

Mobile communications

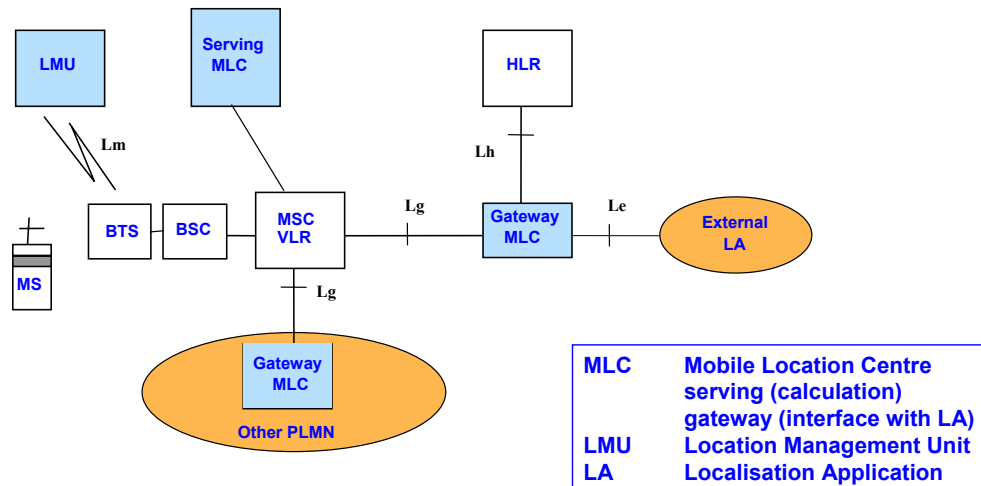


SMS and localisation

Politecnico di Torino
2006



Localisation – general architecture



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The localisation services represent a good example of how, using the mobile network data, it is possible to recover a great value in terms of application capabilities.

The interest of this service class is growing significantly, due to the variety of possible applications in the production and service processes.

Some technology-based solutions have been specified:

Cell Identity + Timing Advance

Uplink Time Of Arrival

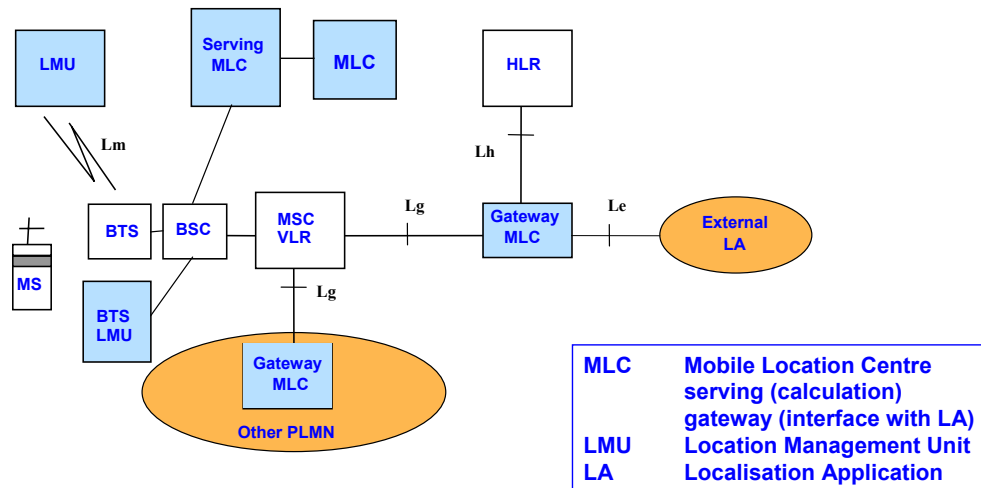
Enhanced – Observed Time Difference

In addition, there are methods based on the joint use of terrestrial and satellite systems like *Global Positioning System* (GPS) and, more recently the Galileo system.

The *Mobile Location Centre* (MLC) calculates the MS localisation through the data received by the LMU. It can be functionally between the *serving* (calculus) and the *gateway* parts.

The *Location Management Unit* (LMU) collects the necessary measures. It is connected to the network through the radio interface, hence it includes a SIM card and the related data.

Localisation – general architecture



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The figure represents an alternative configuration named *BSS Based* for the direct connection between the *Serving MLC* and the *BSC* (the previous configuration is obviously named *Network Based*).

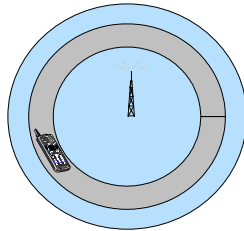
The possible procedures are:

- *Mobile Termination Location Request*
- *Mobile Originated Location Request*
- *Network Induced Location Request*

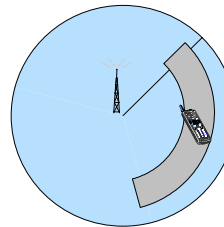
The first two are self-explanatory. The third one is triggered by the mobile but it proceeds without any verification or authentication steps: it is in fact triggered for security reasons.

