in the prediction, it will not affect the angle between measurement and prediction vectors, only a linear scaling of the measurement vector is performed.

The measurement runs were performed at moderate mobile speeds and it was found reasonable to do some further averaging beyond the averaging of the received powers. This second averaging concerns simple averaging after position assignment and is done in space by independent averaging in north-south and east-west direction.

As an example, Fig. 5 shows the visualization of position assignments with the second similarity measure calculation for three different calls during our test drives. For each call we were driving the same route. The number of measurement vectors for each call was in the order of 600. The route was a closed loop and is also visualized by GPS position assignment. It can be seen from Fig. 5 that the position assignments were reproduced very well for the three independent calls. The accuracy in radial direction in relation to circles of constant distances from the serving cell is much better than in tangential direction. This is because the timing advance information contributes to accuracy only in radial direction but not in tangential direction.

To investigate the influence of prediction errors on the accuracy in position assignment different prediction errors in the sense of varying standard deviation values were simulated. Starting with the prediction vector at the position of the same serving cell 'Bergheim' as we carried out our above mentioned measurements we generated 1000 vectors each, where the components are generated by independent Gaussian processes with means equal to the components of the start vector and standard deviation of 4dB and 8dB, respectively, which are typical values for state-of-the-art prediction tools. These sets of 1000 vectors each were processed by the position assignment method with cosine correlation and the frequency of the assignment to a specific position on the 5''x5'' grid was calculated. Again the results are visualized with an underlying map. Fig. 6 shows the result for 8dB standard deviation, Fig. 7 depicts the result for 4dB standard deviation. As assumed with decreasing standard deviation of the prediction, the accuracy in position assignment will increase.

By comparing simulation and measurement and remembering a typical standard deviation of the predicted powers in the order of 8dB the most important influence on position assignment accuracy is the accuracy of the predicted powers.

For further refinement, it is reasonable to interpolate the predicted powers, what can be done by simple 2-dimensional interpolation in space. Another improvement can be gained by weighting the single position assignments by the related value of similarity calculation. Also some weighting of the measured and the predicted powers can improve accuracy. This is reasonable due to the fact that in general the largest prediction errors can be found for large path loss because in this case many reflections or path irregularities have to be considered by the prediction tool which lead to larger accumulated resulting errors.

IV. CONCLUSIONS

In this paper we presented different methods for position assignment of mass data from measurements at the protocol interface in digital cellular mobile radio networks based on a comparison of measurement reports on the mobile terminal position and prediction of received powers by a planning tool. Measurement results taken from the German D1 GSM net were shown and compared with GPS position assignment as reference.
The most important application of position assignment methods introduced in this paper is in 'hot spot' detection of areas of high traffic. This task is of interest especially in existing mobile networks with a fast growing number of subscribers, where small cells have to be integrated into the existing infrastructure in an efficient way without the need for prior installing test base stations to find out their optimal locations.

