# Indoor Positioning Based on Wireless LAN

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# Content

- **Next generation wireless systems** will supply mobile users with a range of new services, which will require a set of technological advancements in the present platform levels and services. Requirements will emerge among others in improved reliable ***time and location estimation***, which will be the integrated backbone information in the multitude of new services and security structures.
  The field of ***wireless location*** is an important public safety feature, which may add many new applications to future wireless mobile systems.

- **Global Navigation Satellite Systems** (GNSS) are nowadays the technique for ***outdoor location estimation***, orientation-direction assistance and land surveying, offering high accuracy, having a constantly decreasing implementation cost.
  The multitude of new GNSS signals for civil and restricted users will give an opportunity to apply the combined information from many satellite systems with the network based solutions from mobile terminals.

- **Cellular networks** can also be used to acquire ***indoor location estimates*** in places where the satellite signals are obstructed. The positioning can be based on the cellular network (triangulation, angle-of-arrival) or on an assisted GPS approach (A-GPS), where data is provided over the cellular network in order to increase the availability of GNSS positioning.
  ***Present and future cellular networks*** will support many alternative short-range wireless communications (Wireless Local Area Network (WLAN), GPRS, Bluetooth, WiMAX and Ultra Wide Band (UWB)), where an existing ***infrastructure for indoor positioning*** is becoming an important application and service. Combined with cooperative communication methods and capabilities future cellular networks will include the backbone information for indoor localization.

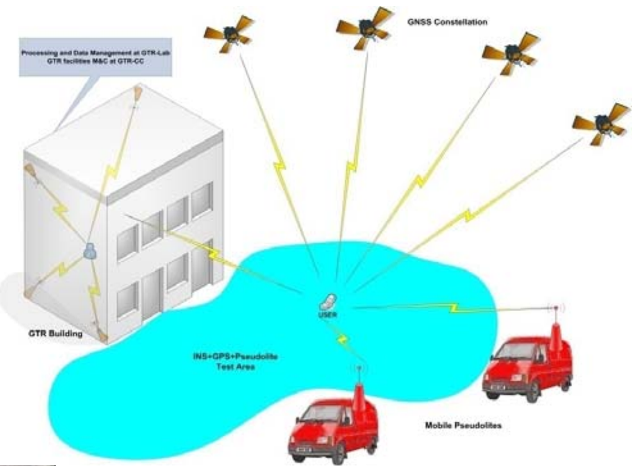
# Outline

- Methods of localization using wireless LAN
- Identification of problem areas for indoor localization
- Cooperative communication
- Results of an indoor WIMAX localization experiment
- Summary

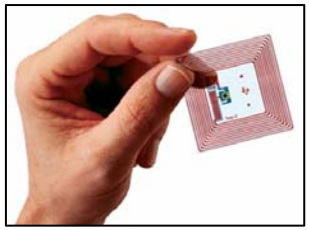
# New Areas

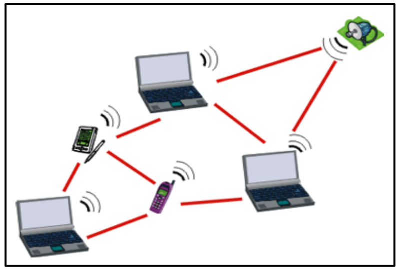
- Indoor and outdoor positioning and localization
- Geo-tagging
- Services-tagging

- Disaster management
- Security
- Environmental monitoring
- Traffic







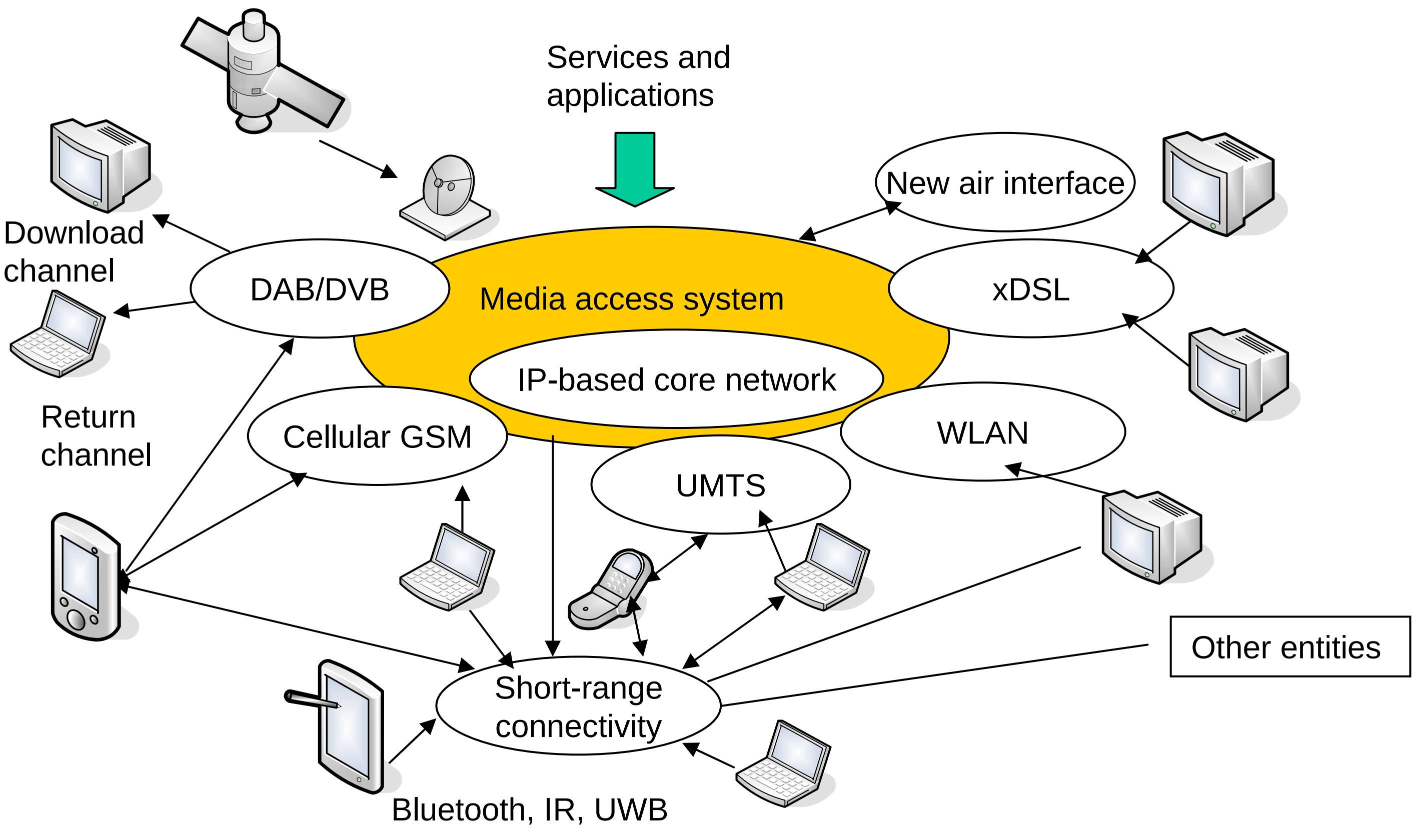
# Geolocation

**Geolocation** has gained considerable attention over the past decade, especially since the FCC in 1996 passed a mandate requiring cellular providers in the USA to generate accurate location estimates for E-911 services.

Such a mandate has been extended also to the EU in 2003, where mobile positioning is considered even a more critical issue, due to the continually increasing mobile originated E-112 calls.

As a consequence, the research in the field of mobile positioning has been boosted as an important public safety feature, which can also add many other potential applications to future mobile systems.

# Heterogeneous Connectivity



# Protocols (OSI Levels)

<table>
<tr><td>Application</td><td rowspan="4">ISUP</td><td rowspan="4">TUP</td><td rowspan="4">DUP</td><td>OMAP</td><td>ASE</td><td>INAP</td><td>MAP</td></tr>
<tr><td>Presentation</td><td colspan="4" rowspan="2">TCAP</td></tr>
<tr><td>Session</td></tr>
<tr><td>Transport</td><td colspan="4">SSCP</td></tr>
<tr><td>Network</td><td colspan="7">MTP Level 3<br>Message routing, link failure re-routing, error messaging</td></tr>
<tr><td>Link</td><td colspan="7">MTP Level 2<br>End-to-end transmission, flow control, message validation, retransmission and error checking</td></tr>
<tr><td>Physical</td><td colspan="7">MTP Level 1 (Message Transfer Part)<br>Defines the physical, electrical and functional characteristics</td></tr>
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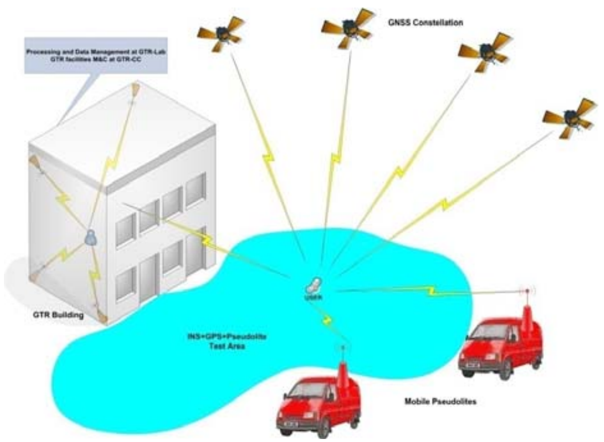
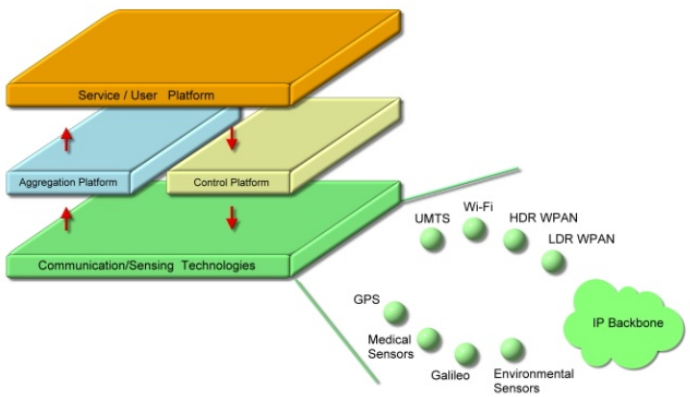


