Mobile terminal location in indoor cellular multi-path environment

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The investigation and its scope

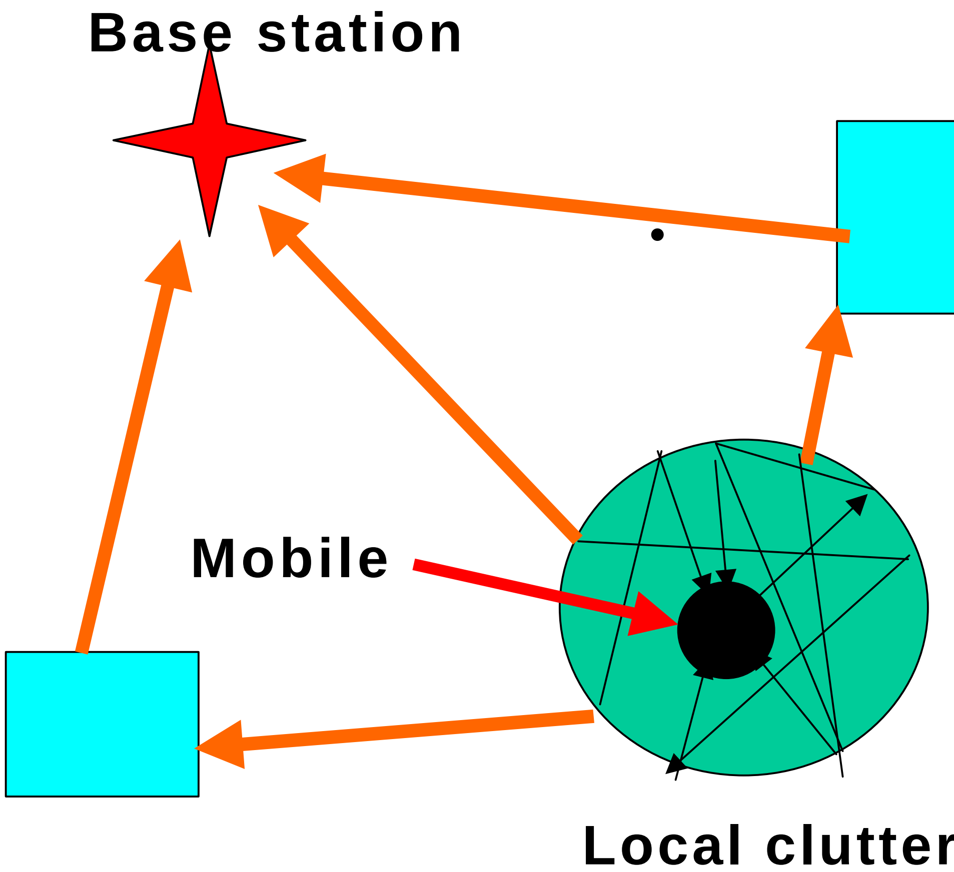
- **Given**
  - Building layout giving the shape and positions of the main scatterers
  - Measurements of the electric field received from the mobile at a finite number of fixed base stations.
  - Array antennas may be deployed at the base.
  - The orientation of the mobile radiation pattern is considered to be random.
- **Investigation**
  - Accurate, reliable and robust algorithms for locating the mobile using a Bayesian approach to inform the estimate about our knowledege of the propagation of radio waves in the given environment.
- **Scope**
  - The study is entirely synthetic
  - The results are entirely obtained using numerical methods
- **Validity**
  - The type of propagation model used in the study is known to agree well with real measurements and inspries confidence in the relevance of the results to real environments.