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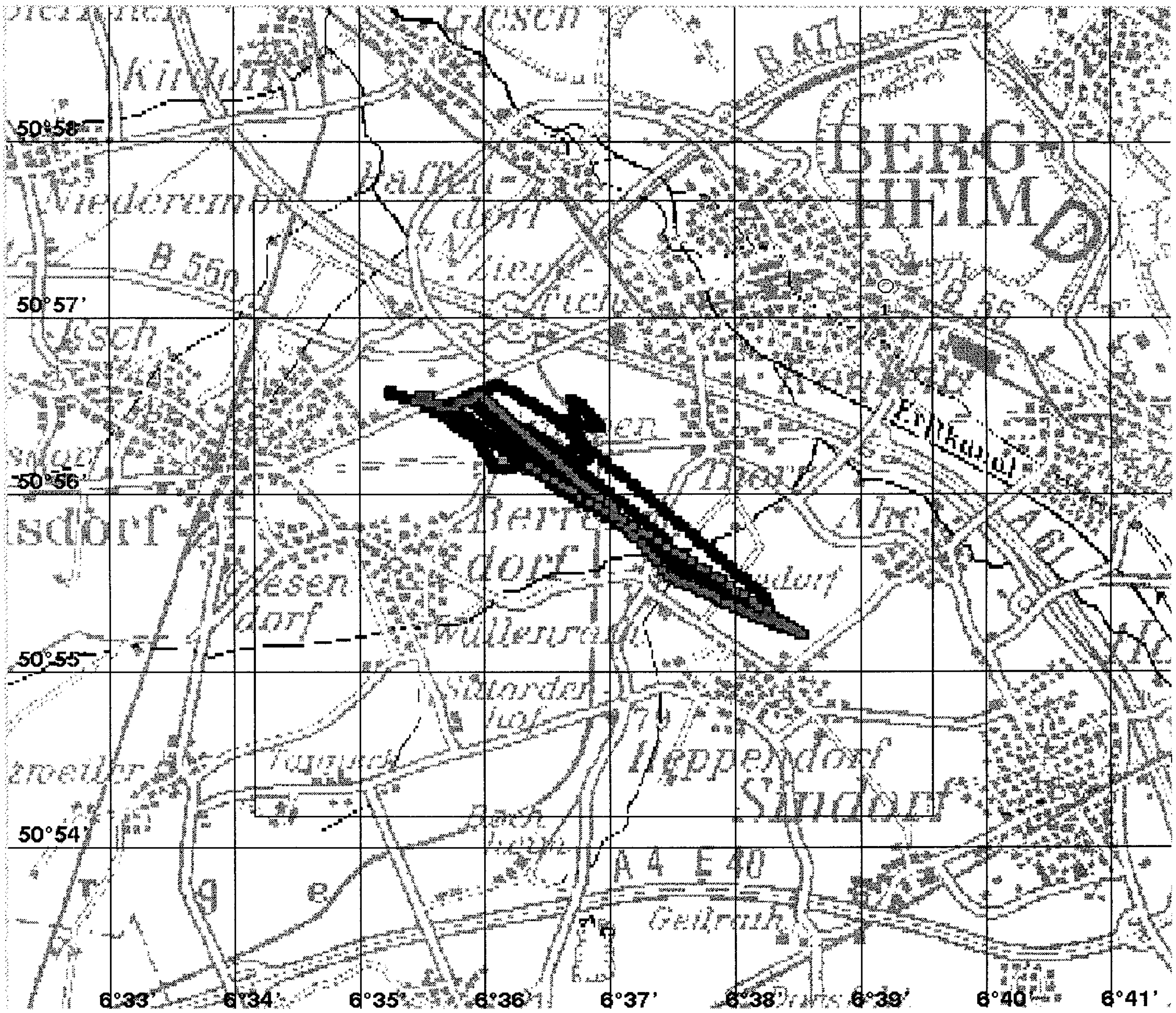

Fig. 5: Three different position measurement examples along the same route plotted in light gray, dark gray and black. For reference the GPS position assignment is plotted in gray.

