Geolocation based on Measurements Reports for deployed UMTS Wireless Networks

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Outline

- Motivation
- Objectives and State of the art
- Algorithm structure
  - Input loading
  - Initial calculations
  - Positioning cycle
  - Validity criteria
  - Output generation
- Assessment method
- Results
- Conclusion and future work

Motivation

- UE location has been one of the biggest challenges over the last years
- Many solutions available, but entail very high implementation costs
- Measurement Report Messages (MRMs) have been studied as a way of geolocating the UE
- On deployed networks: design and maintenance using drive-tests

Objectives

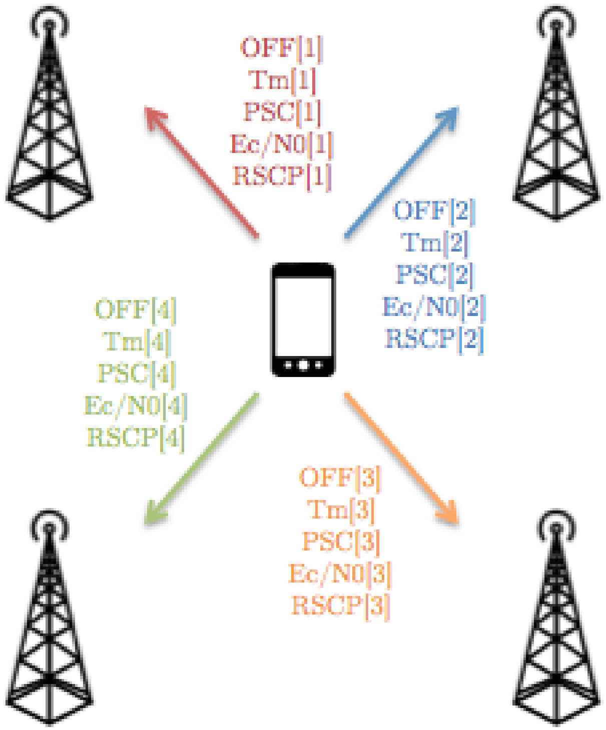
- Develop a data-abstract tool to geolocate the UE:
  - On already deployed UMTS networks
  - Using real MRMs collected in Lisbon
  - Based on Observed Time Difference of Arrival (OTDOA)
- Ultimate goal: reduce the number of drive-tests taken

State of the art

- Available literature is sparse
- Algorithms are proprietary (Ericsson, Qualcomm, Optimi)

Algorithm structure – Input (1)

- MRM data:
- Triggered event
- Cell IDs of Active Set
- Primary Scrambling Codes (PSCs) of Active and Monitored sets
- For each of the radio links:
  - Ec/N0 value
  - RSCP measurements
  - Frame offset (OFF) parameter
  - Chip offset (Tm) parameter



Algorithm structure – Input (2)

- Node B data:
- Cell names
- Cell IDs
- PSCs
- Primary CPICH power measurements
- Geographic coordinates
- Antenna heights

Algorithm structure – Initial calculations (1)

- Uniquely identifying the cells
  - For MS cells, PSC is not enough for identification
  - Search by proximity
  - Using the strongest Ec/N0 active cell as reference
- Elimination of redundant measurements
  - Measured cells located in the same site generate redundant data
  - Decision criterion: RSCP values

Algorithm structure – Initial calculations (2)

3) First position estimation

- Position algorithm used needs an initial estimation, accuracy is important for convergence
- Method (using the three strongest cells):

1. Calculate Pathloss:

$$PL_{[dB]} = Tx_{[dBm]} - \text{RSCP}_{[dBm]}$$

2. Apply the Okumura-Hata model inversely (in order of the distance)
3. Geometric trilateration

Algorithm structure – Initial calculations (3)

4) Observed Time Difference calculation

- On the k-th MRM, between UE and a cell i, is calculated using:

$$OTD_k(i) = 38400 \times \mathrm{OFF}(i) + \mathrm{Tm}(i)$$

(calculated for every non-redundant radio link)

Algorithm structure - Positioning cycle (1)

- Three step cycle that estimates the UE position
- Runs N times or until result stabilization
- Iteration 1 uses Okumura-Hata position estimate, iteration n uses estimate generated by iteration n-1
- The steps are:
  - Estimate propagation delays (τ)
  - Calculate Relative Time Differences (RTDs)
  - Multilaterate using an iterative non-linear Recursive Least Squares algorithm

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Algorithm structure - Positioning cycle (2)

Step 1) Propagation delays

In the k-th MRM, the propagation delay τ between the UE and a cell i is given by:

$$\tau_k(i) = \frac{1}{c} \times \sqrt{(x_{c(i)} - x_{ue})^2 + (y_{c(i)} - y_{ue})^2}$$

(calculated for every non-redundant radio link)

Algorithm structure - Positioning cycle (3)

Step 2) RTD

An RTD sample between two cells/sites i and j can be obtained by:

$$RTD_k(i,j) = \left(OTD_k(i,j) - \frac{\tau_k(j,i)}{0.26 \times 10^{-6}}\right) \bmod (256 \times 38400)$$

- The calculated sample is saved on a cubic matrix, in position (i,j,end)
- Value used is a outlier-attenuated median of the (i,j) array of the matrix, RTD’(i,j)

Algorithm structure - Positioning cycle (4)

Step 3) Iterative non-linear RLS trilateration (1/2)