State of the art location algorithms

- Angle of arrival
- Time of arrival
- Time Difference of arrival
- Hybrid Angle and Time of arrival
- Beacon location algorithms
- Measurement space method:
  - deterministic
  - probabilistic (probability grid) approaches[7]. The method proposed in this paper belongs to this type

Modelling assumptions

- 2D problem. Propagation entirely horizontal
- Indoor or city micro-cell environment
- Discrete scatterers are modelled deterministically using simple polygon shapes.
- Local fading due to clutter of obstacles around the mobile is modelled as a random process
- Penetration through walls is considered
- The impact of the random orientation or the mobile terminal pattern is modelled
- Wideband transmission centred on 900MHz
- The impact of the availability of array antennas at the base terminals is modelled using an eight element linear array of non-interacting dipoles.
- Slow fading (which models prediction error) is assumed to be lognormal.



- Rayleigh fading amplitude
- Uniform phase

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Formulation

- Divide the search area into uniform grid.
- There exists a prior probability of occupancy (by the mobile terminal) for each grid block. A uniform prior probability assignment is used here.
- The location algorithm must calculate the *a posteriori* probability of occupancy using measurements (synthetic here) made at nearby base stations and incorporating knowledge of the propagation environment through the use of building layout maps together with accurate propagation models.
- The probability and likelihood that the mobile occupies the grid block m_j when the measurement at basestation M^l is known are expressed:

$$P(m_j \mid \hat{M}^l) \qquad\qquad L(m_j \mid \hat{M}^l)$$

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Field strength predictions

$$M_j^l = M(l, m_j) =$$

$$= \sum_k A_k(m_j, l) \cdot e^{if_k(m_j, l)} \cdot (a_x + ia_y)$$

Synthetic Measurements

$$\hat{M}^l = M(l, m_0) \cdot (a'_x + ia'_y),$$

m_0 is the true position,

a_x, a_y, a'_x, a'_y are Normal random variables

The likelihood function for a set of observations is defined as

$$L(m_j \mid \hat{\mathbf{M}}) = \prod_{l}^{n} L(m_j \mid \hat{M}^{l})$$

Assuming that electric field around each base station is Normally distributed random variable:

$$P(\hat{M}) = N(\hat{m}, \sigma), P(M_j^{l} \mid m_j) = N(m_j^{l}, \sigma),$$

for a set of the measurements with the present implementation of the algorithm, the likelihood function is formulated as below

$$L(m_j \mid \hat{\mathbf{M}}) = P(m_j) \frac{1}{\sqrt{2\pi}\,\sigma} \prod_{l=1}^{n} \exp\{-(\hat{M}^{l} - m_j^{l})^2 / \sigma^2\}$$

Tracking

Let ***p(m,m')*** be the state transition matrix for the probability that a grid cell ***m,*** is occupied; given ***P(m'),*** the probability that ***m'*** is occupied.
We choose it to be uniformly distributed among the adjacent grid cells and zero elsewhere.

The probability of occupancy ***P(m)*** is updated during tracking by using the following formula

$$P(m) = a \cdot \sum_{m'} P(m') \cdot p(m, m')$$

To track a moving mobile we recalculate the **Likelihood function** in the neighbourhood of the previous location. To do this we use the new set of the synthetic measurements and repeat our location algorithm for this set.

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Description of numerical experiment

- Transmission frequency is 900MHz in a two-dimensional environment.
- Scattering environment: 4 scatterers each is assumed to be perfect electrical conductor.
- Mobile antenna is omni-directional but obstructed by the user’s head.
- 6 base stations each having a linear array of 6 dipole elements spaced with uniform half-wavelength spacing.
- The numerical experiments were performed using ray-tracing (method of images) software. For the simulation: 4 reflections and 1 diffraction were allowed.

