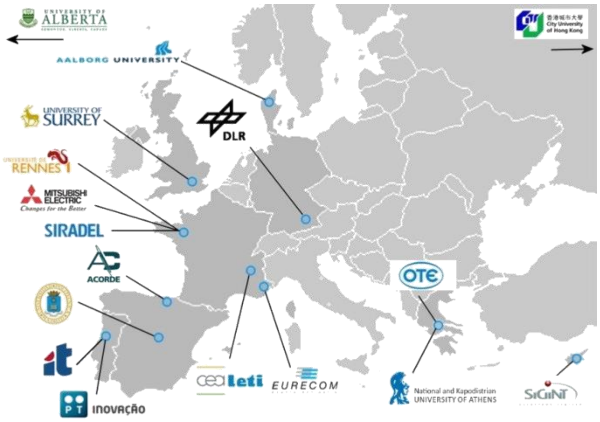
WHERE2 Project

Wireless Hybrid Enhanced Mobile Radio Estimators (Phase 2) is an international project co-funded by the European Commission within the 7th Framework Programme. WHERE2 started in July 2010, with a duration of 3 years, as a successor of the WHERE project, addressing the combination of heterogeneous cooperative positioning and communications in order to exploit complementarities and to enhance the efficiency of future wireless communications systems. The official website link is http://www.ict-where2.eu. For any additional information, please contact Ronald Raulefs (ronald.raulefs@dlr.de) or Armin Dammann (armin.dammann@dlr.de)



In focus

Exploitation of synergies between heterogeneous positioning and communications – WHERE2

The key tangible objectives of the project were:

Localization:

- Enable indoor terminal location with an accuracy at least equivalent to that of outdoor GPS, by combining & extending distributed techniques into the new dynamic heterogeneous and cooperative scenario.

Communications:

- Quantify geo-location-based cooperation gain in wireless communications in terms of throughput, reliability, power consumption, complexity and security.

Realization:

- Developing integrated hardware platform to confirm performance and feasibility of cooperative positioning and communications algorithms by trials.

In WHERE2 we performed two measurement campaigns to collect measurement data for post-processing the data by the algorithmic working groups. Further, the measurement data (http://goo.gl/9CQuLF) was also pre-processed to share it with the public and inclusive documentation (D4.5 - http://goo.gl/EbYPLF) on how to use it.

All our technical work was documented in technical deliverables in detail and was gathered in a single additional document entitled the "WHERE2 System – Deliverable D1.9 (http://goo.gl/NnWAIN)" which had the following classification and content:

Models (WP1)

A specific focus on a common heterogeneous channel modeling "environment" or channel simulation scenario is provided for various purposes in localization.

Positioning in heterogeneous wireless networks (WP2)

New cooperative localization and tracking algorithms have been explored for heterogeneous systems under system relevant constraints, such as communication overhead, latency, etc. Furthermore, classical techniques such as fingerprinting have been improved, i.e. by including results from WP1 (ray-tracing models). Lastly, relative localization capabilities in the absence of anchors were investigated.

Location aware communications (WP3)

Location-dependent communication aspects were investigated with respect to:

i) coordination of network nodes to be considered as relays, interference alignment, coordinated beamforming, etc.

ii) cooperation among mobile terminals which form clusters and the associated security aspects;

iii) for cognitive radio aspects where location-dependent information may be used to infer on attenuations and the interference caused by reusing spectrum. Application specific examples present where the algorithms reside in a communication system and how they interface at various layers.

Calendar

- ICC Workshop in Sydney (2nd Workshop on Advances in Network Localization and Navigation), 14th of June 2014

WP1 Scenarios, relevant models and market feedback

Overview of Main Achievements in WP1

As a first main outcome partners have specified two specific scenarios involving two heterogeneous communication systems with cooperation capability: one with a centralized architecture for wide-range communication (3GPP-LTE-based), and the other with a decentralized, ad-hoc architecture for short-range communication (UWB, ZigBee). In this vein a common channel simulation scenario has also been designed. These scenarios were considered as reference systems for testing the communication-aided localization techniques and the localization-aided communication techniques devised in WP2 and WP3 respectively.

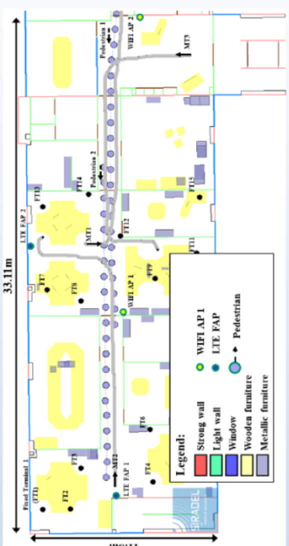
As a second main outcome several channel models suitable for localization and communications systems have been designed. Such models must incorporate the location-dependent statistical properties of the channel links between mobile units/nodes. Document D1.8 (http://goo.gl/SdxjQE) summarizes including the references all the achievements.

