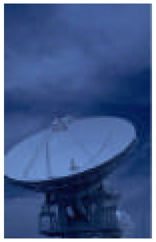
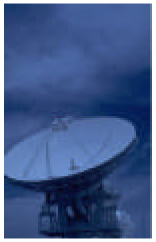
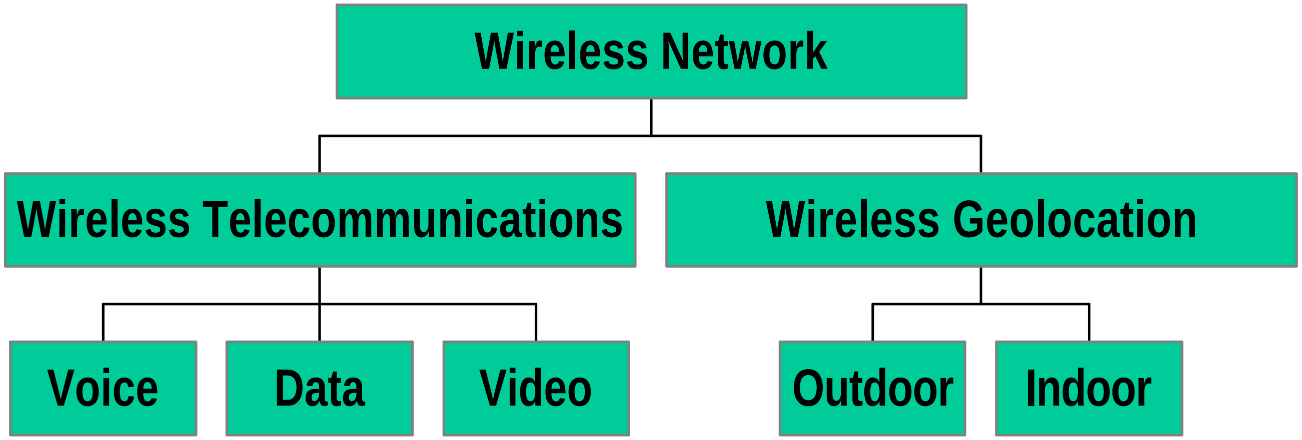


A Framework for Indoor Geolocation using an Intelligent System

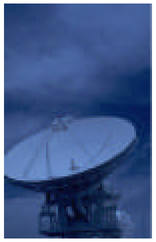
Chahé Nerguizian, Charles Despins and Sofiène Affes



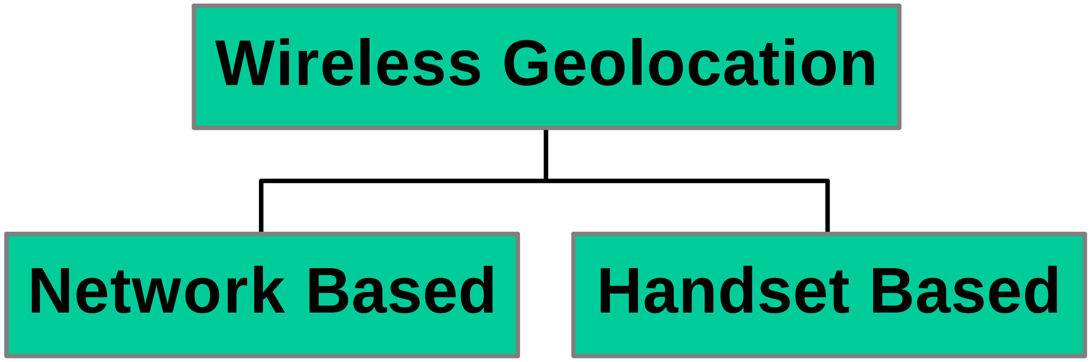
Wireless Applications



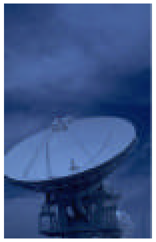
- **Telecommunications and Geolocation applications have different objectives**
- **Basic function of a Wireless Geolocation system is to:**
  - **Gather a particular information about the position of a Mobile Station (MS)**
  - **Process that information to form a location estimate**
- **The particular information could be:**
  - **Received Signal Strength (RSS)**
  - **Angles Of Arrival (AOA)**
  - **Times Of Arrival (TOA)**
  - **Time Differences Of Arrival (TDOA)**



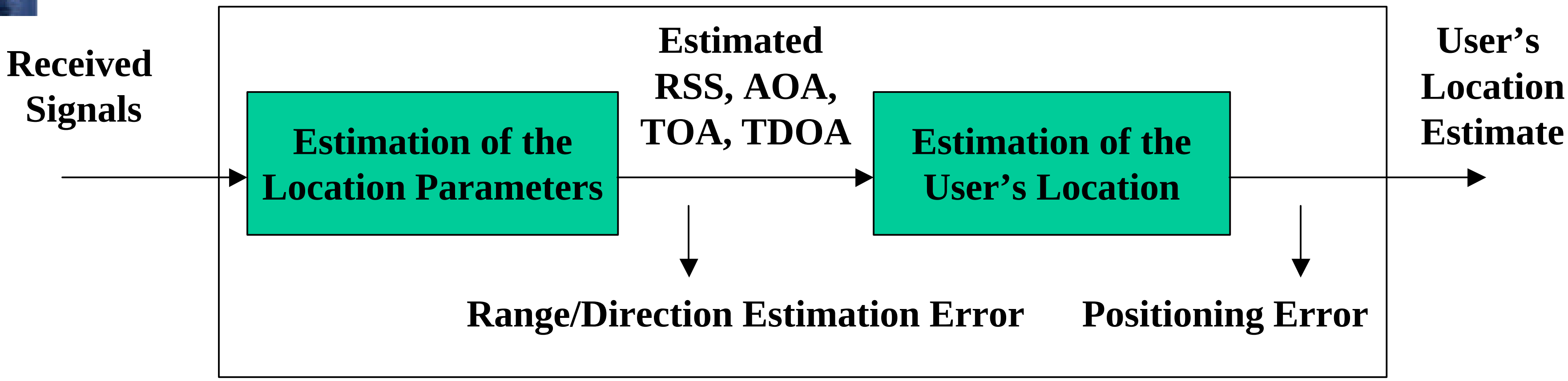
Positioning System Classifications



- **In Handset Based Geolocation, MS receives signals from the Fixed Stations (FS) and computes its own location**
- **In Network Based Geolocation, FSs receive signals from the MS and send the information to a Control Station (CS) where the MS's location is computed**

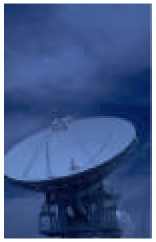


Geolocation Process



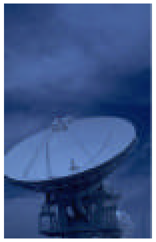
- **Sources of Error:**
  - **Receiver's equipment**
  - **Noise and Interference**
  - **Propagation Channel**
    - **Multipath**
    - **Non-Line Of Sight (NLOS)**

    } → **Range/ Direction Estimation Error** **(most important impact on location accuracy)**
  - **Non Linear Algorithm** → **Positioning Error**