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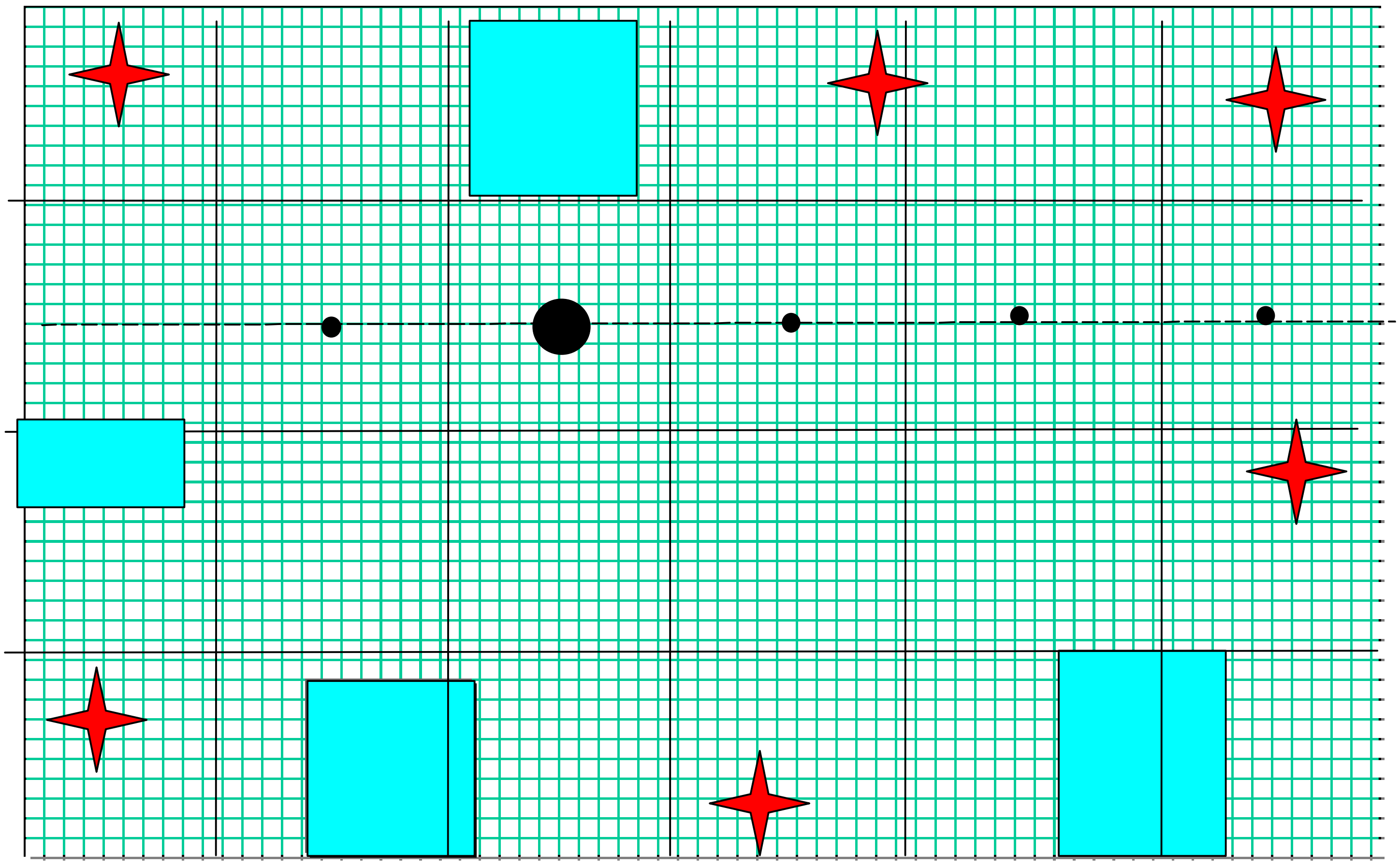
Map of simulated environment



Mobile is situated somewhere along the line:

- Narrowband information about field strength from **6** base stations (BS) with omni-directional antennas appeared to be sufficient for an almost Normal (Gaussian) behaviour of the likelihood function and thus for a unique estimation for the true mobile location.
- Using a six element antenna array at each BS, we observe a unique solution even for **3** BS, the deviation of the estimator being half of the deviation for omni-directional antennas.
- With a broad band measurement $E(\tau)$, our simulations suggest that the true mobile position may be estimated using one BS with an array antenna.
- Although initially unknown, knowing the orientation is very slowly varying can improve the resolution by approximately 20 % in the **tracking** mode of operation.