Cell identity + timing advance

Accuracy depending
on max cell radius and
sector size (ranging from
100 m up to 35 km)



Accuracy depending
• on the distance from the base
station
• on the sector size.
The depth of the arc
depends on the TA measurement
accuracy



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The *Cell Identity + Timing Advance* method uses functions that are already available in the GSM system.

The cell identity is known to the network as soon as the access procedure is completed by the MS. The same holds for the *Timing Advance*. As seen, the *Synchronisation Channel* (following the *Frequency Correction Channel* in the multiframe scheme) is identified in the access phase. The time synchronisation is received by the SCH.

The *Access Burst* sent by the MS through the *Random Access Channel* allows the network to measure the delay accumulated with respect to the synchronisation burst. From the time of reception of the *access burst* the network estimates the global delay accumulated along the complete loop. Considering the frame latency times, the network calculates the *Timing Advance*. The TA is transmitted to the mobile which calculates the transmission time of the next burst.

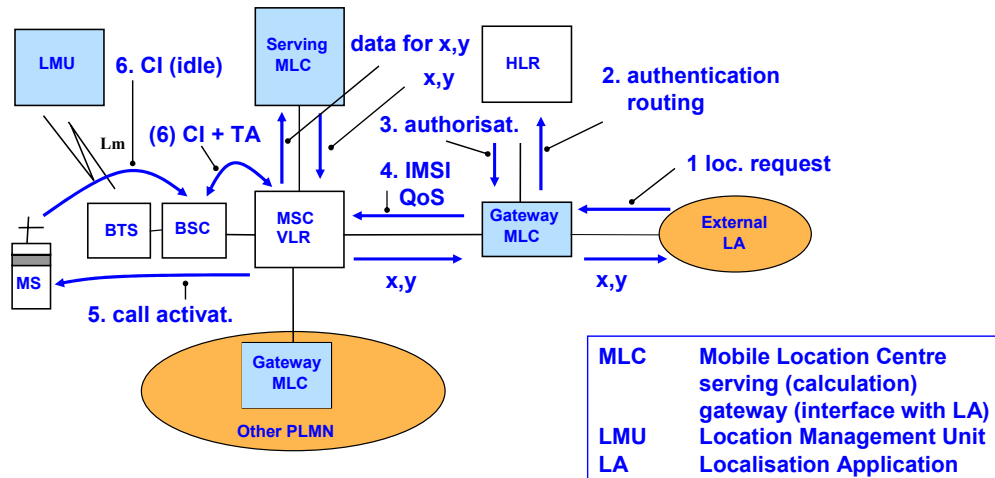
If d is the distance between the MS and the BTS, it can be calculated as:

$$d = c \cdot \frac{TA}{2}$$

Being the cell identity and the above distance known, the network calculates the position of MS within a circular crown or within a sector of the same, depending on the antenna configuration. If TA is measured in multiples of the bit transmission time m , the uncertainty is:

$$\frac{1}{2} \cdot (3.69 \cdot 10^{-6} \cdot 3 \cdot 10^8) = 550m$$

Localisation Cell ID + timing advance *mobile terminating request*

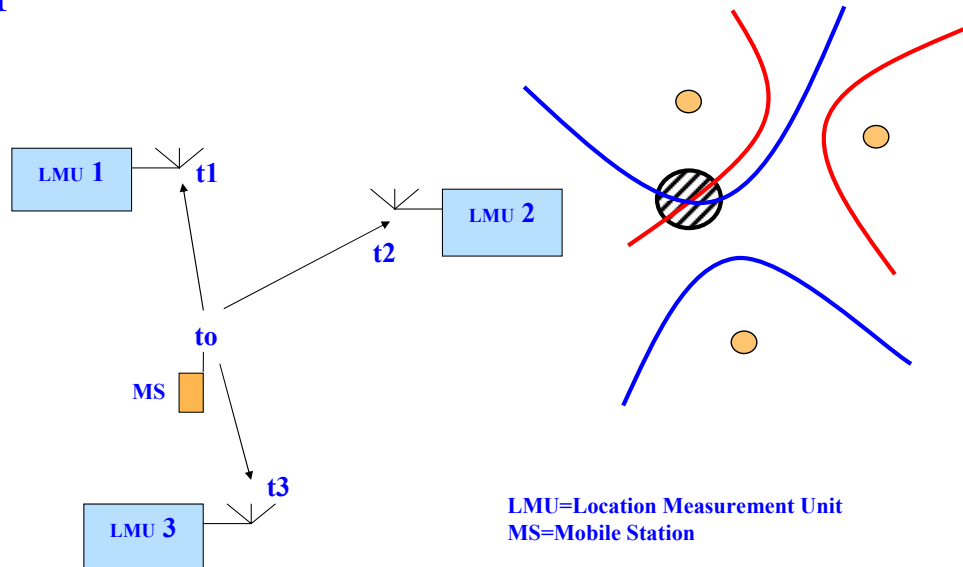


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Obviously, in the case of *cell ID + timing advance*, no impact on the network arises. The MLC has just to know the geographical position of the base stations. The MS is enabling the procedure through an *artificial* call that has to be launched by the MS itself.