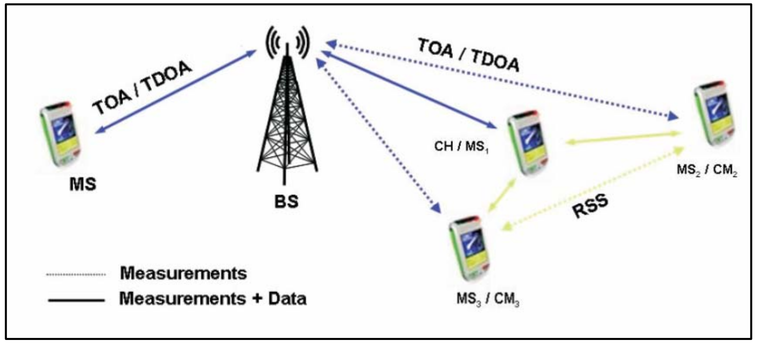



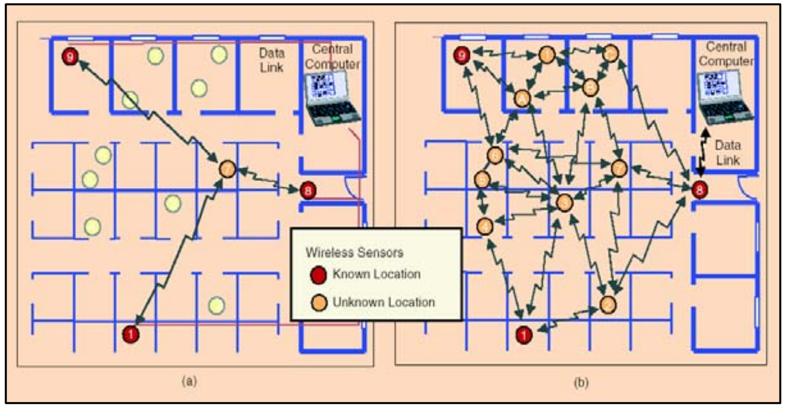
# Cooperative Wireless Positioning

Next generation wireless systems will supply mobile users with a range of appealing services, which will require a range of technological improvements.

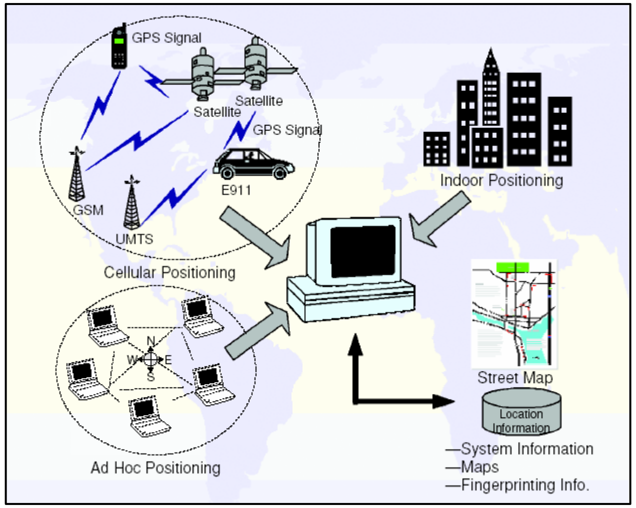
***Cooperation*** is usually defined as a coordinated effort to reach shared goals of a joint activity.

Theoretical and experimental results show that cooperation in many cases is the optimal strategy for obtaining the highest yields.



# Wireless Localization




| INDOOR | OUTDOOR<br>(POSITIONING BY SATELLITE) |
|---|---|
| WLAN<br>—CLIENT-BASED SYSTEM DESIGN<br>—CLIENT-ASSISTED SYSTEM DESIGN | GPS<br>—REQUIRES MINIMAL OBSTRUCTIONS<br>—LONG ACQUISITION TIMES (30 s–15 min)<br>—HAS TO BE SYNCHRONOUS<br>—HIGH POWER CONSUMPTION AND HIGH UNIT COST |
| SENSOR NETWORK<br>—LOCALIZATION WITH BEACONS<br>—LOCALIZATION WITH MOVING BEACONS<br>—BEACON-FREE LOCALIZATION | A-GPS<br>—MUCH MORE ACCURATE: ACCURACY OF 10–50 m CAN BE USED EVEN FOR INDOOR POSITIONING |
| UWB<br>—A PROMISING APPROACH FOR INDOOR GEOLOCATION<br>—CAN ACHIEVE VERY ACCURATE SHORT DISTANCE ESTIMATION | —IMPROVES ACQUISITION TIME (< 10 s)<br>—SYNCHRONOUS OR ASYNCHRONOUS<br>—MORE COST EFFECTIVE THAN GPS<br>—LITTLE/NO HARDWARE CHANGES REQUIRED IN BASE STATIONS |

| OUTDOOR CELLULAR NETWORK POSITIONING (STANDARD) | OUTDOOR CELLULAR NETWORK POSITIONING (NONSTANDARD) |
|---|---|
| GSM (WITH E-OTD)<br>—ESTIMATION WITH 50–125 m OF ACCURACY<br>—SLOW, ABOUT 5 s<br>—SOFTWARE CHANGE IS NEEDED | SMART ANTENNA TECHNIQUES<br>—NO CHANGES IN THE HANDSET<br>—CHANGES REQUIRED IN EACH BASE STATION<br>—ZONING IMPLICATIONS OF ANTENNA CHANGES<br>—NOT AS ACCURATE AS A-GPS IN MOST SITUATIONS<br>—PROVIDE MORE ACCURATE ESTIMATION |
| CDMA/GPRS (WITH A-GPS)<br>—HANDSET NEEDS AN A-GPS RECEIVER<br>—PROVIDES ENOUGH ACCURACY < 10 m | —NO CHANGE IN HANDSET, BUT SPECIAL ANTENNA<br>AT THE BASE STATION IS REQUIRED |
| WCDMA (WITH IPDL, TA-IPDL, OTDOA-PE)<br>—NOT AS ACCURATE AS A-GPS IN MOST SITUATIONS (50 m)<br>—NEED TO BE VISIBLE TO AT LEAST THREE BASE STATIONS<br>—REQUIRES CHANGES IN THE BASE STATION | HYBRID POSITIONING USING DATA FUSION<br>—REDUCTION OF HANDSET HARDWARE COMPLEXITY<br>HYBRID TOA/TDOA/AOA CAN IMPROVE ACCURACY<br>—GPS + CDMA CAN IMPROVE ACCURACY AND COVERAGE |
| CELLULAR ID<br>—NO AIR INTERFACE NEEDED<br>—ACCURACY DEPENDS ON SECTOR SIZE<br>—ACCURACY CAN BE IMPROVED BY HYBRIDIZATION WITH OTHER METHODS SUCH AS CELL ID + RTT<br>—ACCURACY CAN BE IMPROVED WITH OTHER METHODS | PATTERN MATCHING FOR POSITIONING<br>—ONLY SERVER BASE STATION REQUIRED<br>—SOFTWARE SOLUTION WITH HARDWARE MODIFICATION |

# Wireless Localization

**TOA:** Arrival time of a signal transmitted on the forward link (downlink) or on the reverse link (uplink) between an Fixed Reference Point (FRP) (e.g., GPS satellite, BS, AP, sensor, etc.) and an Mobile Station (MS)