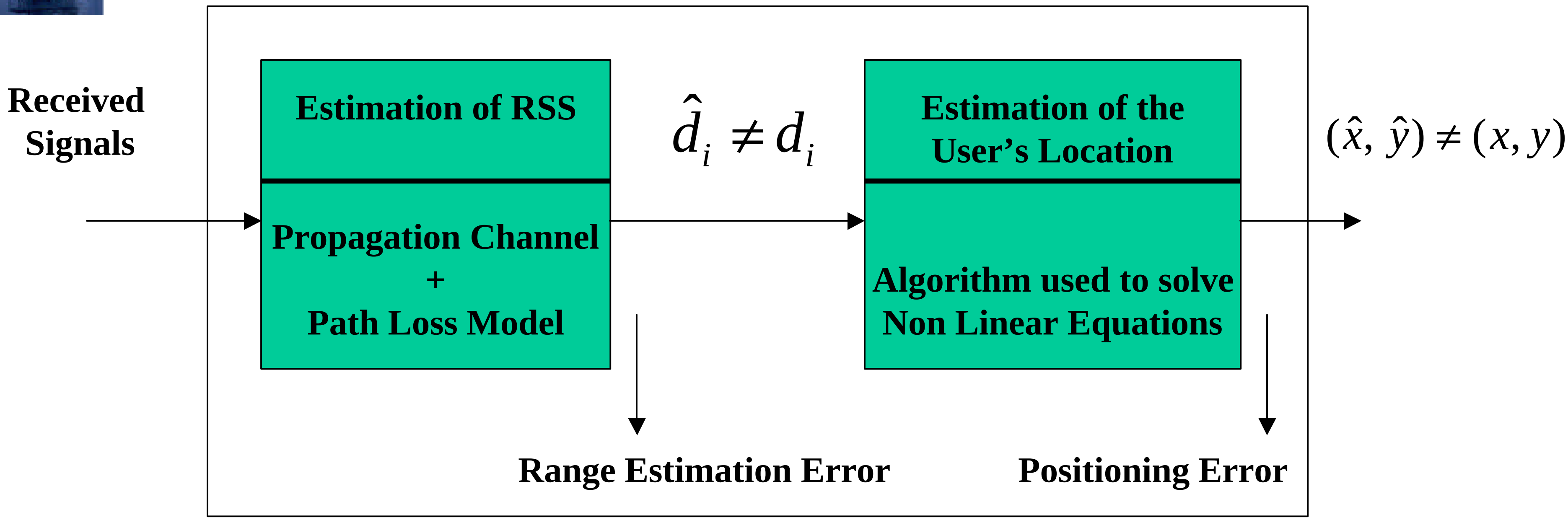


Classical Geolocation Techniques

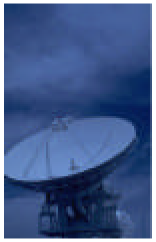
- **Techniques based on:**
  - **Received Signal Strength (RSS)**
  - **Angle Of Arrival (AOA)**
  - **Time Of Arrival (TOA)**
  - **Time Difference Of Arrival (TDOA)**



RSS Geolocation



- **Received signals at 3 FSs and Path Loss Model provide distance or range estimates ($\hat{d}_1, \hat{d}_2, \hat{d}_3$) between MS and FSs**
- **Each estimated range gives a circle centered at the receiver (FS) on which the transmitter (MS) must lie**



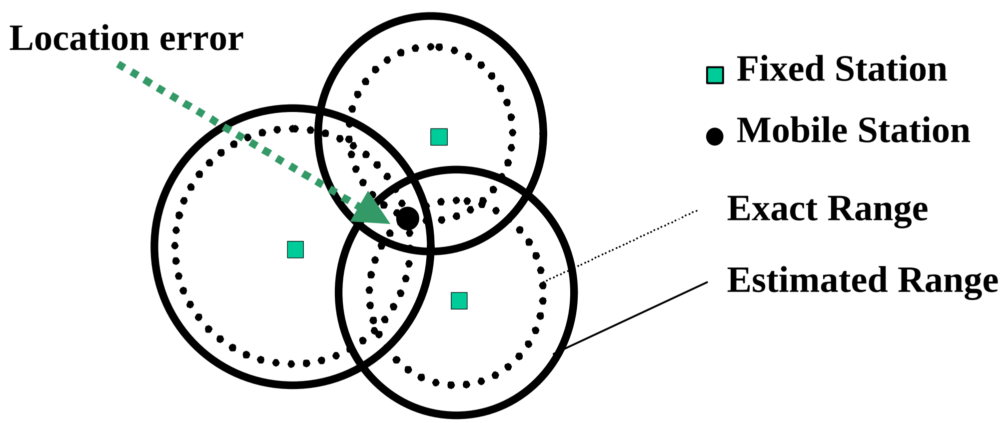
RSS Geolocation (continued)

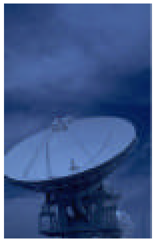
- **Intersection of 3 circles gives :**
  - **a point, if** $\hat{d}_1 = d_1, \hat{d}_2 = d_2, \hat{d}_3 = d_3$

    user's location estimate = exact user's location

  - **a region, if** $\hat{d}_1 \neq d_1, \hat{d}_2 \neq d_2, \hat{d}_3 \neq d_3$

    user's location estimate with large error





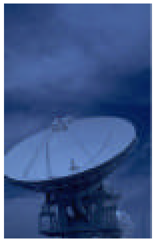
RSS Geolocation (continued)

- **Range Estimation Error due to:**
  - **Multipath**
  - **Non Line Of Sight (NLOS)**
  - **Local Shadowing**
- **Position Estimation Error due to:**
  - **Algorithm used to solve Non Linear Equations**

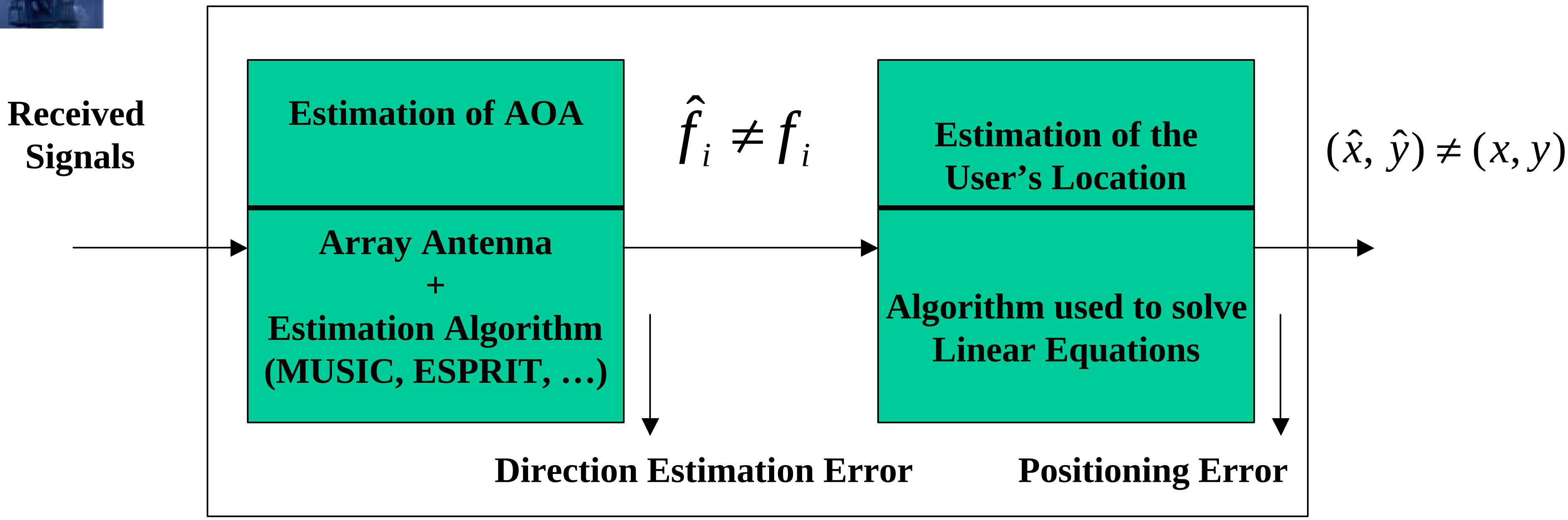
Conclusion

Accuracy of RSS technique depends on:

- **Indoor environment (Multipath, NLOS, Local Shadowing)**
- **Path Loss Model used**
- **Number of FSs used**
- **Algorithm used to estimate user's location**

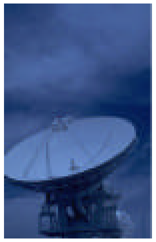


AOA Geolocation



- **Received signals at 2 FSs (array antennas) and estimation algorithm provide angle or direction estimates ($\hat{f}_1, \hat{f}_2$) between MS and FSs**

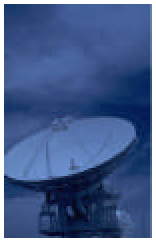
- **Each estimated angle gives a straight line joining the receiver (FS) to the transmitter (MS)**