The figure describes the typical *Cell Identity + Timing advance* procedure when it is generated through a *Mobile Terminating Location Request* from the network application.

Up link Time of Arrival



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In the *Uplink - Time Of Arrival* method, the mobile is forced to perform an intra-cell *handover* (which is subsequently aborted). The *Location Measurement Units* located in the territory, measure the message arrival time (e.g. an *handover access*). The units have to have the same synchronisation base of the MS and know the exact message transmission time (the network is supplying this information).

The three LMUs measure the arrival times of the message t_1, t_2, t_3 . If d_1, d_2 , are the distances of the mobile with respect to LMU 1 and LMU 2 respectively, the difference between the two distances is:

$$d_1 - d_2 = c \cdot (t_1 - t_2)$$

Which defines the MS position as a point of one of the two branches of an hyperbolic function with foci in LMU 1 and LMU 2. the above expression holds in that the LMUs refer to the same time basis, hence t_1, t_2, t_3 do not have to be corrected. In the process, the SMLC chooses what LMUs must *listen to* the message and sends to all of them the necessary information, including the emission time of the MS message.

A second hyperbolic function with foci in LMU 1 and LMU 3 one can evaluate the intersection point between the two: the MS localisation is evaluated. The hyperbolic functions are determined by considering that:

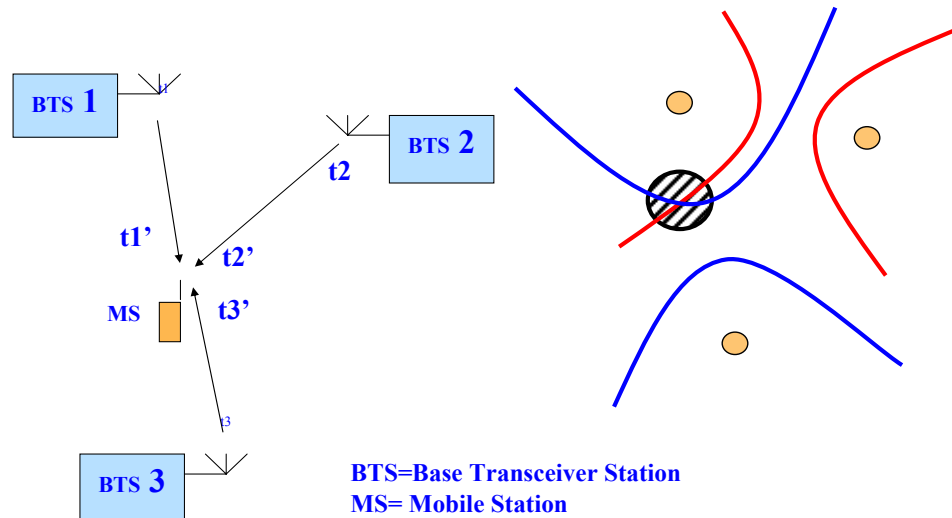
$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}; i = 1, 2, 3$$

The localisation accuracy depends on a series of factors tied to the propagation conditions (*multi path*), to the synchronisation accuracy, to the allocation of the LMUs.

The LMUs are preferably allocated in the BTSs.

There are impacts on the BSC. No impact on the mobile terminal.

Enhanced observed time difference



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The *Enhanced – Observed Time Difference* method is based on a concept that is to some extent, the dual concept with respect to the previous one. In this case it is the mobile that registers the arrival times of the messages generated by the base stations. The mobile must know the instants t_1, t_2, t_3 in which the base stations transmit their messages whose times of arrival t_1', t_2', t_3' MS has to measure. The network takes the duty of informing MS about the transmission time.