**Methods for calculating TOA:**

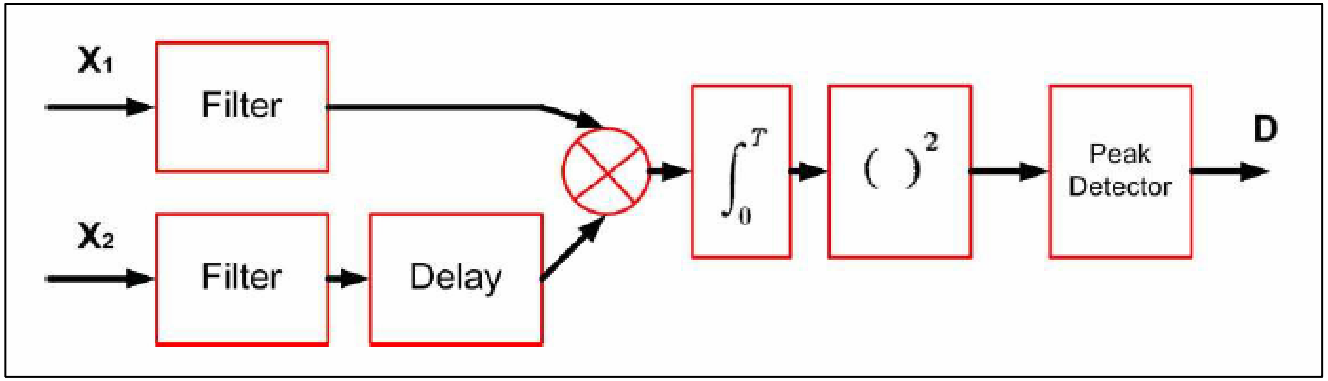
- If the clocks between the transmitting unit and the receiving unit are accurately synchronized, then the time delay is determined by subtracting the known transmit time from the measured TOA
- In asynchronous networks, a common practice is to use two-way (or round-trip) TOA measurements. In this method, one element transmits a signal to a second element, which immediately replies with its own signal. At the first element, the measured delay between its transmission and its reception of the reply is twice the propagation delay plus a reply delay internal to the second element. This internal delay is either known, or measured and sent to the first element to be subtracted
- The state of the receiver clock (its bias compared with absolute time) can be considered to be an unknown parameter and included in the data fusion

**TOA is a standard technique in GNSS, but *not* in cellular networks.**

**TDOA:** Difference in the arrival times of a signal transmitted between multiple FRPs and an MS

**Method for calculating TDOA:**

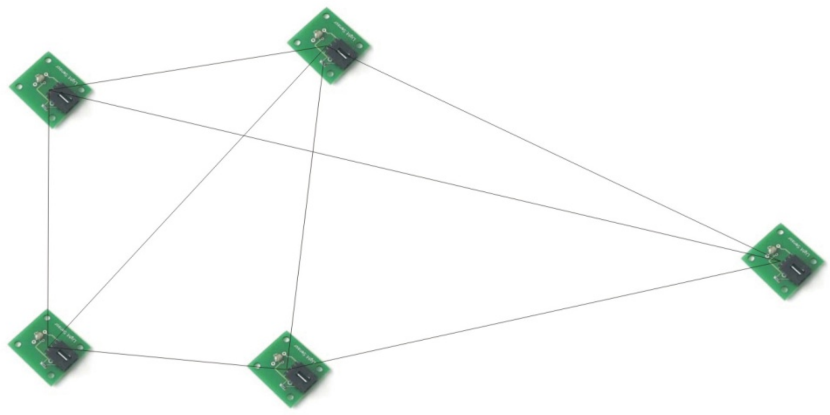
– Two reference points (FRP), which are assumed to be synchronized with each other (in case of BSs, this is done via GPS), transmit a signal to an MS. Then, the MS performs the cross-correlation of the two versions of the received signal, and the peak of the cross-correlation gives the value of TDOA

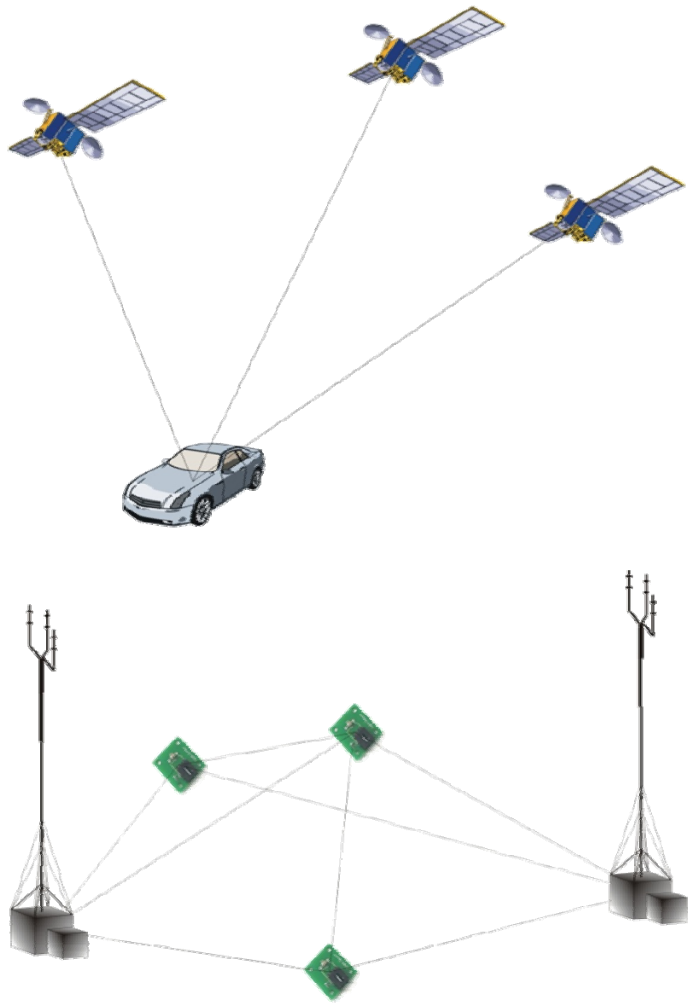



**Standard technique in cellular networks** (GSM and UMTS)

**Absolute location:** When there is a universal reference system – usually earth coordinates in terms of latitude and longitude

**Relative location:** When the reference is assigned to one of the nodes in the network (e.g., ad-hoc networks)





**AOA**: Angle of arrival of a transmitted signal

## Methods for calculating AOA:

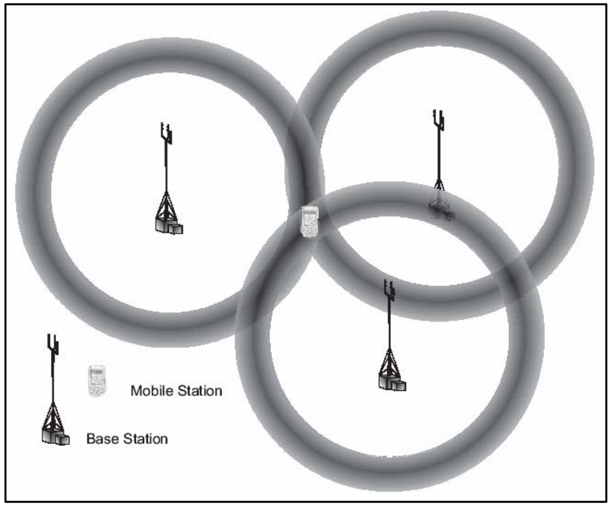
- AOA estimates can be obtained by using an antenna array. The direction of arrival of the MS signal can be calculated by measuring the phase difference between the antenna array elements or by measuring the power spectral density across the antenna array - known as beam-forming.

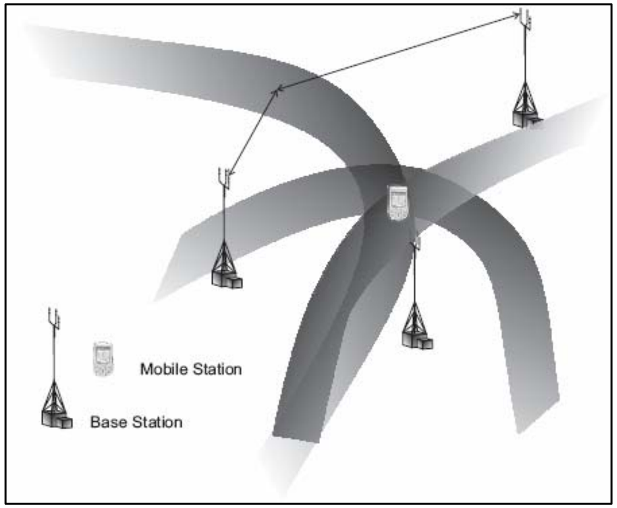
**RSS:** Received power of a signal transmitted

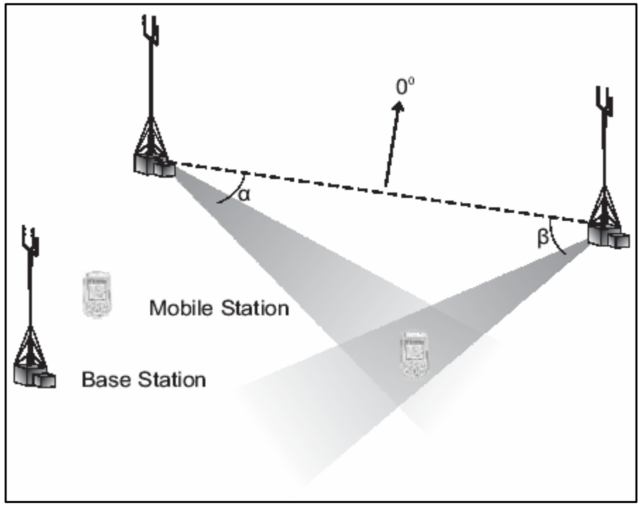
## Hybrid positioning techniques:

Utilize a combination of time, time-difference, angle and signal strength measurements (e.g., hybrid TDOA/AOA, etc.)