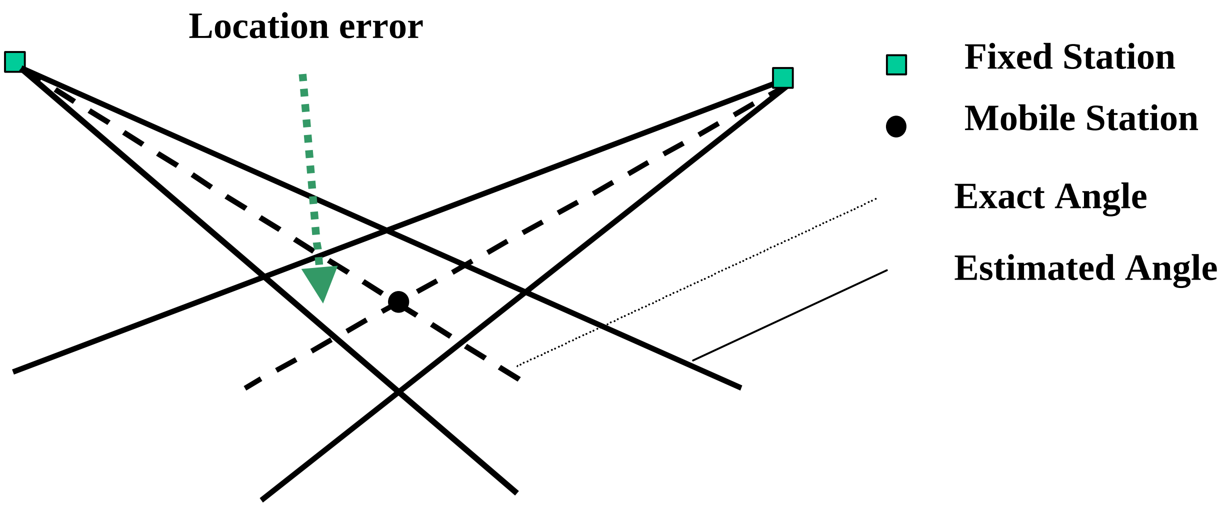
AOA Geolocation (continued)

- **Angular resolution or accuracy of direction measurements (array antennas) induces spread of estimated angle**

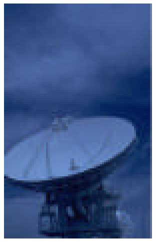
- **Intersection of 2 straight lines gives:**
  - **a point, if** $\hat{f}_1 = f_1, \hat{f}_2 = f_2$
    → **user's location estimate = exact user's location**
  - **a point, if** $\hat{f}_1 \neq f_1, \hat{f}_2 \neq f_2$
    → **user's location estimate with error**
  - **a region, if** $\hat{f}_1 \neq f_1, \hat{f}_2 \neq f_2$ **and angular spread**
    → **user's location estimate with large error**



AOA Geolocation (continued)



- **Direction Estimation Error due to**
  - **Multipath**
  - **Non Line Of Sight (NLOS)**
  - **Angular accuracy of array antenna**

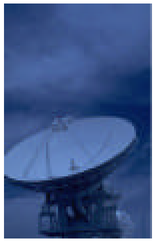


AOA Geolocation (continued)

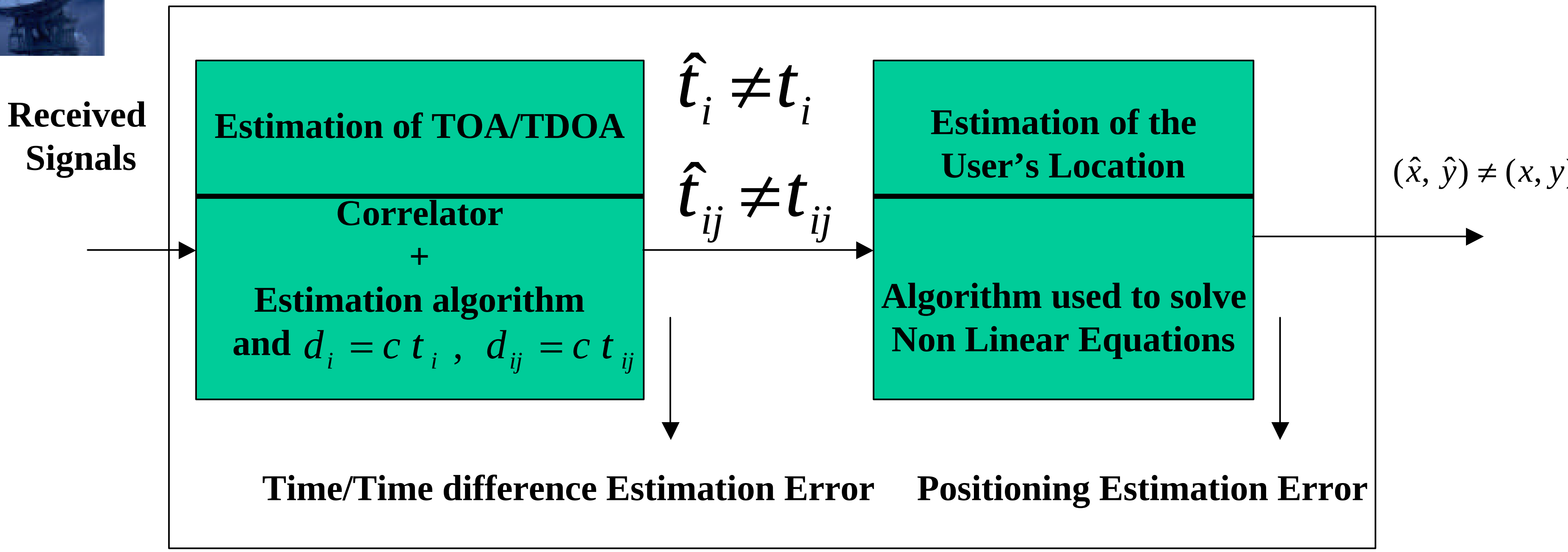
Conclusion

Accuracy of AOA technique depends on:

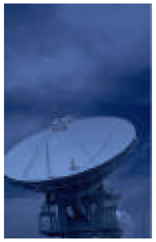
- **Indoor environment (Multipath, NLOS)**
- **Plane wave/near field propagation model used**
- **Algorithm used to estimate direction of arrival**
- **Angular accuracy of array antenna**
- **Number of FSs used**
- **Geographical location of MS relative to FSs**



TOA/TDOA Geolocation

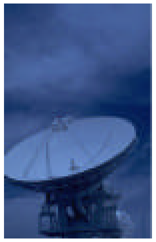


- **Received signals at 3 FSs and estimation algorithm provide time / time difference estimates ($\hat{t}_1, \hat{t}_2, \hat{t}_3$ / $\hat{t}_{12}, \hat{t}_{13}, \hat{t}_{23}$) between MS and FSs / pairs of FSs.**



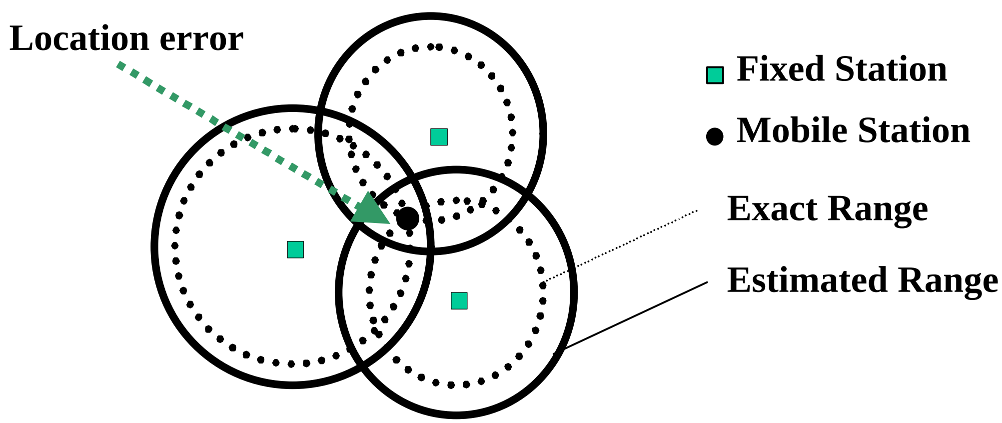
TOA/TDOA Geolocation (continued)

- **Signal speed of propagation known, time / time difference estimates provides range / range difference estimates ($\hat{d}_1, \hat{d}_2, \hat{d}_3$ / $\hat{d}_{12}, \hat{d}_{13}, \hat{d}_{23}$)**
- **Each estimated distance (associated to time estimate) gives a circle centered at receiver (FS) on which transmitter (MS) must lie**
- **Each estimated range difference (associated to time difference estimate) gives a hyperbola with foci at receivers (FSs) on which transmitter (MS) must lie.**



TOA/TDOA Geolocation (continued)

- **Intersection of 3 circles (TOA) gives :**
  - **a point, if** $\hat{d}_1 = d_1, \hat{d}_2 = d_2, \hat{d}_3 = d_3$
    user's location estimate = exact user's location
  - **a region, if** $\hat{d}_1 \neq d_1, \hat{d}_2 \neq d_2, \hat{d}_3 \neq d_3$
    user's location estimate with large error