Finally, a special effort was also devoted to follow standardization processes of current and emerging communications systems, like LTE, LTE-A, and to monitor the activities of standardization bodies on localization and cooperative communications.

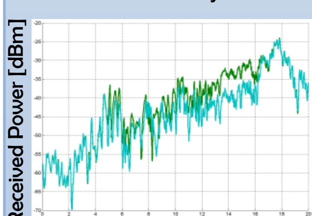
Common Channel Simulation Scenario

The scenario includes **mobility, outdoor-to-indoor** and **indoor-to-indoor** links, and **short range** links for radio access technologies such as LTE and Wi-Fi.

Layout of the common scenario



Example of prediction along a mobile radio link with (blue) and without (green) human crowd activity

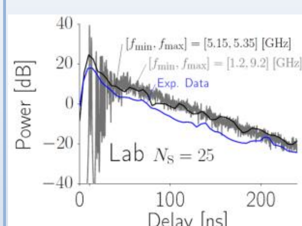


Multi-link Channel Models

Modelling of reverberant in-room channels

Multi-link models of **path-loss, mean delay** and **rms delay spread** are based on a distance-dependent delay power spectrum model.

Models of the impulse response of reverberant channels based on **propagation graphs** have been devised. They include **the avalanche effect** of the times of arrival of components, which is critical for time-of-arrival based localization methods.



A dynamic stochastic model characterizing delay dispersion

Spatial point processes and Campbell's theorem are used to assess channel characteristics such as the **time-frequency correlation** of **time-dynamic** channels.

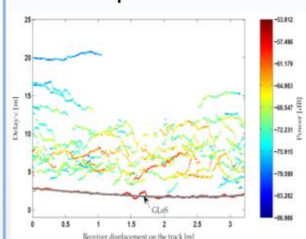
Multi-link channel modeling

The models include **multi-link correlation** of e.g. **non-line-of-sight bias, received power, mean delay** and **clusters**.

Time-variant Channel Models

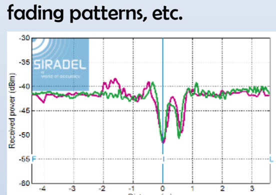
Estimation of in-room time-variant channel parameters

Tracking algorithms (EKF-SAGE) for the parameters of path-components of the channel response.



Time-variant fluctuations due to indoor human-crowd activity

Experimental investigation and modeling of the influence of **crowed activity** on channel parameters, like Rice factor, fading patterns, etc.



Stochastic models of antenna responses and human-induced rotation

Experimental characterization of **UWB antenna responses** using **spherical harmonics**.

Sparse channel estimation

A robust low-complexity estimator of the number of dominant path-components (and their parameters) in the channel response.

Evolved Ray-tracing

Wide- to ultra-wideband conversion of ray-tracing tools

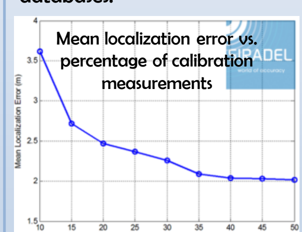
The tool, which uses **band-segmentation**, is available as an extension module of the **TruNET simulator**.

Novel indoor-to-outdoor site-specific models

The models **enhance prediction** of path-loss, delay power profiles and angular power profiles by integration of **building information** like windows and internal walls.

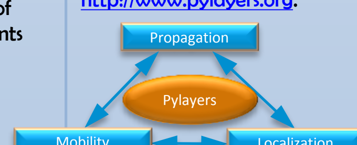
Refined ray-tracing simulations by measurement insertion

The method locally corrects the ray-tracing coverage maps by insertion of measurement data to **improve the quality of RSS** based fingerprint databases.



PyLayers

An **open source indoor propagation simulator** for dynamic localization applications: http://www.pylayers.org.



WP2 Heterogeneous context-aware cooperative positioning

Overview of Main Achievements in WP2

WP2 was in charge of providing estimation/decision algorithms to reliably and accurately determine the mobile terminals' (MT) location in compliance with the overall WHERE2 system architecture. The latter allows centralized and decentralized paradigms depending on the operating contexts (i.e. in terms of available connectivity, a priori information about the environment, embedded MT capabilities…). Accordingly, these WP2 location determination engines could be either running at MT (user-centric) or be hosted at a centralized server (operator's view).