The distance between the mobile and the station i is:

$$d_i = c \cdot (t_i' - t_i - \Delta t_i)$$

Where Δt_i measures the time shift between MS and BTS, due to the non-alignment of MS and BTS (not synchronous).

$$d_i - d_k = c \cdot (t_i' - t_k') - c \cdot (t_i + \Delta t_i - t_k + \Delta t_k)$$

If the stations are synchronous, we have:

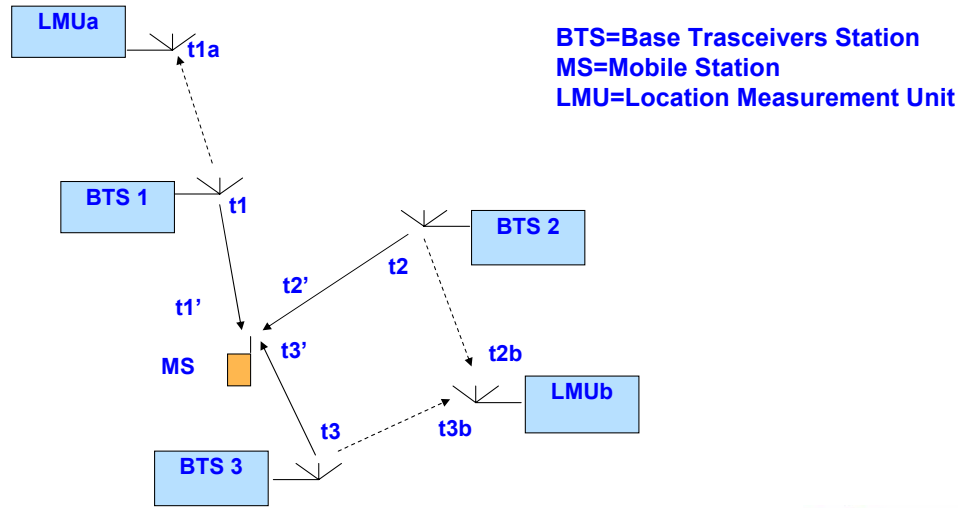
$$d_i - d_k = c \cdot (t_i' - t_k') \quad \forall i \neq k$$

which represents the point where the mobile is (branch of an hyperbolic function with foci in BTS $_i$ and BTS $_k$). By choosing two hyperboles (two couples of stations) the same geometrical configuration studied in the previous case arises.

The difference between the two methods resides in the synchronisation mechanism implemented between the stations. This synchronicity was guaranteed in the *Up Link Time of Arrival*, by the time alignment of the LMUs.

In the real situation, the BTSs not necessarily are synchronous in a strict sense. In this case synchronous LMUs are to be introduced, able to recover the time alignment (which cannot be known at the MS level).

Enhanced observed time difference (II)



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When the BTSs are not synchronous, it is then necessary to introduce synchronous LMUs located at a known distance from the base stations (in case of figure 2, 2 LMUs are located at a distance of d_{ia} and d_{ib} from the station i ($i = 1, 2, 3$) respectively). The LMUs are monitoring the transmissions of the same stations, which show an arrival time of t_{ia} and t_{ib} ($i = 1, 2, 3$) at the LMUa and b respectively.

It can be verified that:

$$d_{ia} - d_{kb} = c \cdot (t_{ia} - t_{kb}) - c \cdot (t_i + \Delta t_i - t_k - \Delta t_k)$$

from which one can obtain (remember the previous expression linking $d_i - d_k$, in function of Δt_i and Δt_k):

$$d_i - d_k = c \cdot (t_i' - t_k') - c \cdot (t_{ia} - t_{kb}) + (d_{ia} - d_{kb})$$

where all the variables are known, partly to the terminals and partly to the LMUs. As in the other cases, it is possible to proceed with the hyperbolic functions, by considering that:

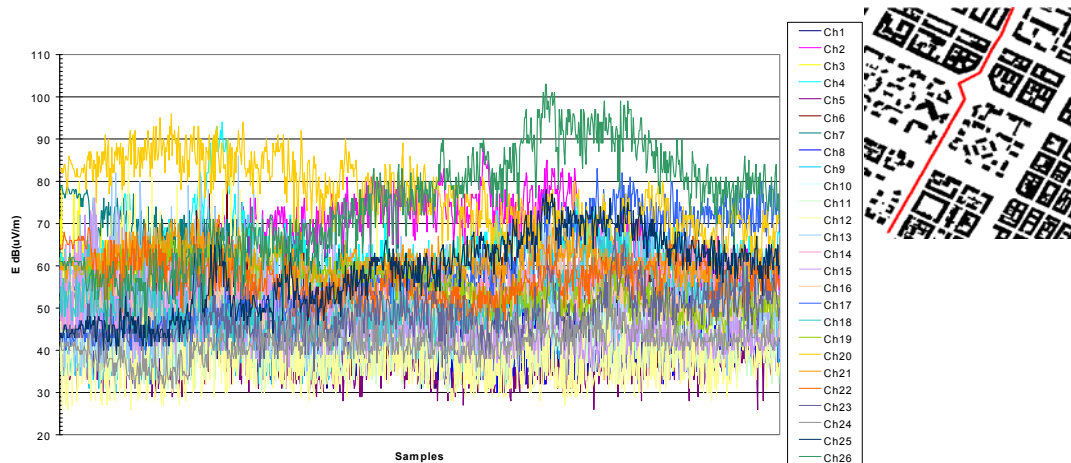
$$d_i = \left[(x - x_i)^2 + (y - y_i)^2 \right]^{1/2}; \quad i = 1, 2, 3$$

Circle-based approaches can be adopted.