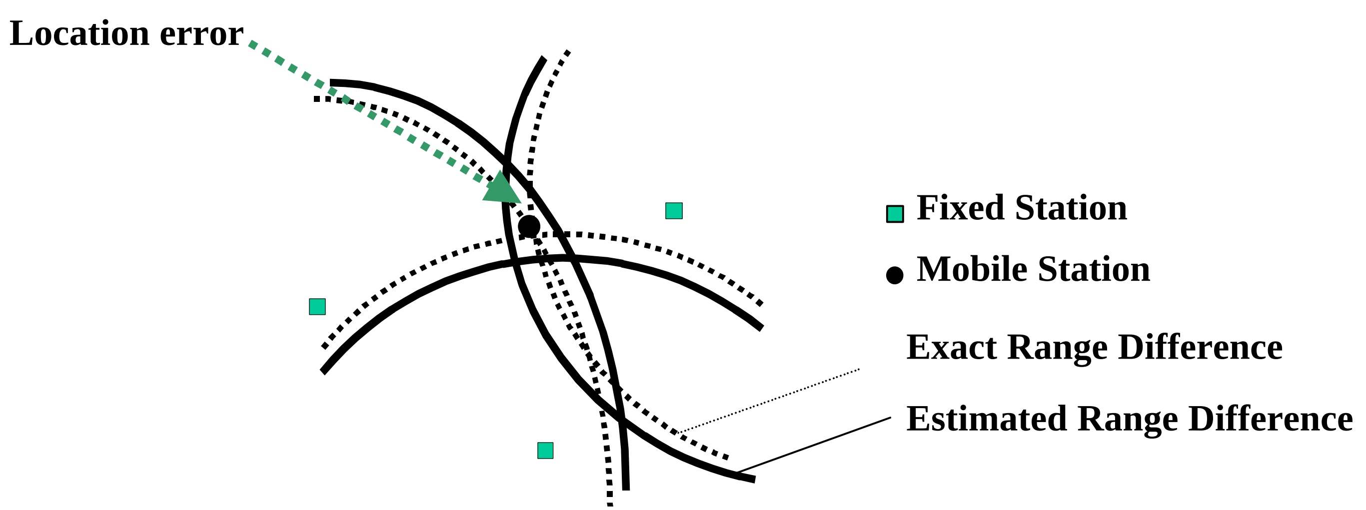


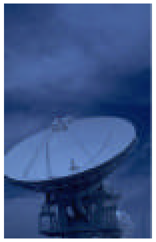
TOA/TDOA Geolocation (continued)

- **Intersection of 3 hyperbolas (TDOA) gives:**
  - **a point, if** ($\hat{d}_1 = d_1, \hat{d}_2 = d_2, \hat{d}_3 = d_3$)

    ⇨ **user's location estimate = exact location**
  - **a region, if** ($\hat{d}_1 \neq d_1, \hat{d}_2 \neq d_2, \hat{d}_3 \neq d_3$)

    ⇨ **user's estimate with large error**





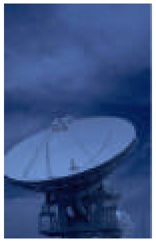
TOA/TDOA Geolocation (continued)

- **Range / Range Difference Estimation Error due to:**
  - **Multipath**
  - **Non Line Of Sight (NLOS)**
- **Position Estimation Error due to:**
  - **Algorithm used to solve Non Linear Equations**
- **TOA requires a strict time synchronization between transmitter and receivers**
- **TDOA requires only a time synchronization between receivers**

Conclusion

Accuracy of TOA/TDOA technique depends on:

- **Indoor environment (Multipath, NLOS)**
- **Algorithm used to estimate time / time difference of arrival**
- **Number of FSs used**
- **Algorithm used to estimate user's location**
- **Geographical location of MS relative to FSs**



Geolocation Techniques for Indoor Environment

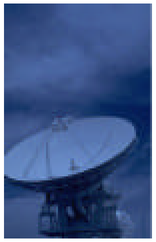
- **Classical Techniques based on:**
  - **Received Signal Strength (RSS)**
  - **Angle Of Arrival (AOA)**
  - **Time Of Arrival (TOA)**
  - **Time Difference Of Arrival (TDOA)** → most popular one
- **Main source of location error : Multipath in the absence of LOS**

Solution

- **Mitigate effect of Multipath**
- **Use Multipath as constructive information (selected solution)**

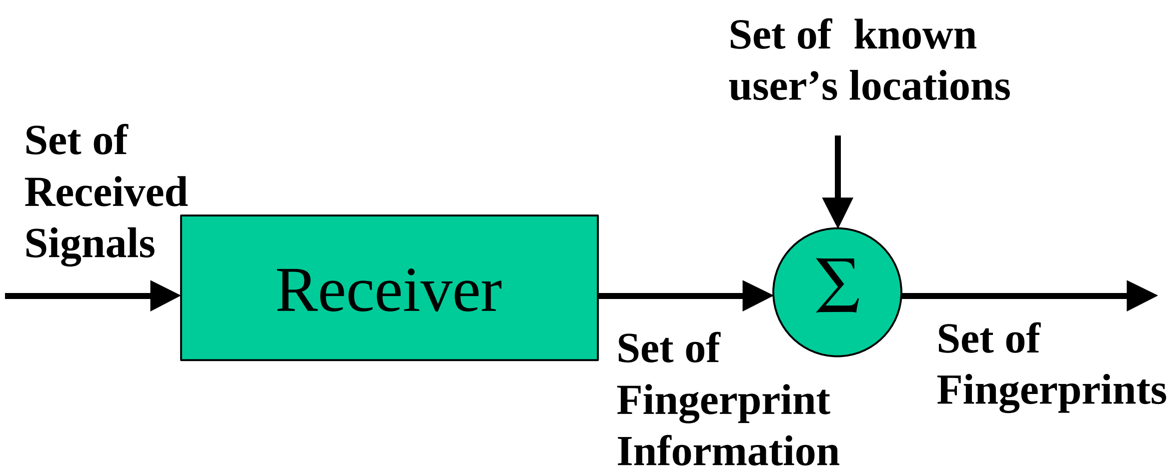
Conclusion

⇨ **Geolocation Technique based on Received Signals Fingerprint**



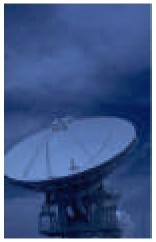
Geolocation Technique based on Received Signals Fingerprint

- **Operation of Geolocation Technique is based on 2 phases :**
  - **–Off-Line phase (Phase of data collection) or Learning phase**
  - **–Real-Time phase (Phase of user's position location)**
- **Off-Line phase consists of recording a set of Information (in a database) as a function of the user's location covering the entire zone of interest, forming a set of Fingerprints**
- **Each Fingerprint corresponds to a Fingerprint information associated to a known user's location**



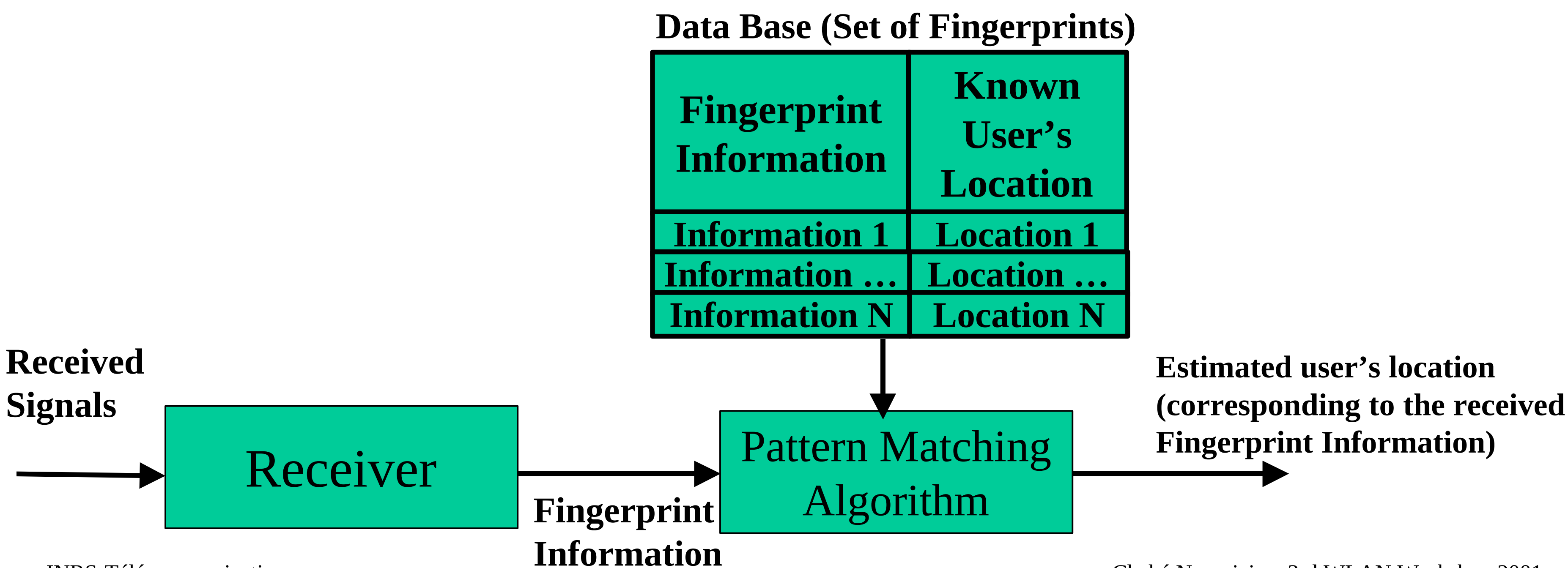
Data Base (Set of Fingerprints)