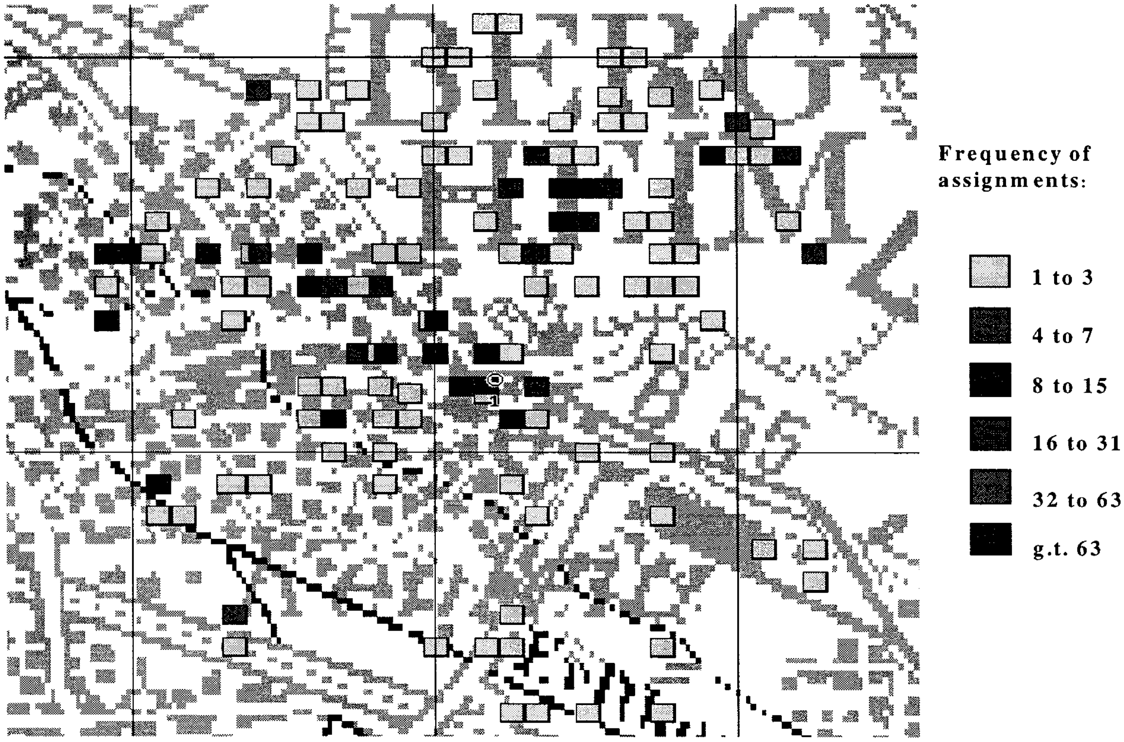

Fig. 6: Simulation result for frequency of position assignment with 8dB standard deviation: correct position marked by small circle

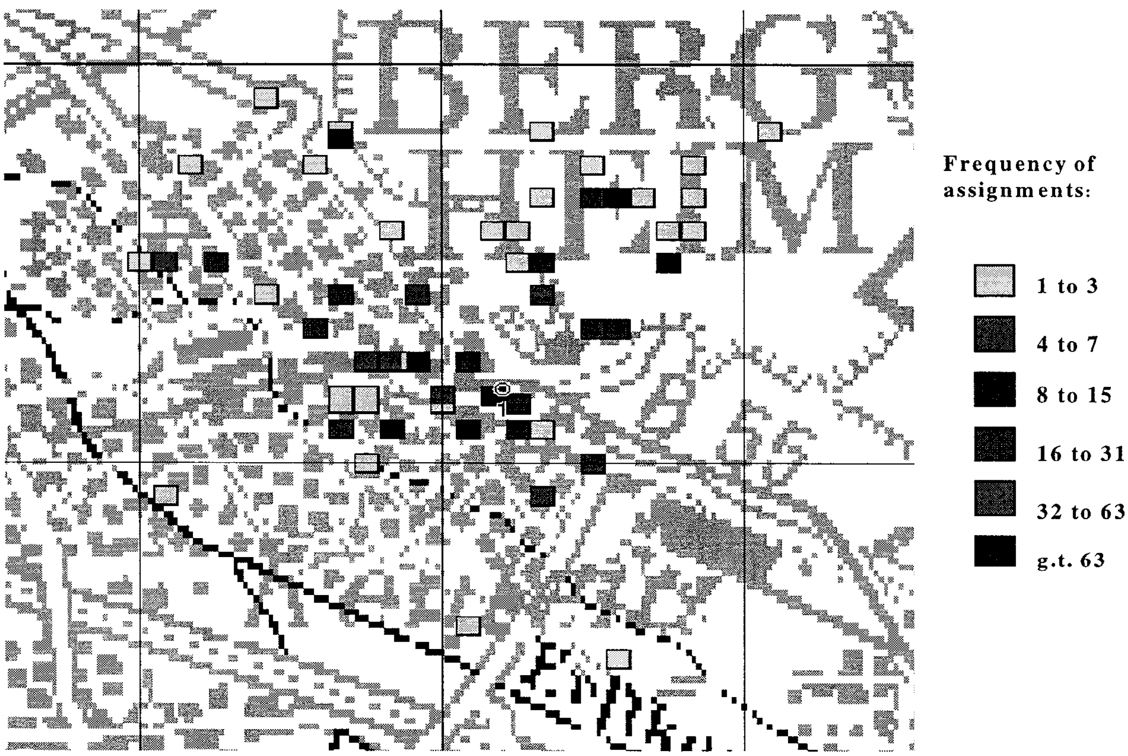

Fig. 7: Simulation result for frequency of position assignment with 4dB standard deviation: correct position marked by small circle