In this procedure, the SMLC requires the MS to measure the arrival times of the messages coming from the surrounding BTSs. These measures are sent to the SMLC. The same SMLC asks the appropriate LMUs (from both the geographical and topological viewpoint) to measure the arrival times of the same signals.

Measured signals in central Turin

example



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Some importance is covered by a completely new family of localisation methods. They are based on the measure of the power received by the surrounding stations that are measured by the MS, even in *stand-by* conditions.

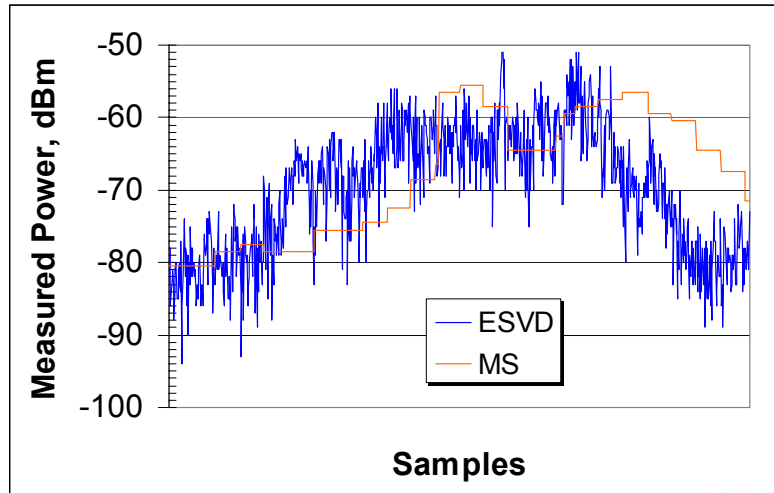
The figure shows the level of the signal received from various stations measured in different sampling instants along a given MS path. Each colour is associated to a specific station.

It can be easily understood that, in steady-state conditions and *n-uple* of signal powers can be used to characterise every elementary area of the covered zone (signature). Moreover, very likely, the same signature is characterising different areas.

This is the conceptual base on which a non-intrusive localisation mechanism can be defined.

Measured power levels

signal levels measured by a test receiver R&S ESVD and a mobile phone in "idle" mode



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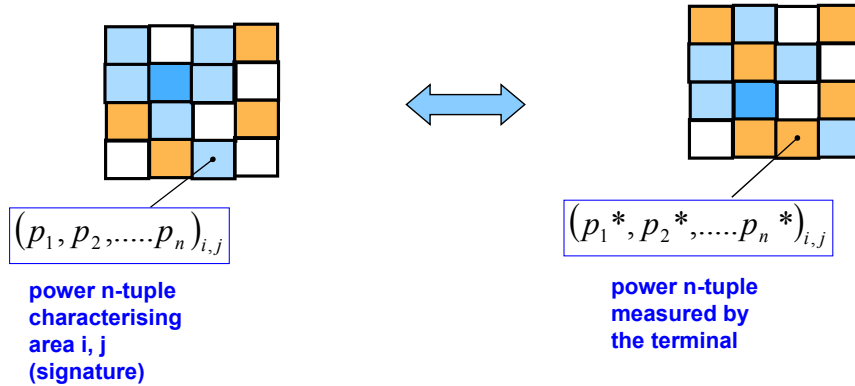
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Awfully, the power levels characterising the area can be known just through two procedures that are both characterised by errors:

- the measure performed by the mobile
- the estimate of the received power in each elementary area performed through mathematical/empirical methods already considered for the coverage calculations

The figure reports the first kind of error: the one associated to the MS-performed measurement.

A conceptual scheme



$$(i, j)_{location} \equiv (k, l): \min_{(n,m)} \left\{ distance \langle (\bar{p}_{n,m}); (\bar{p}_{n,m}^*) \rangle \right\}$$

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The localisation problem is resolved by comparing the measurements performed by the mobile with the estimates of the power levels developed in the coverage planning phase.