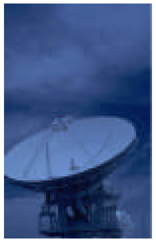
Fingerprint Information	Known User's Location
Information 1	Location 1
Information 2	Location 2
Information …	Location …
Information …	Location …
Information N	Location N



Geolocation Technique based on Received Signals Fingerprint (continued)

- **For Real-Time phase, specific Fingerprint Information is obtained from measured received signals and compared with recorded set of Fingerprints (database)**
- **A Pattern Matching Algorithm is then used to identify the closest recorded information of the database to the measured one, thus defining the corresponding user's location**





Types of Fingerprint Information

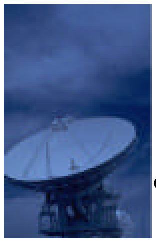
Received Signals → Receiver → Fingerprint Information →
- 3 or more Signal Strengths
- Multipath Angular Power Profile
- Multipath Power Delay Profile

Received Signal Strengths (Narrowband measurements) → Radar → Network Based Indoor Geolocation using WLAN Technology

Received Signal Strengths (Narrowband measurements) → DCM → Handset Based Outdoor Geolocation using GSM Cellular Technology

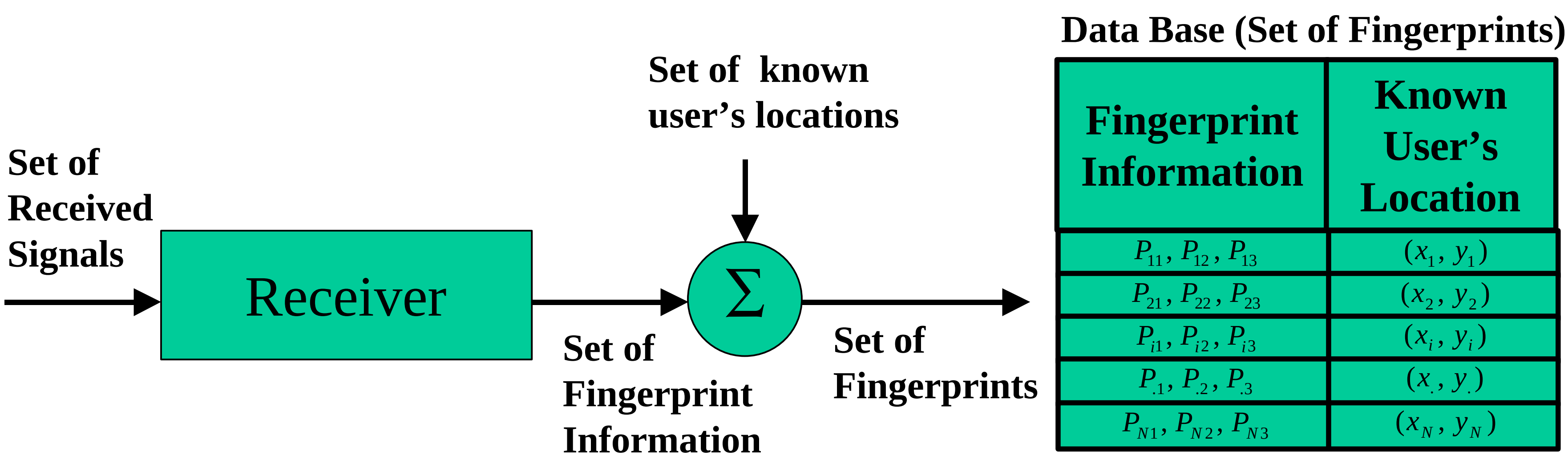
Received Multipath Angular Power Profile → Radio-Camera → Network Based Outdoor Geolocation using Cellular Technology

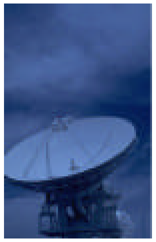
Received Multipath Power Delay Profile (Wideband measurements) → Proposed System → Network Based Indoor Geolocation using different Technologies



Radar System (Microsoft Corporation)

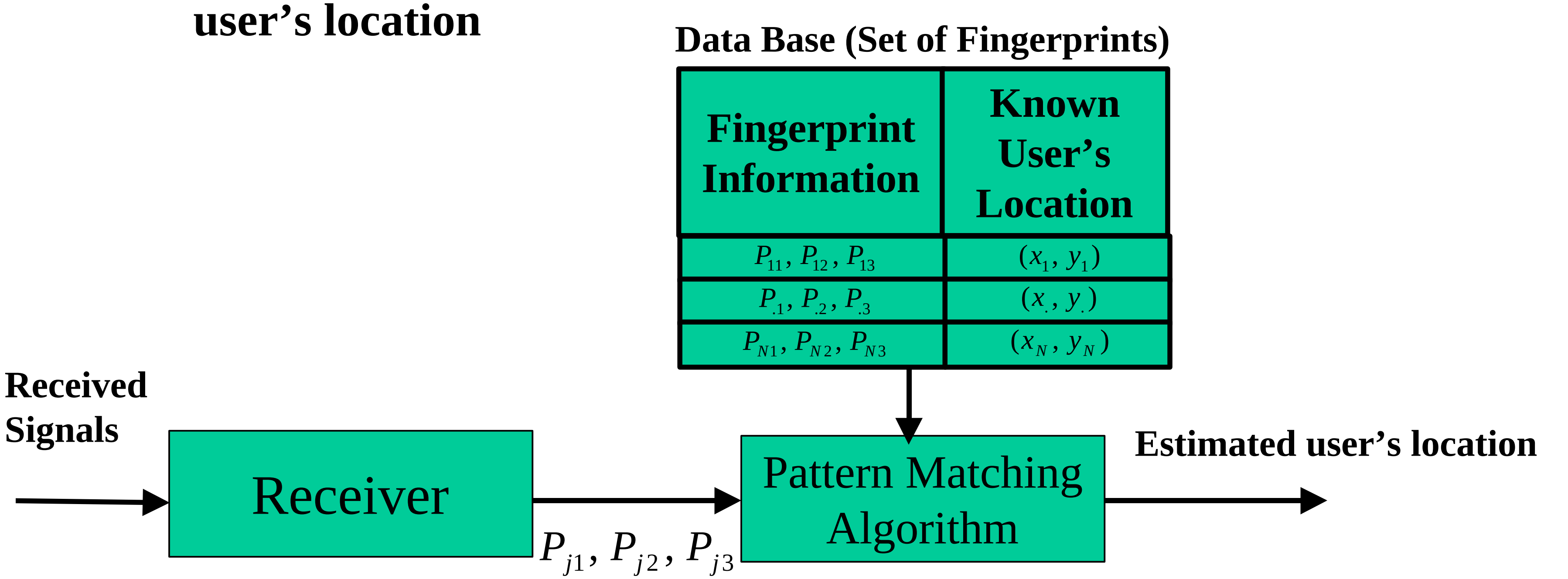
- **RF based system for locating and tracking users inside buildings**
- **Network based indoor Geolocation**
- **Operation with WLAN technology**
- **Fingerprint Information based on Received Signal Strengths (RSS) at 3 Access Points (AP)**
- **Off-Line phase gives a set of Fingerprints corresponding to 3 Received Signal Strengths (P_{i1}, P_{i2}, P_{i3}) as a function of user's location (x_i, y_i), { i = 1, 2, ..., N }**