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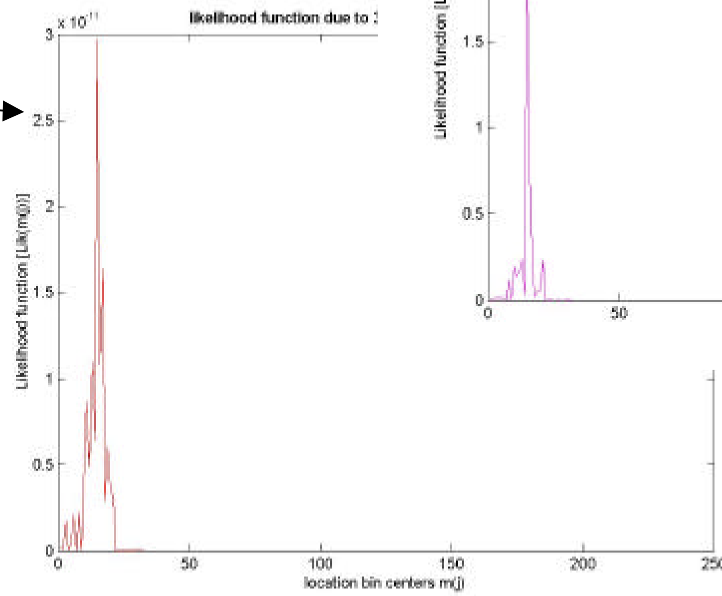
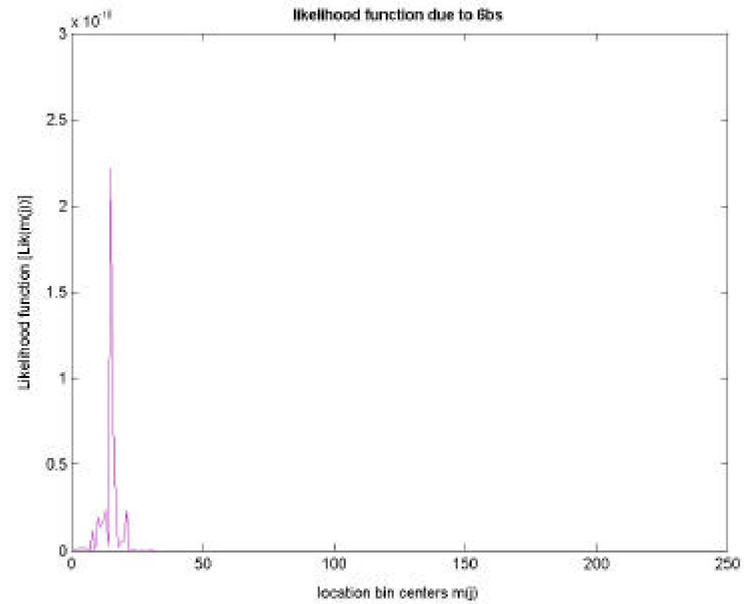
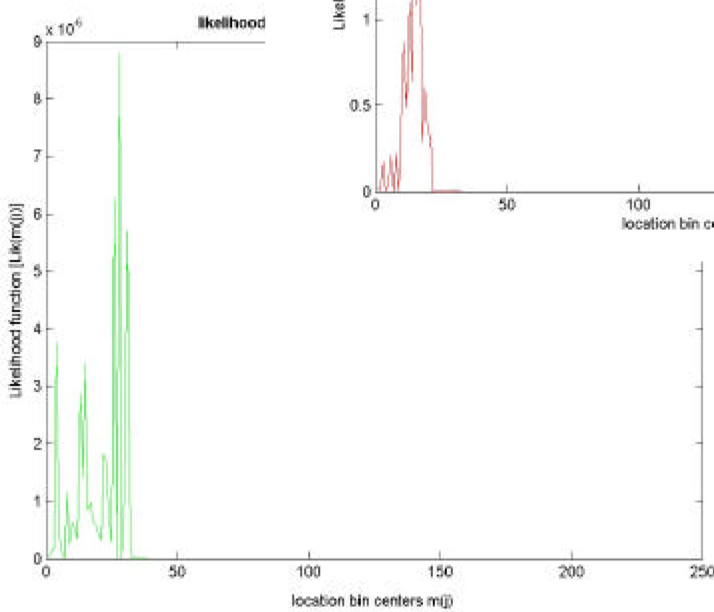
Likelihood function