**Triangulation** **Hyperbolation** **Angulation**




Techniques used in Cellular Networks

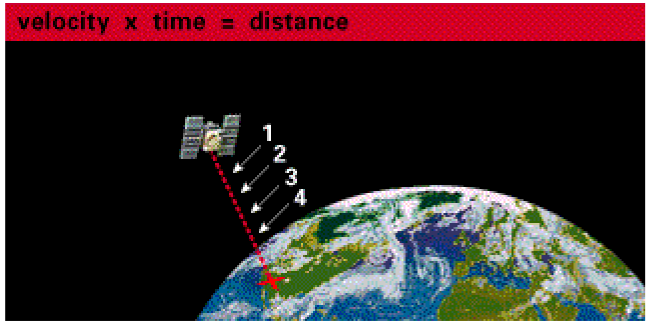
## *Measuring Distance from a Satellite*

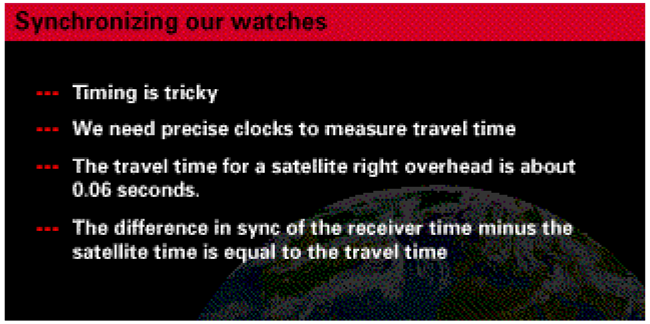
Distance to a satellite is determined by measuring how long a radio signal takes to reach our receiver from that satellite.

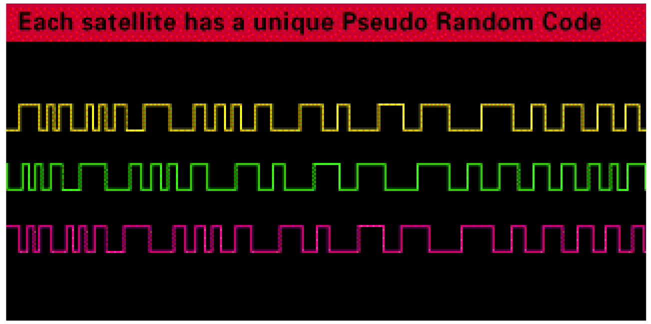
To make the measurement we assume that both the satellite and our receiver are generating the same pseudo-random codes at exactly the same time.

By comparing how late the satellite's pseudo-random code appears with respect to our receiver's code, we can determine how long the signal took to reach us – having a precise time information.

By multiplying that travel time by the speed of light, we can get the distance.

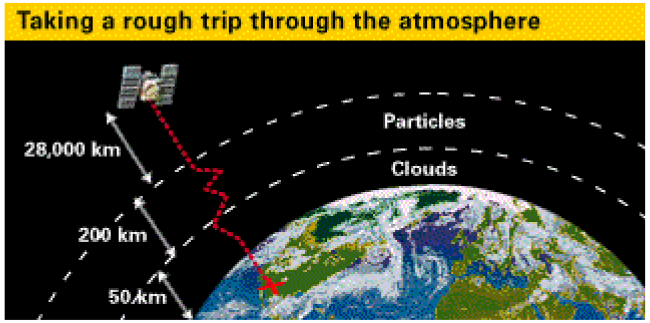


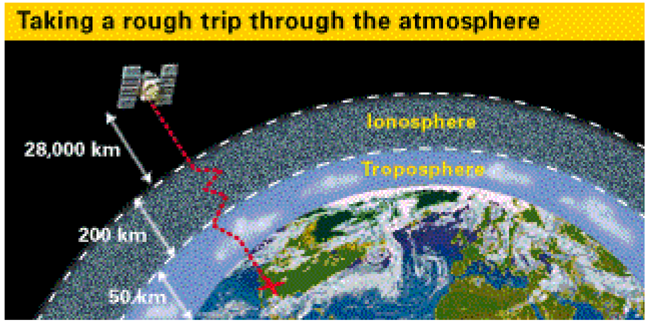



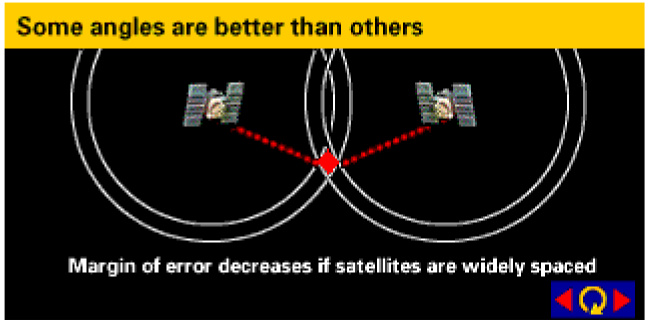
DTU

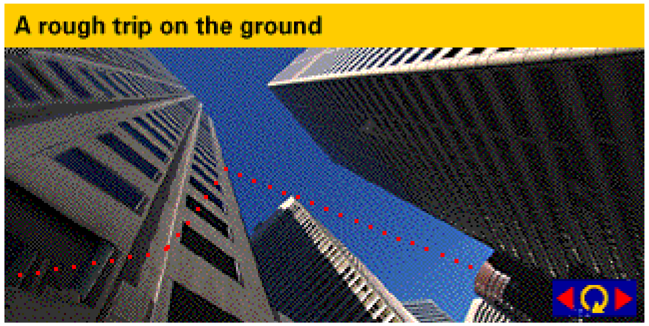
# GPS Error Sources







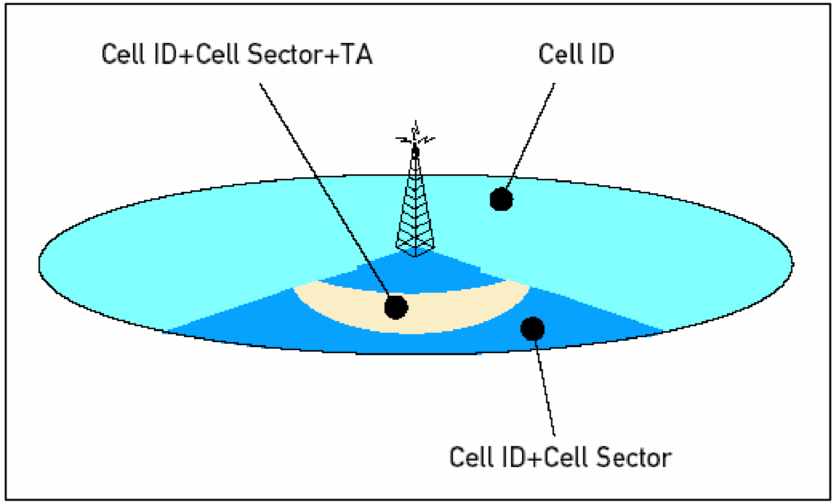

Summary of GPS Error Sources

| Typical Error in Meters (per satellites) | Standard GPS |
|---|---|
| Satellite Clocks | 1.5 |
| Orbit Errors | 2.5 |
| Ionosphere | 5.0 |
| Troposphere | 0.5 |
| Receiver Noise | 0.3 |
| Multipath | 0.6 |

**Cell ID**: It requires the network to identify the BS (Base Station) to which the MS (Mobile Station) is communicating with and the location of that BS

**Cell ID + Cell Sector**: The location of the MS is defined as the [latitude, longitude] of the center of the cell sector

**Cell ID + Cell Sector + TA (Time Advance)**: This method makes use of the time offset information transmitted from the BS to an MS. This is usually done in order to adjust the relative transmit time of a mobile handset, correctly aligning the time at which its signal will arrive at the BS.



## *EOTD for GSM*
## *(Enhanced Observed Time Difference)*

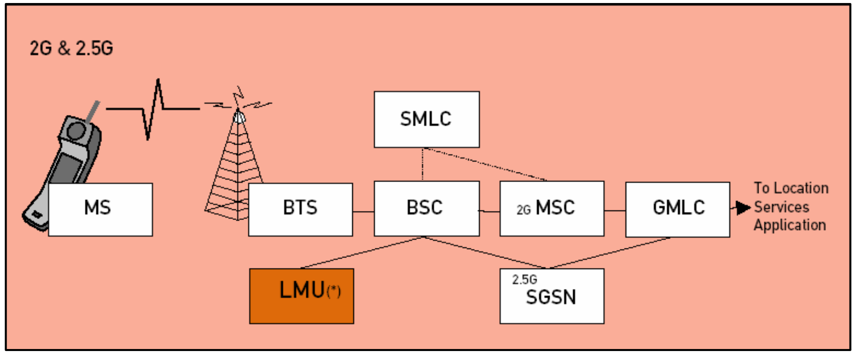
The E-OTD method requires a *synchronous network*. Location Mobile Unit (LMU) devices are therefore required to compute the clock differences between BSs and send this information to the corresponding Base Stations (BS). The serving BS then broadcasts this synchronization information to the Mobile Station (MS).