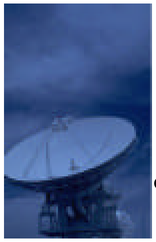




Radar System (Microsoft Corporation) (continued)

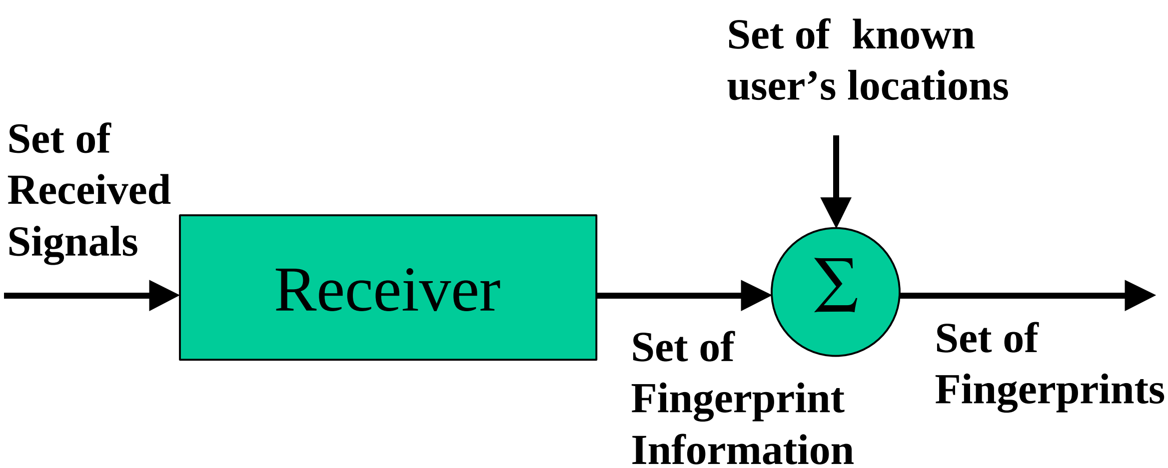
- **For Real-Time phase, specific (P_{j1}, P_{j2}, P_{j3}) is obtained from measured received signals and compared with recorded set of Fingerprints (database)**
- **A Pattern Matching Algorithm, using an Euclidean distance (in signal space), chooses location that minimizes distance between specific observed RSSs and recorded set of Fingerprints, and therefore estimates user's location**





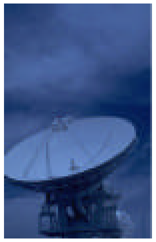
DCM Method (VTT Information Technology)

- **RF based system for locating and tracking outdoor users**
- **Handset based outdoor Geolocation**
- **Operation with GSM Cellular technology**
- **Fingerprint Information based on Received Signal Strengths (RSS) at 7 Base Stations (serving cell + 6 strongest neighbors)**
- **Off-Line phase gives a set of Fingerprints corresponding to 7 Received Signal Strengths ($P_{i1}, P_{i2}, P_{i3}, P_{i4}, P_{i5}, P_{i6}, P_{i7}$) as a function of user's location (x_i, y_i), { i = 1, 2, ..., N }**



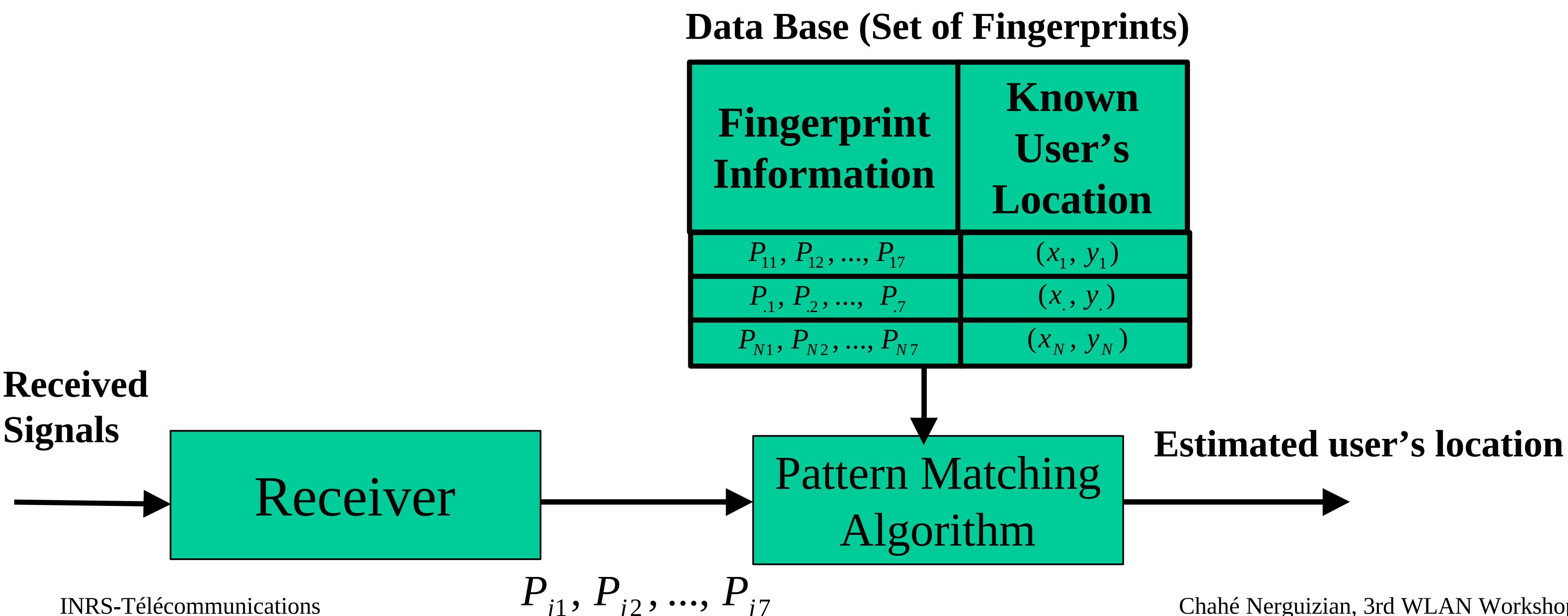
Data Base (Set of Fingerprints)

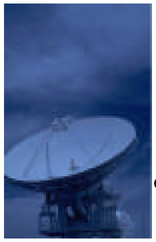
Fingerprint Information	Known User's Location
$P_{11}, P_{12}, ..., P_{17}$	(x_1, y_1)
$P_{21}, P_{22}, ..., P_{27}$	(x_2, y_2)
$P_{i1}, P_{i2}, ..., P_{i7}$	(x_i, y_i)
$P_{.1}, P_{.2}, ..., P_{.7}$	$(x_., y_.)$
$P_{N1}, P_{N2}, ..., P_{N7}$	(x_N, y_N)



DCM Method (VTT Information Technology) (continued)

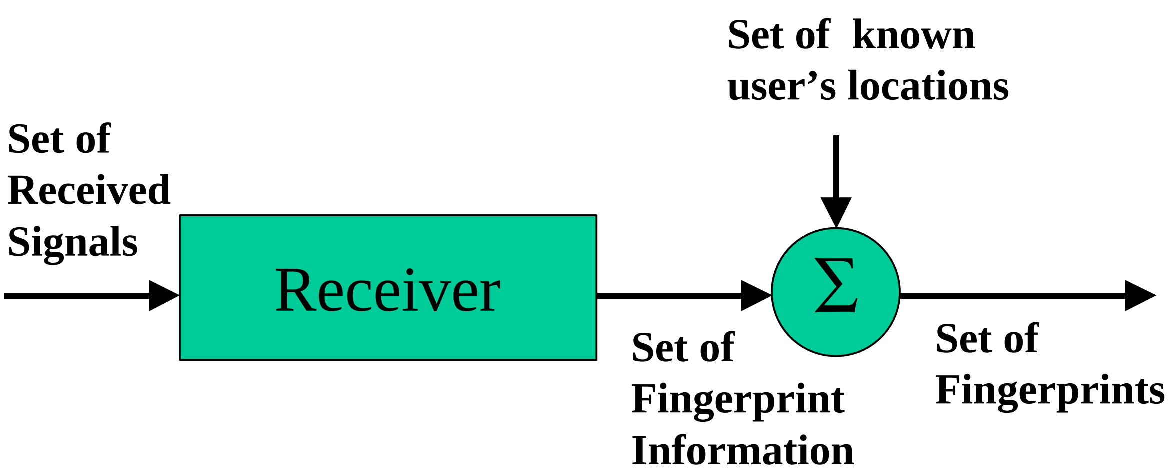
- **For Real-Time phase, specific ($P_{j1}, P_{j2}, \ldots, P_{j7}$) is obtained from measured received signals and compared with recorded set of Fingerprints (database)**
- **A simple correlation or more advanced Pattern Matching Algorithm is used between specific observed RSSs and recorded set of Fingerprints, and therefore estimates user's location**