3 base stations





6 base stations



1 base station

Evolution of the likelihood function with increasing amount of measurements

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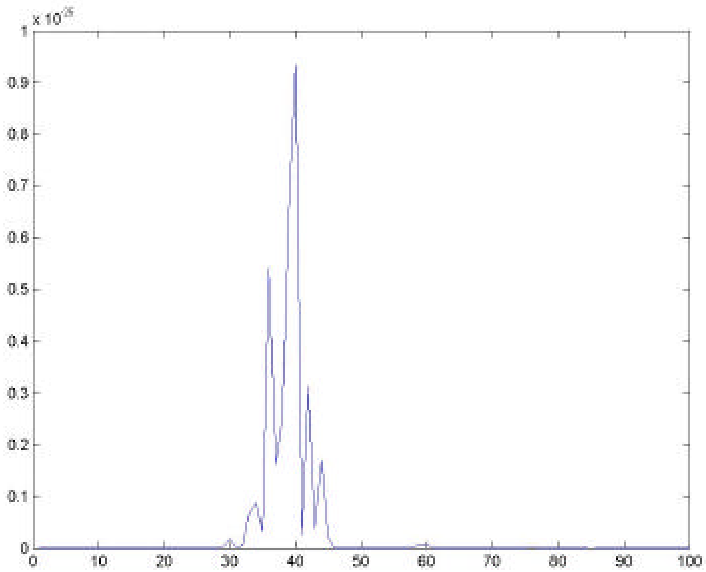

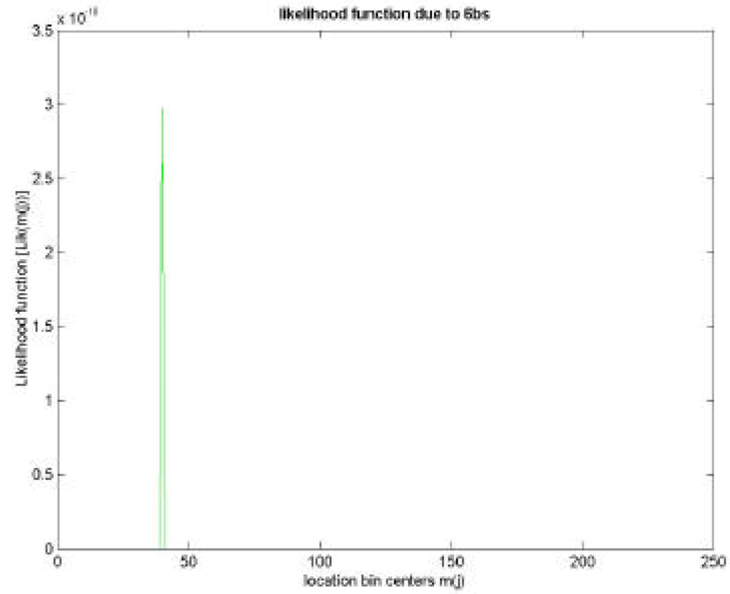

Likelihood function for position number 40 (actual) for omni-directional antenna (left) and for antenna array (right)

Conclusions

- Simulations suggest that a mobile location resolution of **2 m** is possible and that this may be improved by using array antennas (spatial diversity).
- Our simulations revealed the following
  - Thus we observed a resolution 2.4 m for 6 base stations with single antennas where the orientation of mobile is unknown.
  - For 6 base stations with six-element array antennas, we observed a resolution 1.4 metres where the orientation of the mobile is unknown.
  - Tracking improves location resolution further

Future plans

- Enhancement of the environment model
- Trial of algorithm performance in a real environment.

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