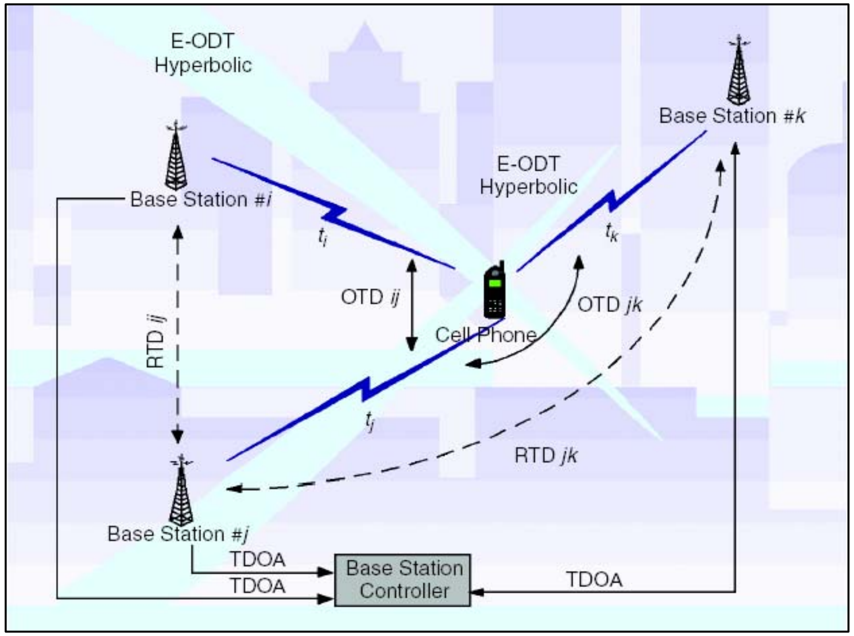
The weaknesses of the system are:

(1) Location estimation cannot be performed in areas without at least three visible BSs;

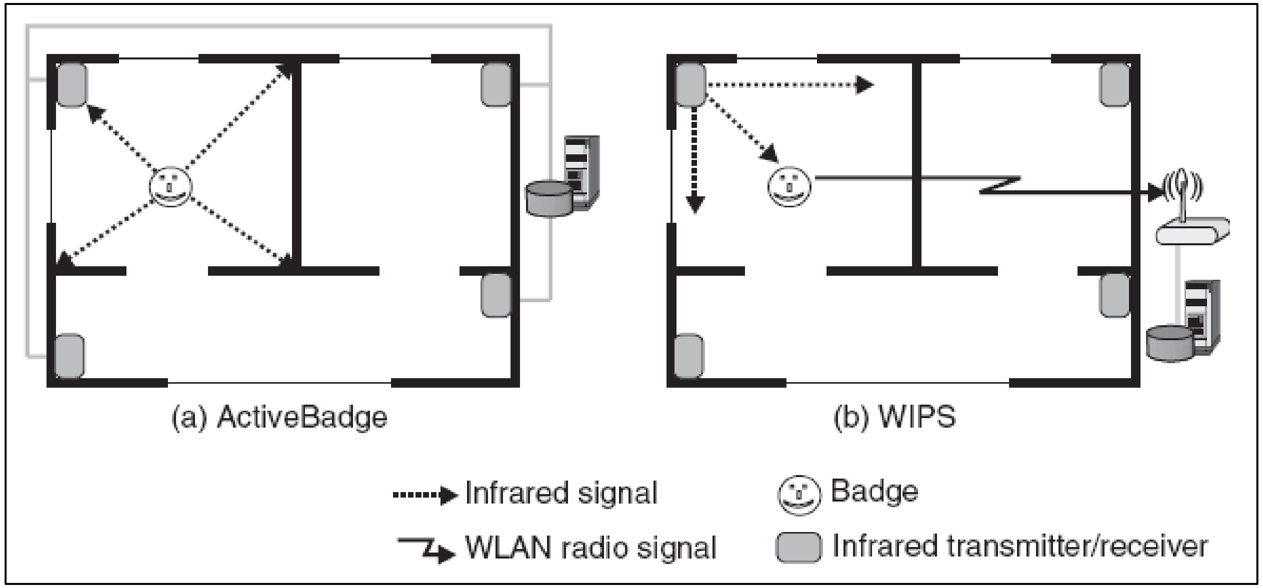
(2) Multipath can degrade location measurements; and

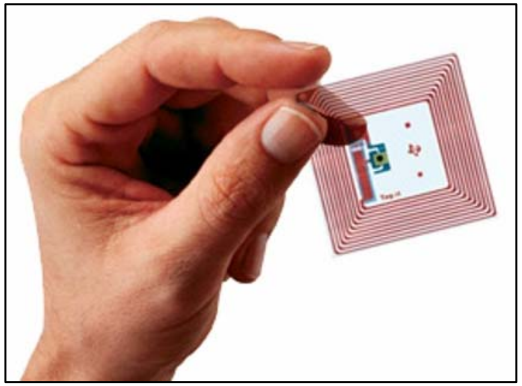
(3) The method is not compatible with other networks.



# Alternative Assisted Wireless Localization



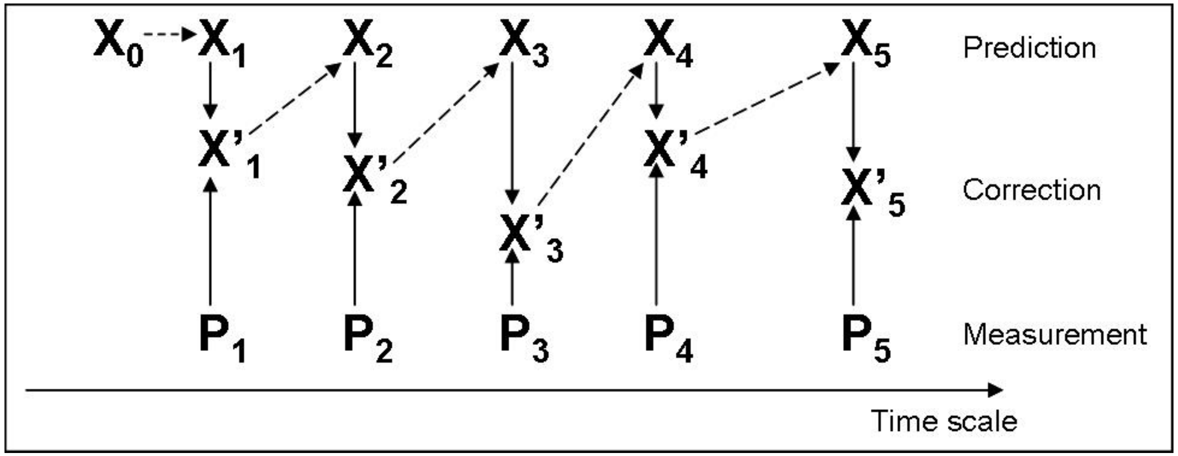



**RFID:**

- Method: proximity sensing
- Signal: radio
- Measurement: ID
- Typical accuracy: < 3 m

## Bayesian Filtering:

- Bayesian filtering techniques are techniques that estimate the state of a dynamic system based on noisy sensors' measurements.
- To the specific case of location information estimation in scenarios with static or moving devices, the Bayesian filtering techniques are being used in order to optimize accuracy.

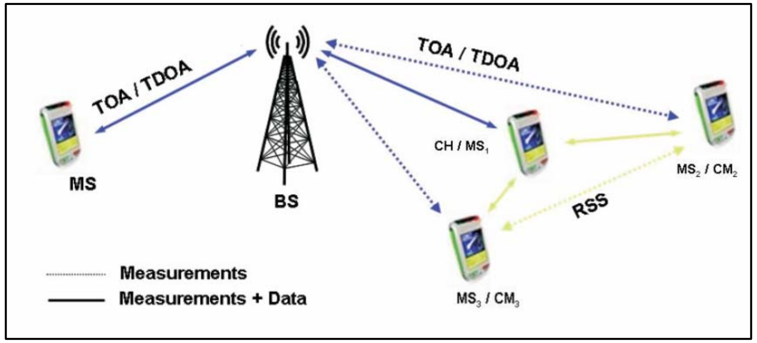


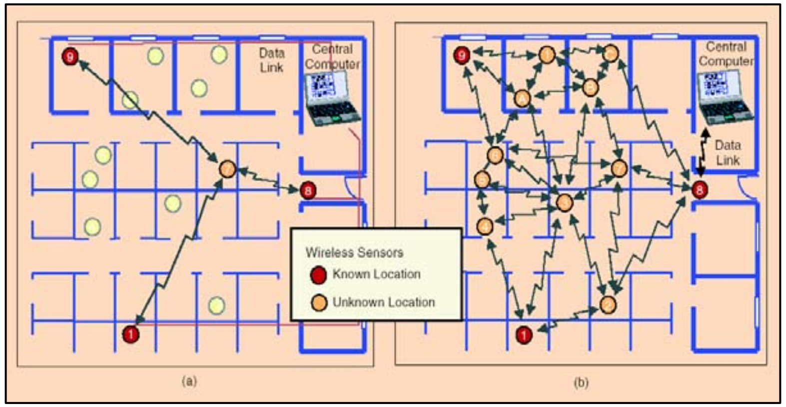
# Cooperative Wireless Indoor Localization