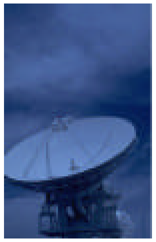
RadioCamera (US Wireless Corporation)

- RF based system for locating and tracking outdoor users
- Network based outdoor Geolocation
- Operation with Cellular technology
- Fingerprint Information based on Multipath Angular Power Profile at one Array Antenna per cell
- Off-Line phase gives a set of Fingerprints corresponding to Received Multipath Angular Power Profile $P_i(f)$ as a function of user's location (x_i, y_i), { i = 1, 2, ..., N }



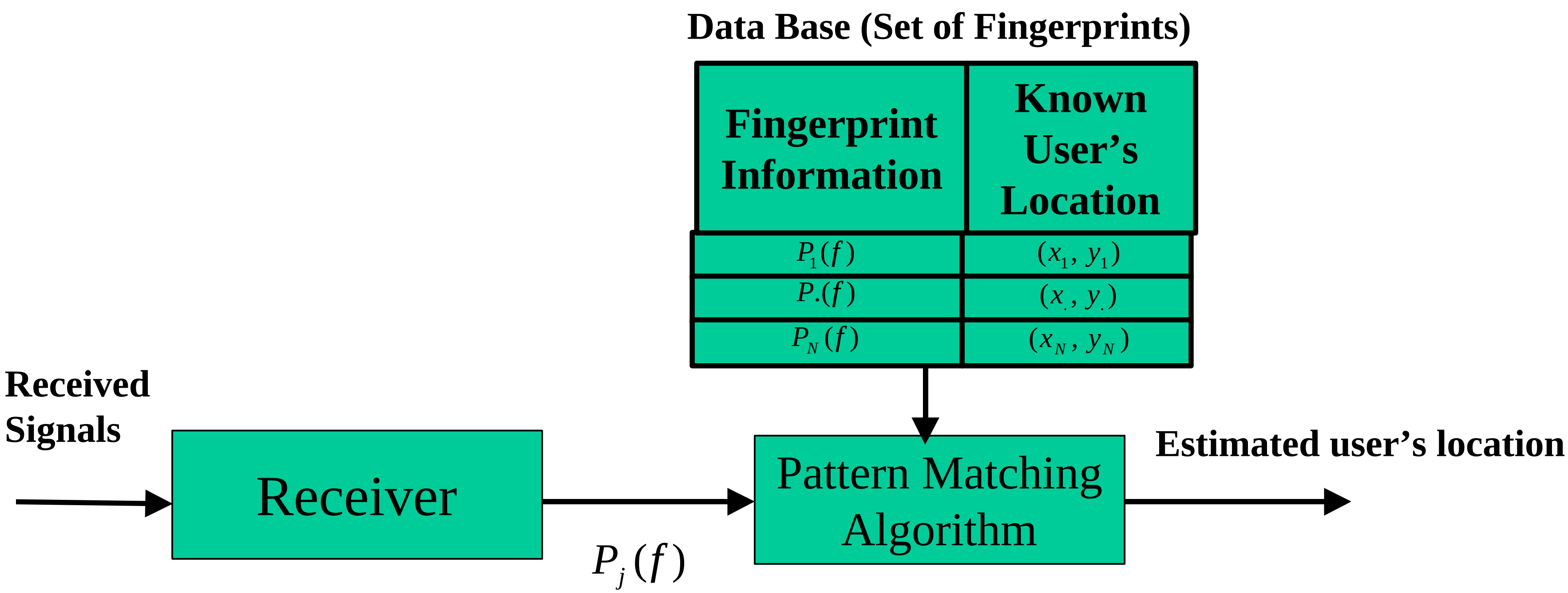
Data Base (Set of Fingerprints)

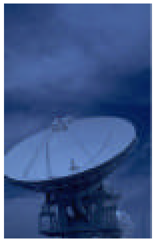
Fingerprint Information	Known User's Location
$P_1(f)$	(x_1, y_1)
$P_2(f)$	(x_2, y_2)
$P_i(f)$	(x_i, y_i)
$P_.(f)$	$(x_., y_.)$
$P_N(f)$	(x_N, y_N)



RadioCamera (US Wireless Corporation) (continued)

- **For Real-Time phase, specific $P_j(f)$ is obtained from measured received signals and compared with recorded set of Fingerprints (database)**
- **A Pattern Matching Algorithm, using an Euclidean distance (in signal space), chooses location that minimizes distance between specific observed $P_j(f)$ and recorded set of Fingerprints, and therefore estimates user's location**





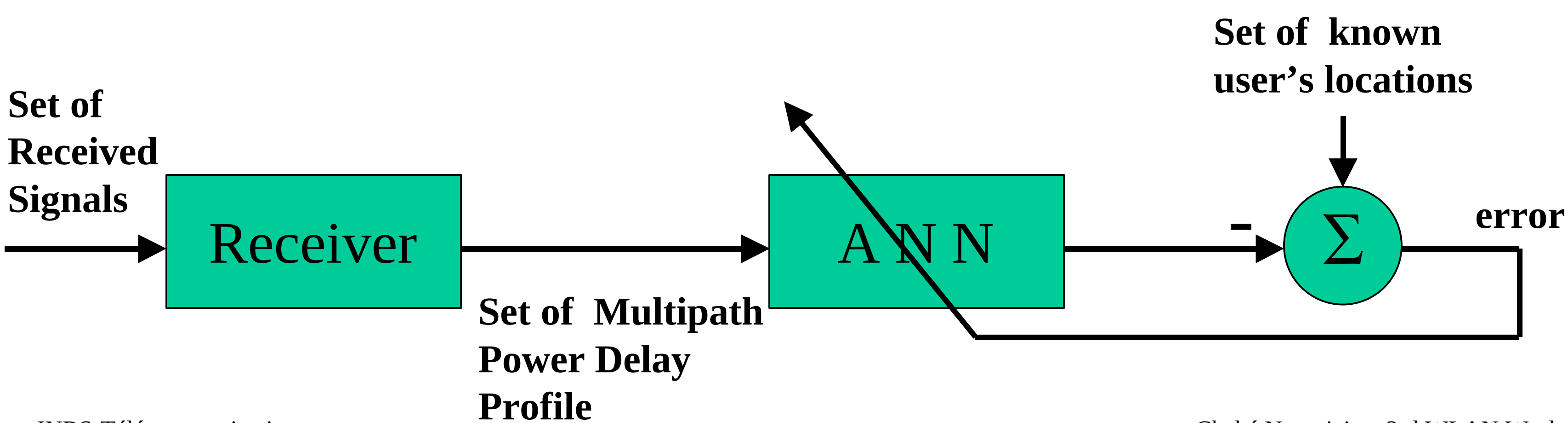
Proposed Indoor Geolocation System

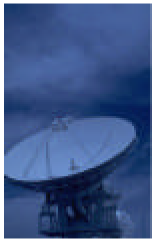
- **RF based system for locating and tracking users inside a mine**
- **Network based indoor Geolocation**
- **Operation with Cellular Radio, Impulse Radio and WLAN technologies**
- **Fingerprint Information based on Multipath Power Delay Profile** $P_i(t)$ **at one Fixed Station**

- **Artificial Neural Network (ANN) used to :**
  - **Learn Set of Fingerprints corresponding to Received Multipath Power Delay Profile** $P_i(t)$ **as a function of user's location (** x_i, y_i **) ,** **{ i = 1, 2, ..., N }** **Training Phase**
  - **Obtain user's location from a specific received Multipath Power Delay Profile** $P_j(t)$ **Recalling Phase**

Proposed Indoor Geolocation System (continued)