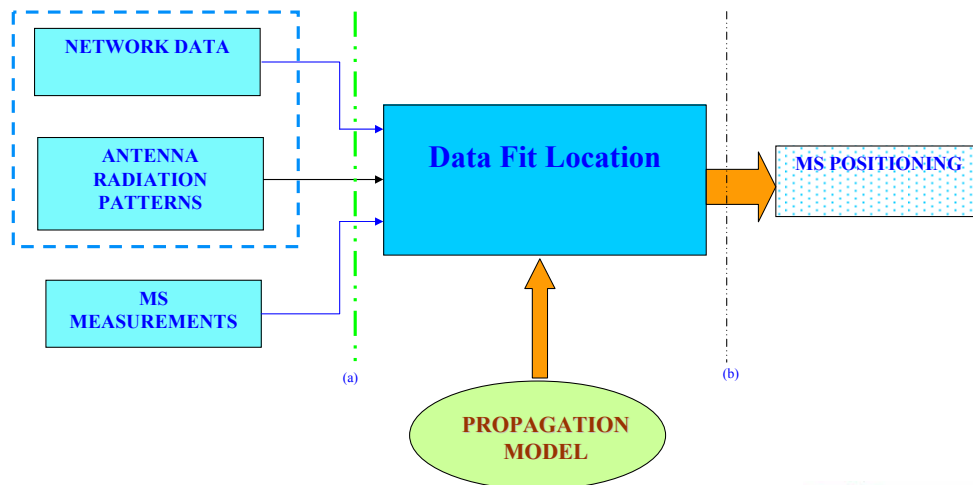
So, a measure is compared with an estimate.

The problem is then reduced to the minimisation of a complex function which represents the *distance* between the measure and the estimate.

Many approaches are possible, in function of the metric utilised to represent the overall problem. The basic value resides in the fact that no more is needed to evaluate the location of an MS than what already available for the normal functionality of the cellular network. For this reason, the method is fully non-intrusive.

The only problem to be solved is to organise the MS transmission of the collected measurements.

The basic location engine



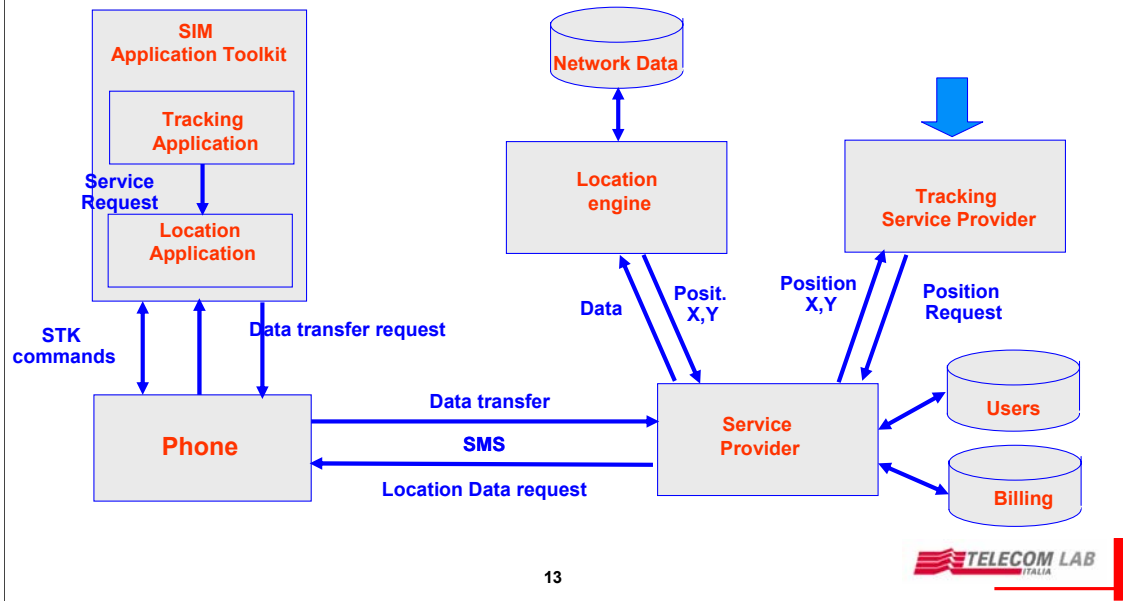
The figure reports the functional configuration of the localisation engine and the information on which it is based.

The data collected by the terminal utilise the *SIM Application Toolkit* functionalities to be grouped and transmitted. The client can be inserted in the SIM. Either the user or the network can trigger the localisation process:

- the SIM asks the terminal to transfer the last series of measurements (that the terminal is performing in any case over the BCCHs of the neighbour stations)
- the MS client assembles the measurements on an SMS which is sent to the network server registering the estimates of the power values (the signatures)
- the server calculates the MS position and supplies it to the application which has requested the localisation.

The procedure is fully transparent to the network.

Tracking - data flow



The example is clarifying the exchanges taking place in the network.