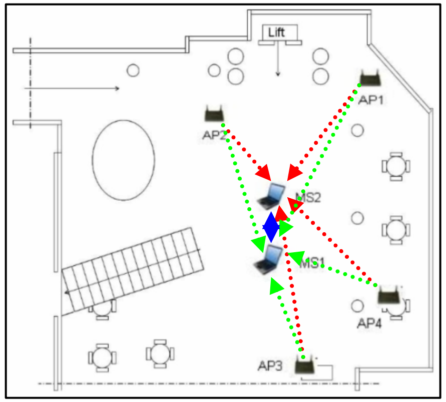
**Mobile WIMAX (IEEE standard 802.16e)**

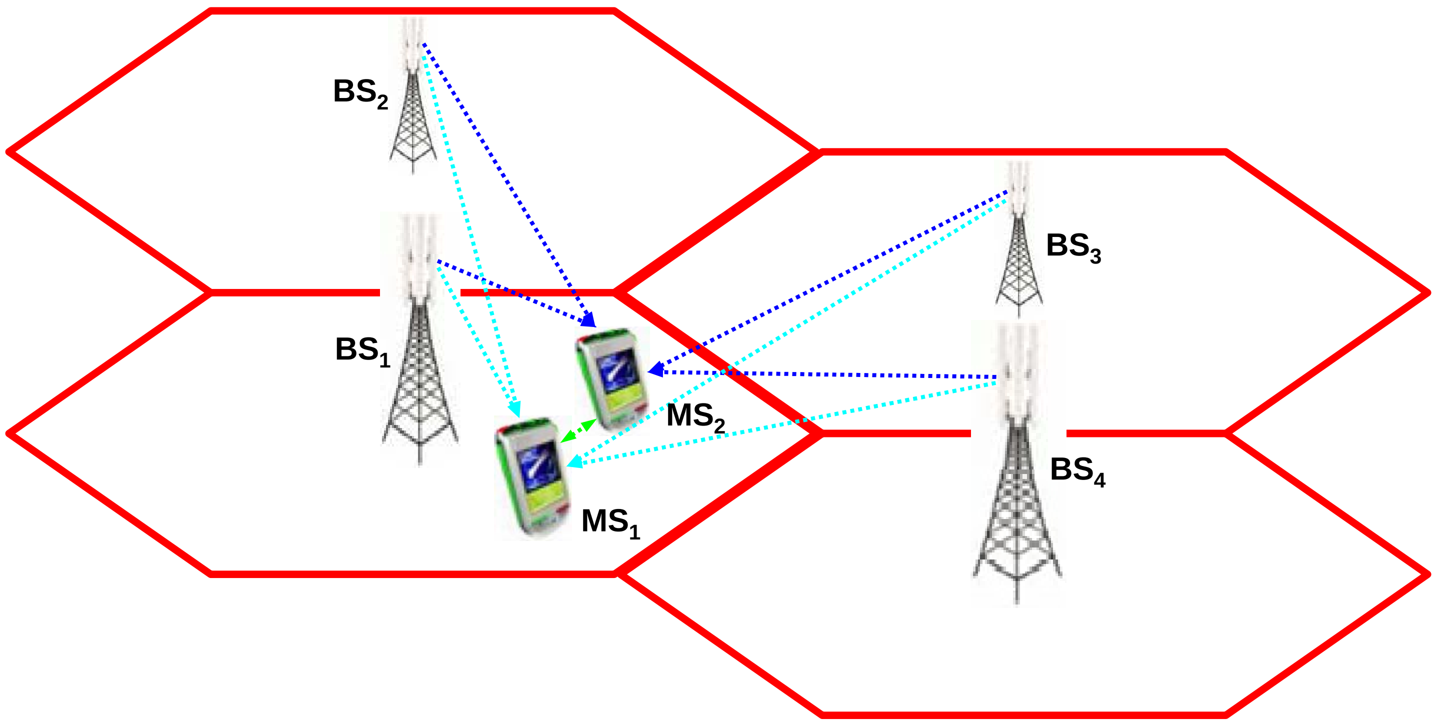
**OFDMA (Frequency Division Multiple Access and Time Division Multiplex)**