A system of equations is generated:

$$f_k(x,y) = \begin{bmatrix} f_{k,1,2}(x,y) \\ f_{k,1,3}(x,y) \\ \vdots \\ f_{k,1,n}(x,y) \end{bmatrix}$$

Each iteration a correction to the value is applied, reducing the sum of squared residuals:

$$\min_{x,y} \| f(x,y) \|_2^2 = \min_{x,y} \left(\; f_1(x,y)^2 + f_2(x,y)^2 + \ldots + f_n(x,y)^2 \; \right)$$

Algorithm structure - Positioning cycle (5)

Step 3) Iterative non-linear RLS trilateration (2/2)

Each equation uses measurements from an MRM k reporting data from a cell/site pair (i,j):

$$f_{k,i,j}(x,y) = r_{k,i,j} - d_{k,i,j}(x,y)$$

where

$$r_{k,i,j} = c \times 78 \times \left(OTD(i) - OTD(j) - RTD'_k(i,j) \right)$$

and

$$d_{k,i,j}(x,y) = \sqrt{(x_{c(i)} - x_{ue})^2 + (y_{c(i)} - y_{ue})^2} - \sqrt{(x_{c(j)} - x_{ue})^2 + (y_{c(j)} - y_{ue})^2}$$

Algorithm structure – Validity criteria

Measures to assess the validity of the estimates (per-MRM basis). An estimate is invalid if:

- Negative RLS cycle exit flag
- Number of cycle iterations, K, is reached
- One (or more) of the samples is excessively deviant from the outlier-attenuated median. i.e.,

$$\delta_{RTD} = |RTD_k(i,j) - RTD'_k(i,j)| \geq \Delta_{RTD}$$

for a maximum error tolerance value

Algorithm structure – Output

- Text logs
- Raw MRM data
- CSV table
- Google Earth KML files
  - Active Set size
  - Ec/N0

Assessment method

- MRMs were from a drive-test
- Corresponding GPS measurements used to test accuracy of estimates
- Some intermediate calculations are necessary
  - Clock drift offset correction
  - Weighted linear interpolation
  - Distance calculation (Haversine formulae)

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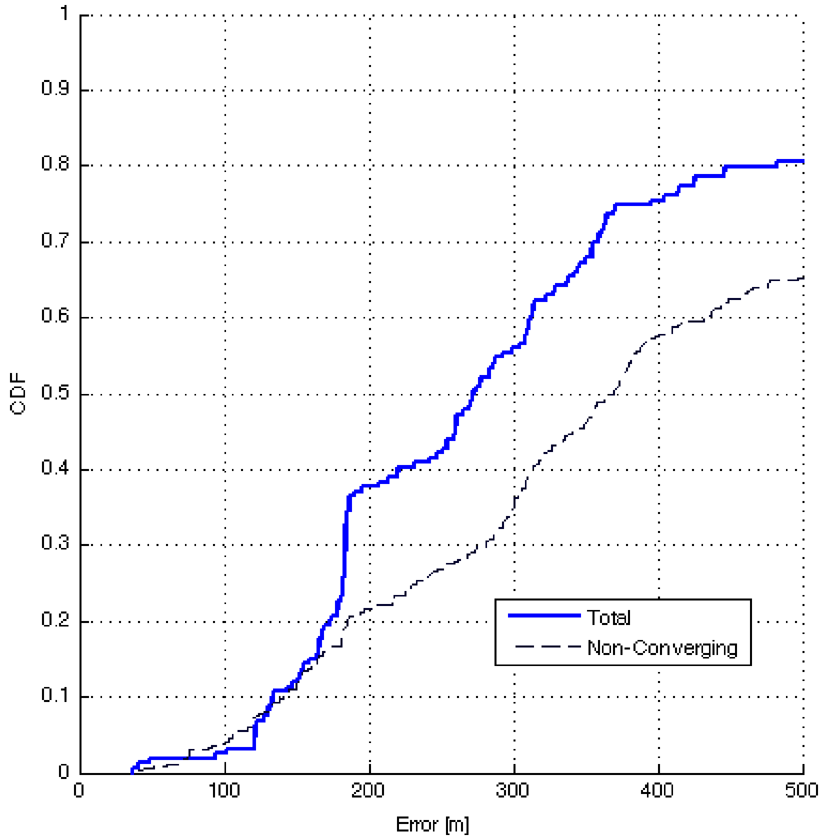
Results (1)

Analyzability and validity percentages:

Total MRMs	1123
MRMs w/ ≤ 2 measurements	630
MRMs w/ ≥ 3 measurements	493
Analyzable MRMs [%]	43.9
Valid estimates	159
Invalid estimates	334
Valid MRMs [%]	32.252

Results (2)

CDF of the positioning error:



Results (3)

Median of the positioning error: 272.62 meters

Factors:

- Radio environment, terrain
- OTDOA-based algorithm
- Trilateration method (<3-cell MRMs are useless)
- Proximity PSC scanning not completely infallible
- No elevation data
- Approximations
- Assessment method
- OTD/RTD low resolution
- Burst error bias

Conclusion and future work

- Promising starting point towards a fully-usable post-deployment low-cost geolocation solution
- Key additions should be considered, such as:
  - 3D calculation
  - Model-based Kalman filtering
  - Real-time analysis capability
  - Multi-trace analysis capability
  - LTE-compliancy (depending on the MRM parameters available)

Thank you for your time

Questions?