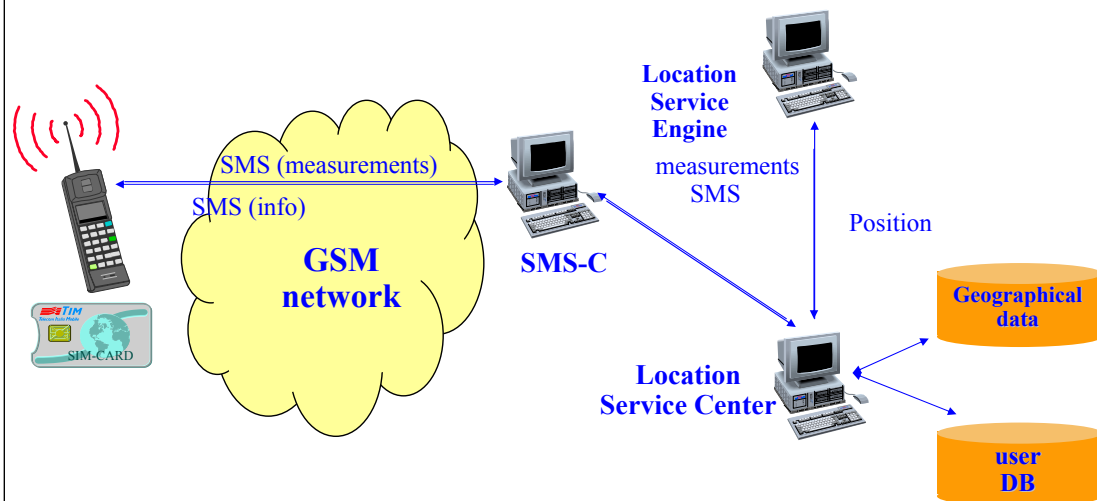
It is a service for the tracking of the position of a mobile terminal. The *tracking* application generates (possibly according to a given pace) the localisation requirements.

The SIM asks the terminal to transfer the measured data. The application creates the SNS containing the data and requires the MS to transmit it.

The network delivers the measures to the *Location Engine* which, on the base of the network data (the estimates) calculates the co-ordinates (x, y) to the service application (to the *Service Provider*).

The procedure can be activated by the same *Service Provider*.

STK based service

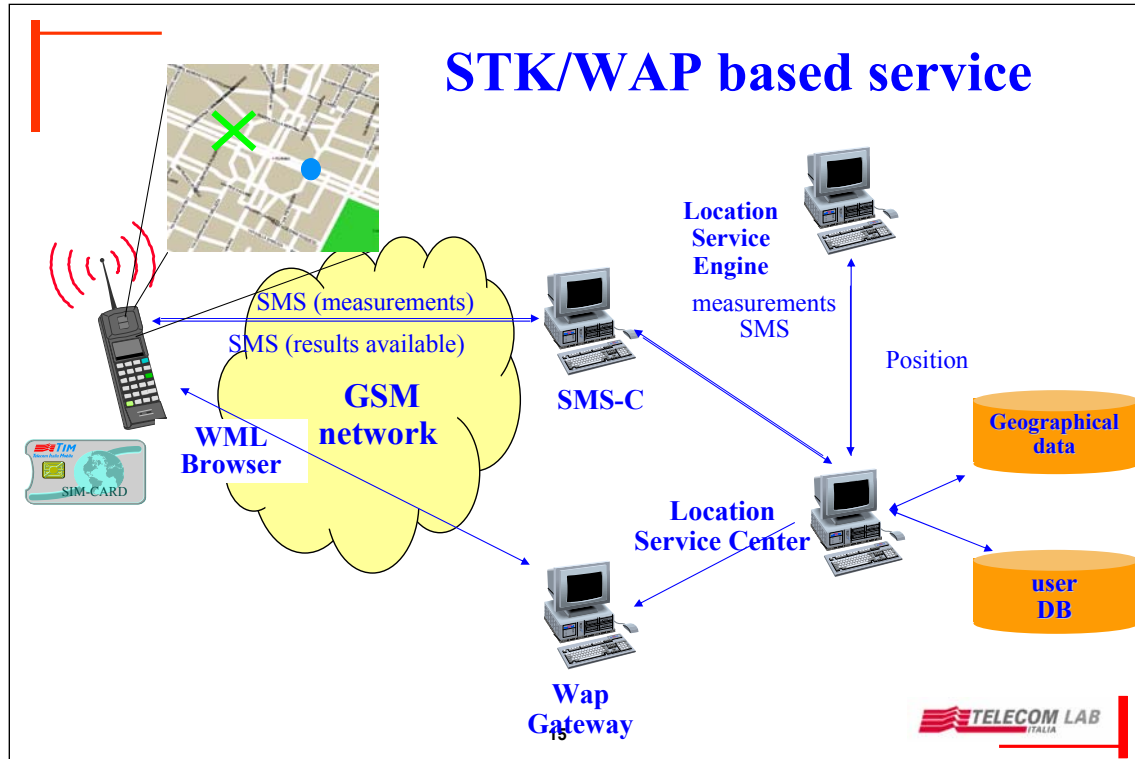


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Services are directly realised thanks to the technological approach described. The described technique has a great interest due to its transparency with respect to the network and the low cost of implementation.