**Wireless LAN (IEEE standard 802.11a-n)**

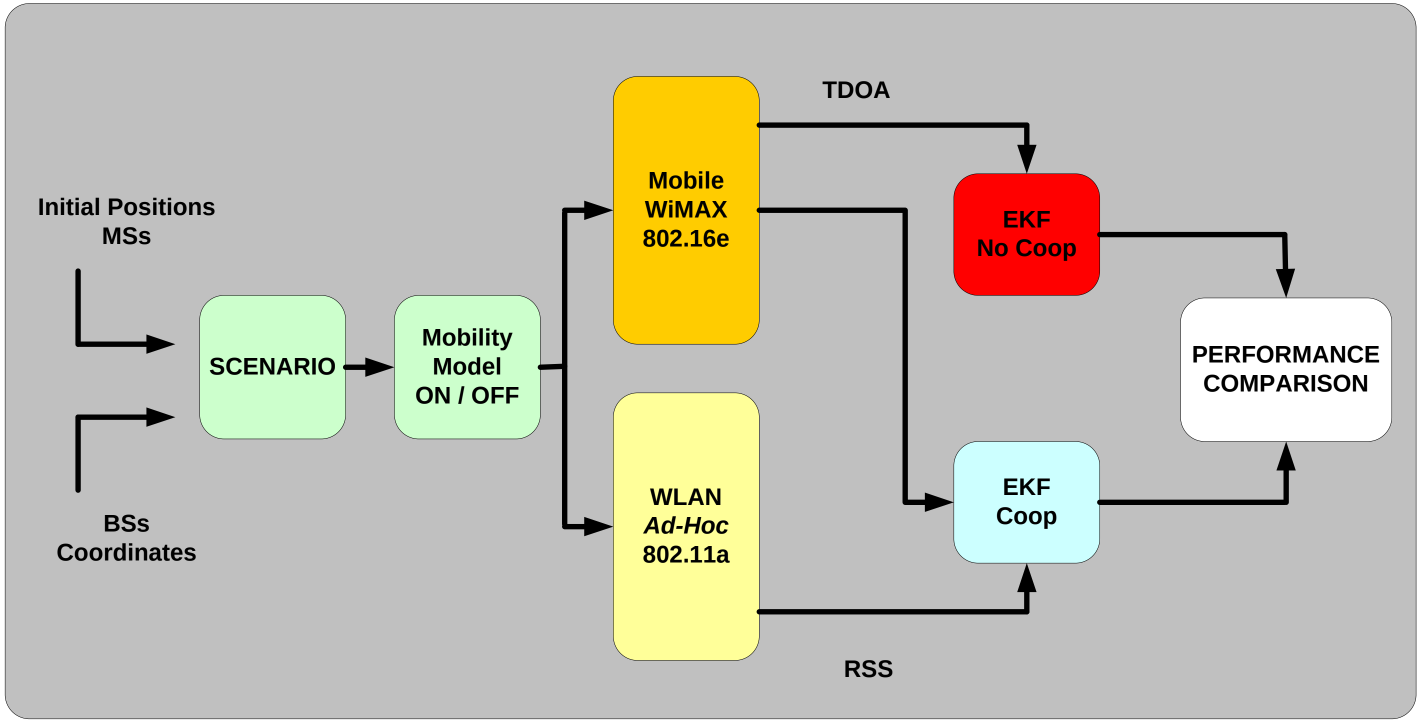


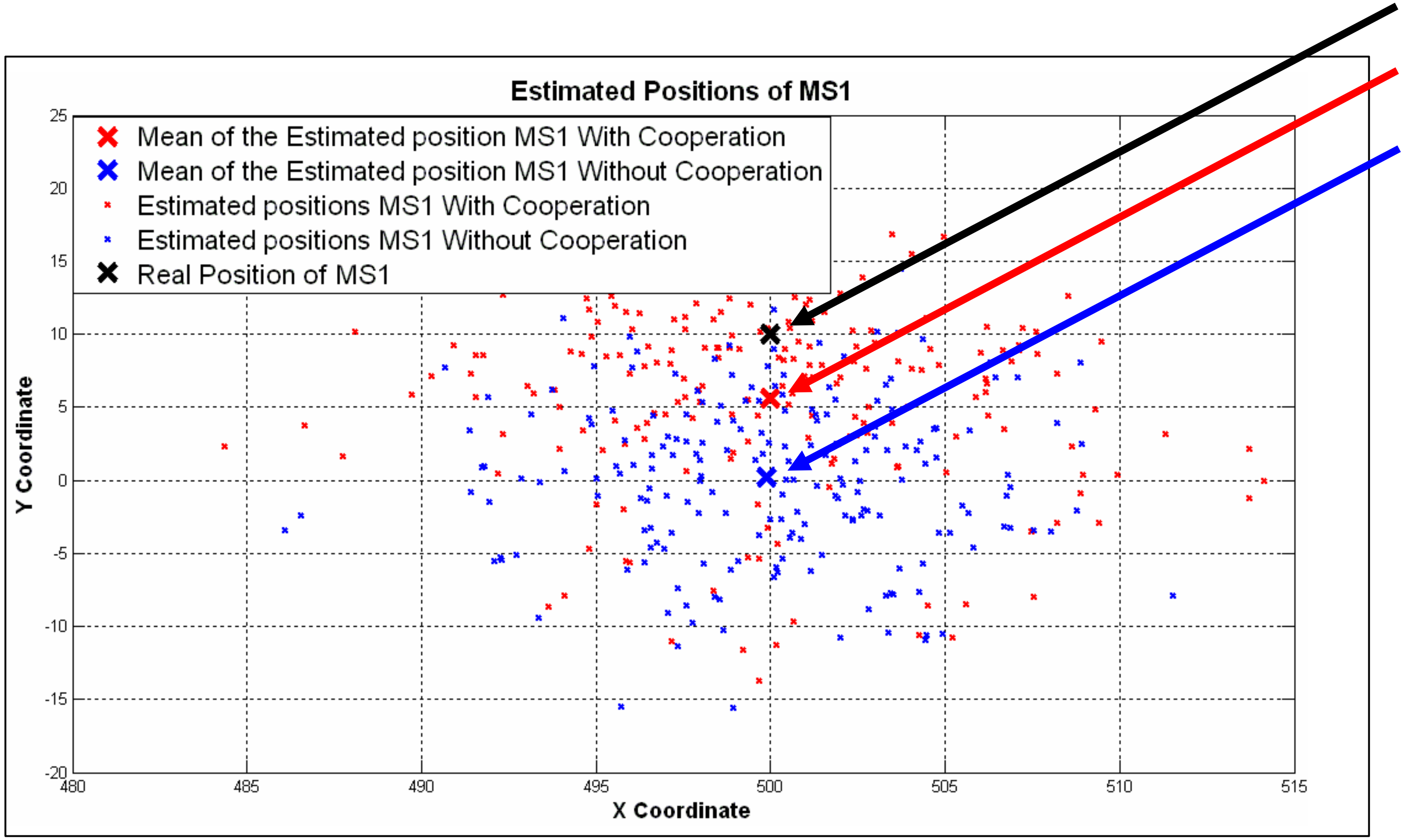




$MS_1$ and $MS_2$ are connected to $BS_1$, which is considered as the reference BS for TDOA measurements


TDOA
Initial Positions
MSs
Mobile
WiMAX
802.16e
EKF
No Coop
SCENARIO
Mobility
Model
ON / OFF
PERFORMANCE
COMPARISON
WLAN
*Ad-Hoc*
802.11a
EKF
Coop
BSs
Coordinates
RSS

200 sets of 200 measurements of
TDOA and RSS (Received Signal Strength)

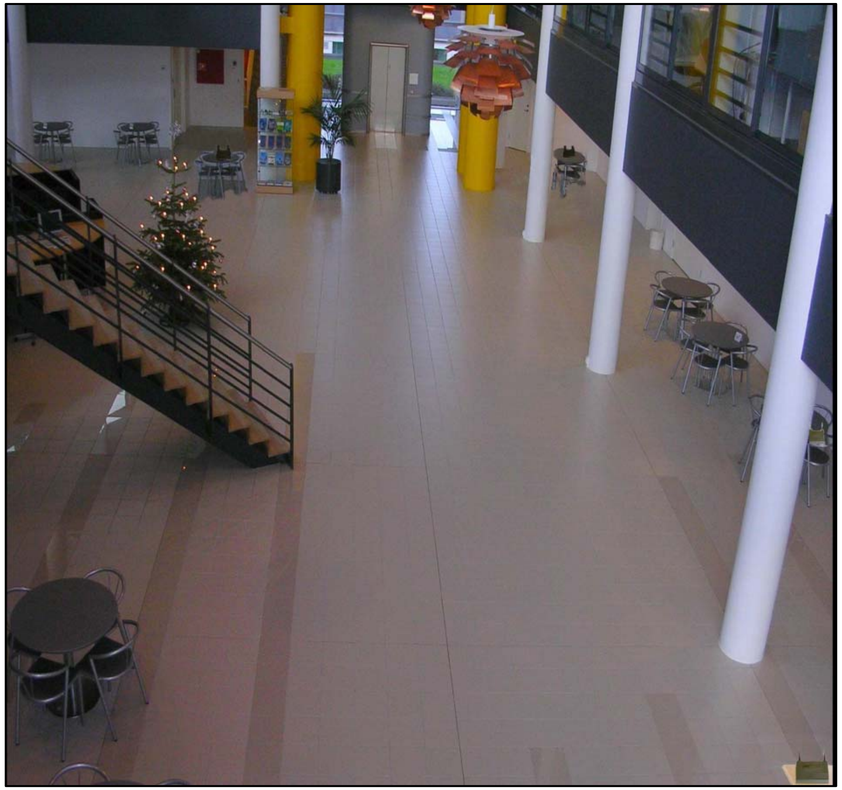


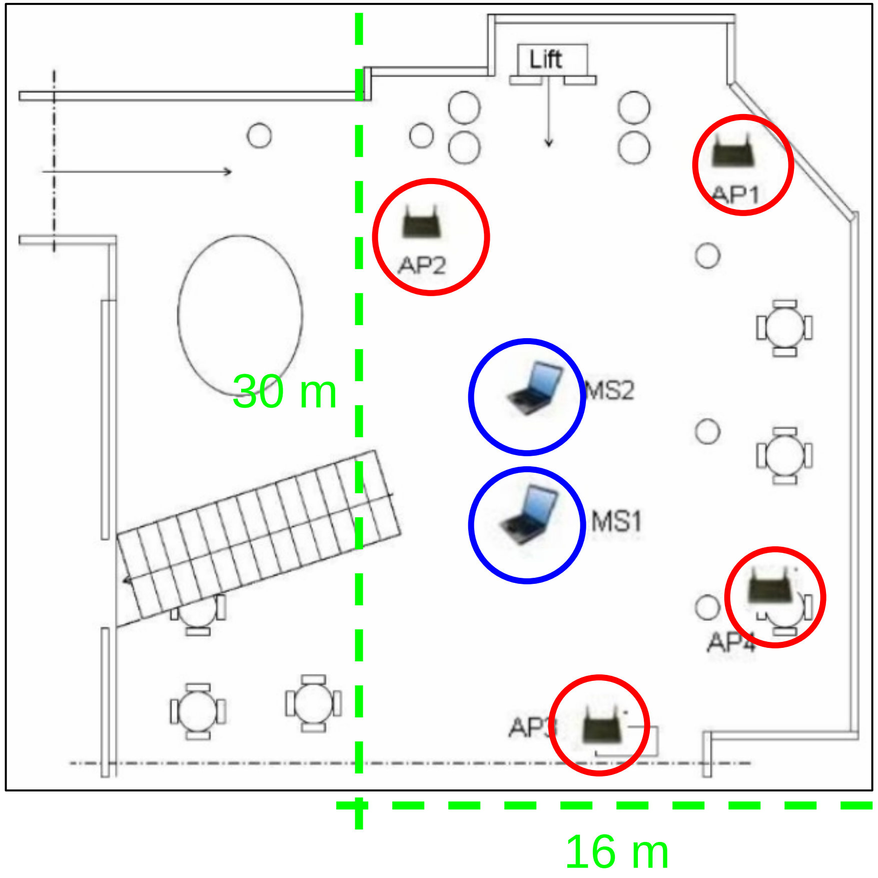
| STEPS | 1:500 | 501:1000 | 1001:1500 |
|---|---|---|---|
| RMSE MS1 Without Cooperation | 41.62 m | 43.98 m | 42.56m |
| RMSE MS1 With Cooperation | 33.05 m | 43.11 m | 42.50m |
| RMSE MS2 Without Cooperation | 40.42 m | 43.98 m | 37.56m |
| RMSE MS2 With Cooperation | 31.48 m | 43.33 m | 37.55m |