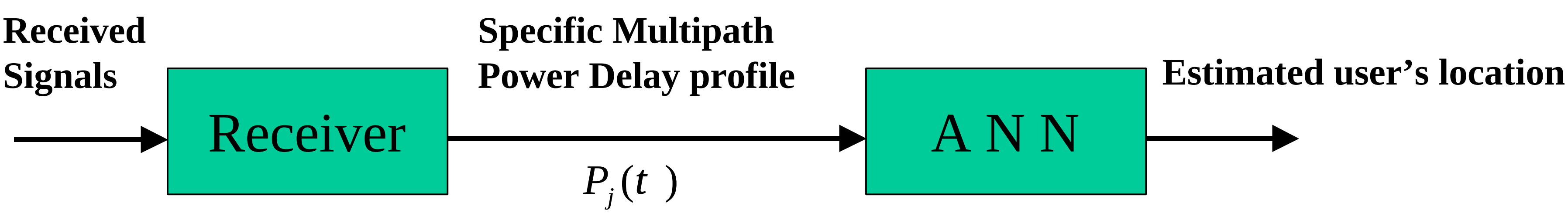
- **Back Propagation (BP) type ANN used as function approximator (Non Linear Regression)**
- **For Training Phase (Off-Line Learning Phase), each input of ANN corresponds to Multipath Power Delay Profile received by Fixed Station**
- **Training Phase of ANN corresponds to adjustment of its internal free parameters (weights and biases) by minimizing a performance function (mean square error)**
- **Training Phase is equivalent to recording the Set of Fingerprints**

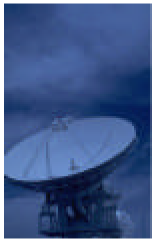




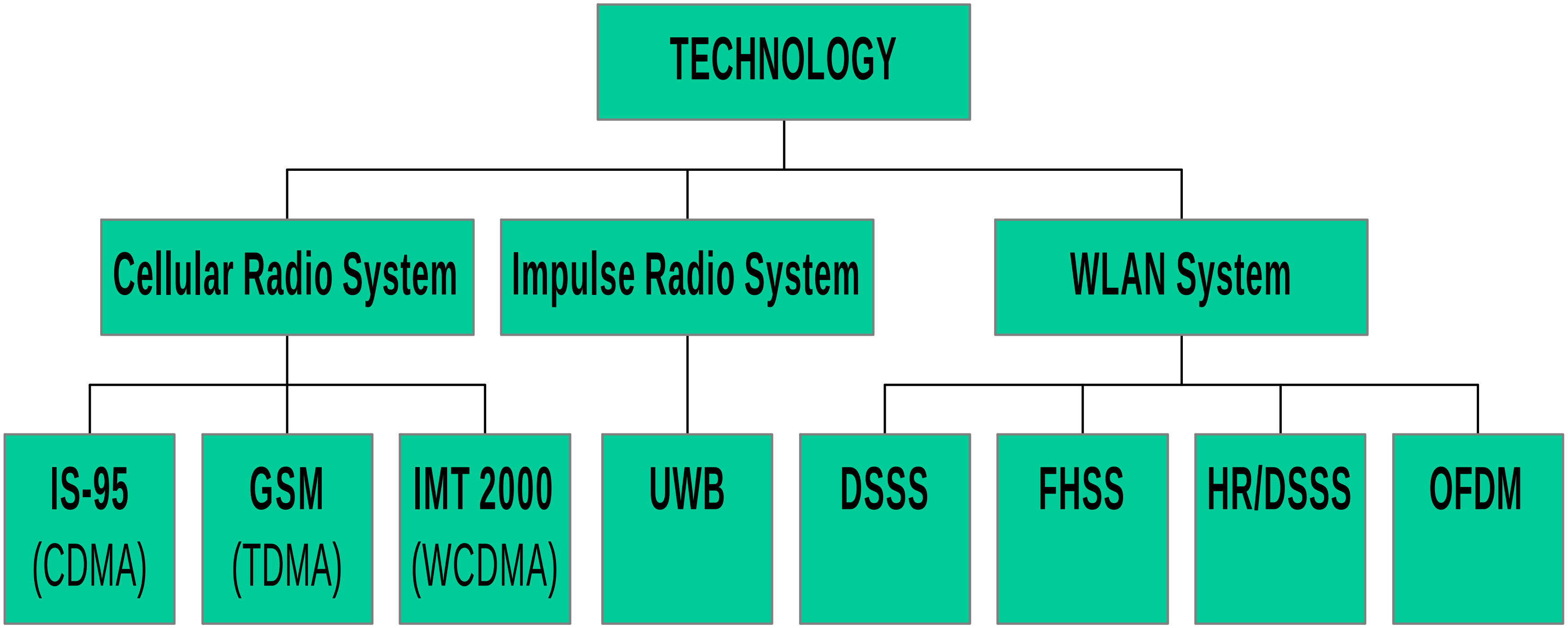
Proposed Indoor Geolocation System (continued)

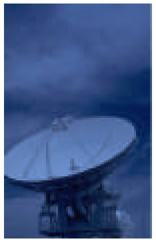
- **Properly Trained ANN has a generalization property :**
  - **Robustness of ANN to input perturbations**
  - **Generalization rather than memorization of ANN (network gives right location for unseen and non trained input)**
- **For Recalling Phase (Real-Time Phase), Multipath Power Delay Profile of a specific Mobile Station is measured $P_j(t)$ and applied to the input of ANN (acting as Pattern Matching Algorithm)**
- **The output of ANN corresponds to the estimated value of user's location**





IMPLEMENTATION'S TECHNOLOGY

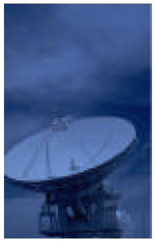




TECHNOLOGY versus TIME RESOLUTION

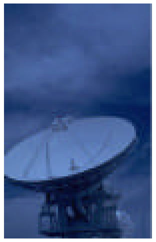
Cellular Radio	IS-95 (CDMA)	815 nanosecond
	GSM (TDMA)	3700 nanosecond
	IMT 2000 (WCDMA)	250 nanosecond
Impulse Radio	UWB	Few nanosecond
WLAN	DSSS	500 nanosecond
	FHSS	500 nanosecond
	HR/DSSS	90 nanosecond
	OFDM	20 nanosecond

Time resolution $\cong$ Inverse of the Bandwidth



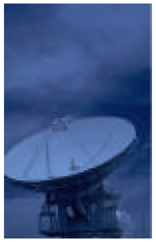
IMPORTANCE OF TIME RESOLUTION

- **In indoor environments :**
  - **The largest excess delay corresponding to the detectable Multipath component is approximately 500 nanosecond**
  - **The resolution of the Multipath Differential delays is in the nanosecond range**
- **To model Multipath Power Delay Profile (MPDP), the excess delay of all the Multipath components must be resolvable** → ***For the proposed system, a high time resolution is needed to obtain the MPDP***



IMPORTANCE OF TIME RESOLUTION (continued)

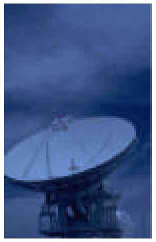
- **Impulse Radio UWB and WLAN OFDM are good candidates for the proposed indoor Geolocation system**
- **Other Technologies can be used if some modifications are applied, such as :**
  - **Use of super-resolution methods**
  - **Use of over-sampling techniques**



CONCLUSION

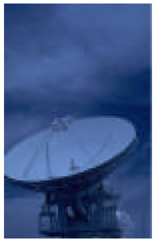
- **Indoor Geolocation technique based on Multipath Power Delay Profile (MPDP) Fingerprint is a good choice in adverse environments (Multipath with NLOS)**
- **High Time Resolution is needed for MPDP measurements**

  (the main challenge for the application of the proposed system)
- **Use of Artificial Neural Network (ANN) as pattern matching algorithm has the following advantages :**
  - **Robustness of the system to input perturbations**
  - **Generalization rather than memorization of the network (network gives right location for unseen and non trained input)**
  - **Quick response during the recalling phase due to parallelism and off-line training**



CONCLUSION (continued)

- **Location accuracy depends on the size of the segmentation (square grid) of indoor environment layout used to define user’s physical locations (information used in the training set of ANN)**
- **A new training phase is needed when indoor environment is modified**
- **Possibility to use redundancy of the system due to its simplicity (one fixed station with a trained ANN)**
- **Generalization of the user’s location system from 2D to 3D is straight forward with ANN**



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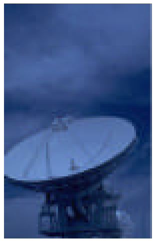

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