The figure represents an information service.

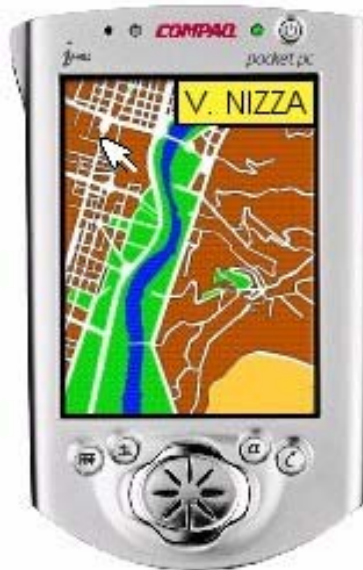


This solution is more sophisticated than the previous one. It is based on a WAP terminal.

The transaction takes place in two phases:

- The first takes place through the same mechanism described before; the terminal receives besides the textual information received by the SMS, also the necessary info needed to perform the localisation
- The second consists in downloading through WAP, the map of the place where it is located (reporting for instance, the place where the requested store is located)

PDA/Pocket PC to represent town maps



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With appropriate terminals, the representation can be presented in a clear way (even zooms on the image can be made available).

Accuracy and complexity comparison

	Stand-alone GPS	Network-aided GPS	TDOA or AOA	E - OTD	Cell ID/TA Network based	Enhanced Cell ID STK based
Handset Requirements	Hardware & software mods.	Hardware & software mods.	None	Software mods.	None	None SIM ToolKit application
Network Requirements	Minor modifications	Additional HW (ref stations)	High complexity Additional HW (LMU)	Additional HW (LMU) Netw. nodes SW mods.	Network nodes SW mods.	None
Location Accuracy	20 - 80 m	5 - 30 m.	150 - 250 m	75 ? - 150 m	500 m - ?	100 - 175 m
Coverage Reliability	Inconsistent due to urban canyons & indoors	Inconsistent due to urban canyons & indoors	Good, with difficulties due to multi-path propag.	Good, with difficulties due to multi-path propag.	High (indoor included)	High (indoor included)
Implementation Cost	Low	Moderate	High	High	Moderate	Low
Availability	Car only. Handset not yet available	Car only. Handset not yet available	?	Handset not yet available	Yes. Moderate time to deploy	Yes. Fast to deploy
Principal Players	Trimble, Qualcomm		Cell-Loc, TruePosition	Siemens, Ericsson, CPS	Siemens, Ericsson, Cellpoint	TILAB

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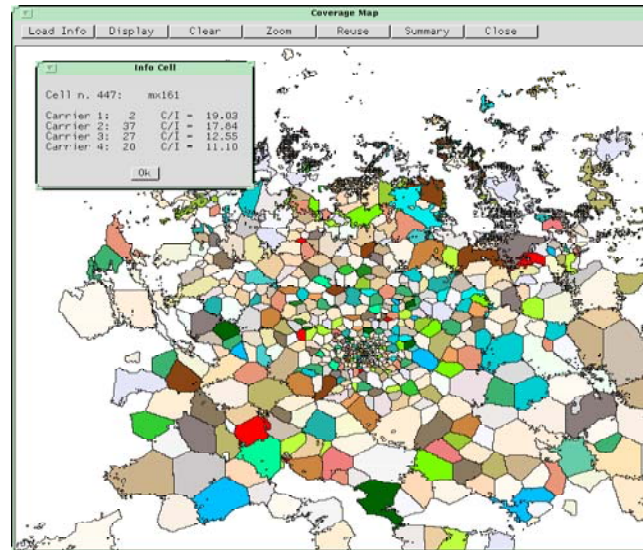


The methods present different levels of accuracy.

It is important to evaluate the accuracy with respect to the application goal that is pursued. The GPS cannot be replaced with these localisation methods for all those case when a great accuracy is requested (e.g. precise tracking of fleets). One of its limits is that it cannot work indoor. Often, it can be used in conjunction with do not present this limitation. All the other methods are suited for consumer applications.

Until now, the localisation services didn't have a great diffusion in the mobile service context. Many market research assign a growing importance mostly due to the growing interest for context-aware services or to location-based games played in real time on the basis of the relative distance of the players.

Localisation services - re-use of planning and configuration data



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Location-aware services may then be based on an extensive re-use of the cellular planning data.