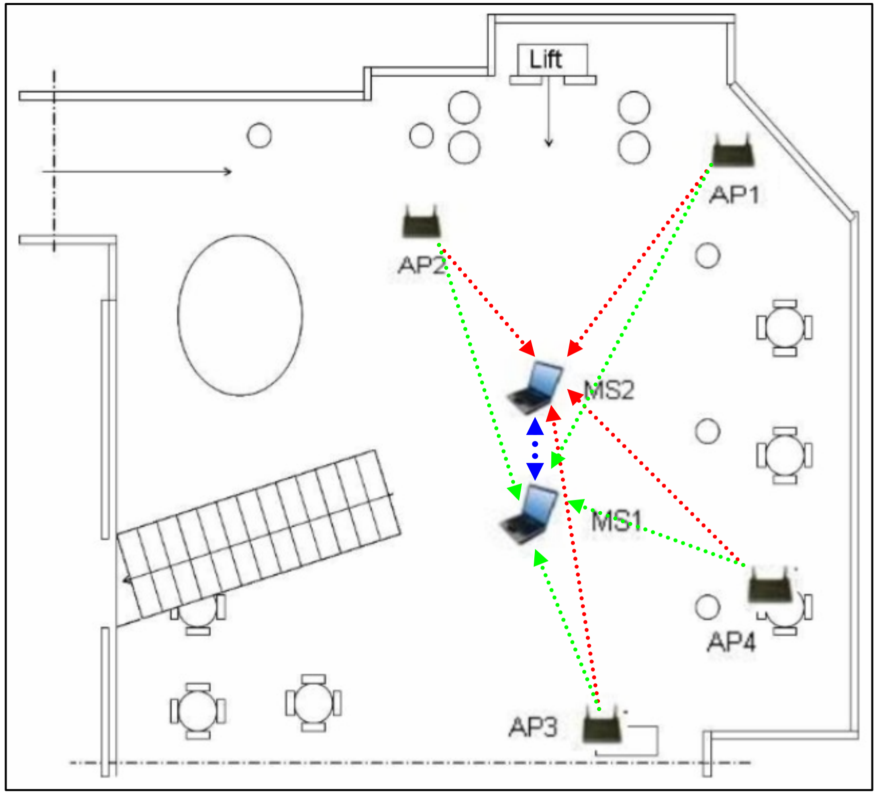
| STEPS | 1:500 | 501:1000 | 1001:1500 |
|---|---|---|---|
| MS1 Gain [%] | 20.6 | | |
| MS2 Gain [%] | 22.2 | | |

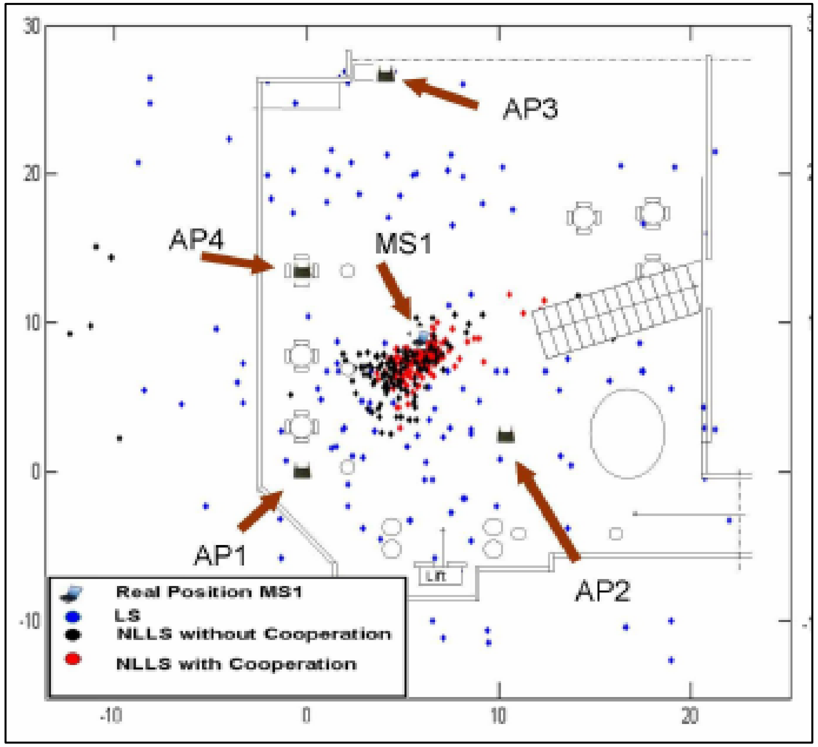
**NO COOPERATION**

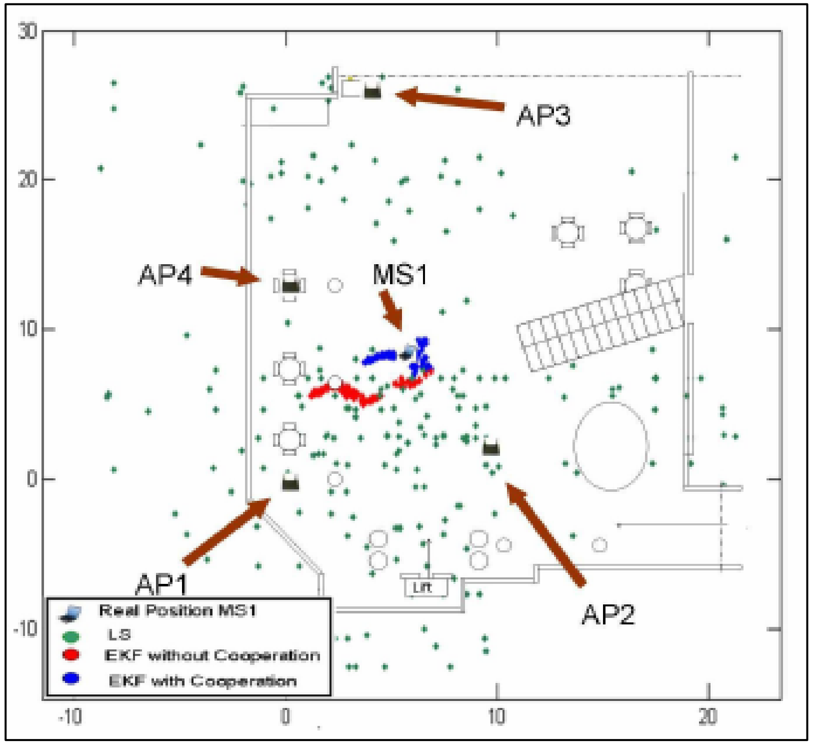
# Cooperative Wireless Indoor Positioning



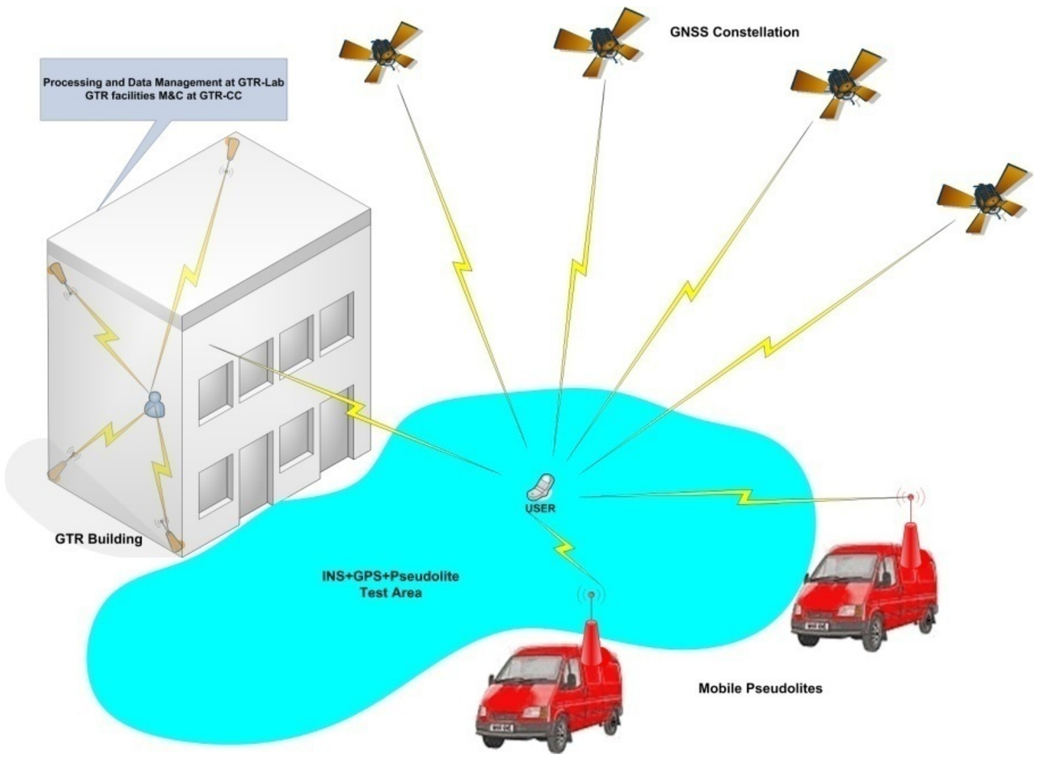



Lift
AP1
AP2
MS2
MS1
AP4
AP3




| | LS | NLLS | EKF |
|---|---|---|---|
| Cooperation off | 15.51 m | 3.35 m | 3.77 m |
| Cooperation on | - | 2.17 m | 1.61 m |


GNSS Constellation
Processing and Data Management at GTR-Lab
GTR facilities M&C at GTR-CC
GTR Building
USER
INS+GPS+Pseudolite
Test Area
Mobile Pseudolites

# Thank You !