For the three years of project, the WP2 research efforts were directed in four main directions, aiming at the development of new cooperative and heterogeneous positioning methods in synergy with communication means (D2.4 - http://goo.gl/A8Jw2I), the improvement of classical non-cooperative centralized fingerprinting techniques, the incorporation of non-radio modalities (map knowledge, inertial data) into the location problem (D2.5 - http://goo.gl/4LPYy8), and the extraction and learning of contextual information (mobility patterns and habits, in-site radio parameters, room dimensions) (D2.6 - http://goo.gl/2N5T4U).

Most proposals were successfully tested and compared through the use of common realistic simulation data from WP1 and real measurement data from WP4, highlighting the main limitations but also fine contextual complementarities of the different approaches.

Besides the significant scientific knowledge brought in the field of wireless localization, as reflected by extensive dissemination activities (11 journals, > 65 conference papers, 5 completed PhDs…), several tangible outcomes are also currently under exploitation by industrial WHERE2 partners.

Cooperative Positioning Message Passing

Improved robustness

• Against **harmful connectivity** conditions:
- *Loopy networks*: Generalized NBP method based on pseudo-junction tree (NGBP-PJT), Uniformly-reweighted NBP method (URW-NBP)
- *Sparsely connected networks*: Probabilistic connectivity models (VMP, TP-NBP)

• Against **outliers and/or wrong beliefs** propagation: (Re)sampling methods (MIS-RP, PRC), Multi-modal densities (B-VMP)

Reduced complexity and overhead

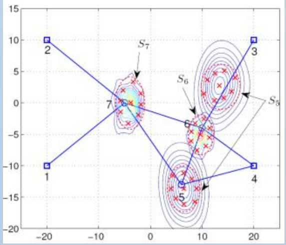
• **Simplified messages** (VMP) and discrete **local approximations** for multi-hop (TP-NBP)

Extension to mobility

• **Particle Belief Filter** (prediction/correction) & NBP
• **Smoothing/Filtering messages** (from future/past) in NBP

Theoretical analysis

• Graph **identifiability & localizability** conditions



Intrinsic Synergies with Communications

Link selection for power & complexity saving

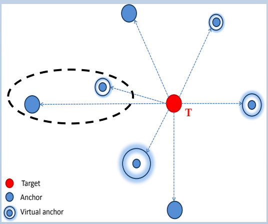
• **Coalitional Games** (utility functions optimization) including virtual anchors' location uncertainty, irrelevant angular redundancy
• **Static & velocity-based hybrid CRLB criteria** for jointly heterogeneous & cooperative networks

Resource allocation for limited interference & localization accuracy

• **Location CRLB-based distribution of OFDM subcarriers** to mobile multi-users
• CRLB integrating **interference coordination** btw. neighboring ranging nodes

Cooperation for low overhead & hearability

• **Opportunistic ranging through over-listening** (based on other MTs' talks) for limited training overhead
• **Limited nb of MTs using training sequences** for ranging
• Mitigation of **multi-cell BS hearability issues** in trilateration



Advanced Fingerprinting

Simplified deployment

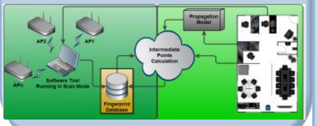
• **Alleviated measurement campaign** for prior database calibration through advanced propagation models (e.g. Ray-Tracing simulations, local simplified models…)
• **Limited nb of reference Access Points** using PDP as fingerprints

Improved robustness and accuracy

• **Reduced sensitivity to cross-device dispersion** (e.g. btw. smartphones, laptops….)
• Inclusion of **user's mobility** patterns and habits (constrained by maps)

Improved synergy with communications

• Incorporation of **communication-oriented metrics** (PER, AP load…) as part of radio signatures
• Tighter **intrication with location-based handover**



Adaptation to the Environment

Improved Ranging

• **PDP-based** ranging
• In-site iterative **learning of AP-dependent path loss parameters** for RSSI ranging

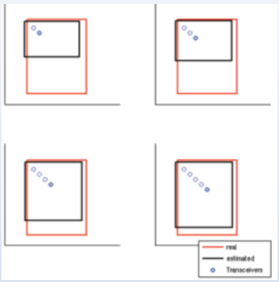
NLOS localization

• **Single Bounce Model** (SBM)

Inferred Contexts

Opportunistic building features extraction

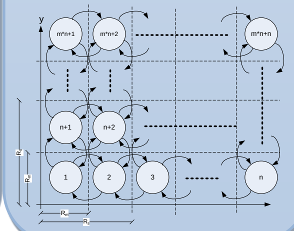
• **Simultaneous (anchor-less) indoor localization and room mapping:**
- *Self-to-self Narrow Band channel analysis with sectorized antennas*
- *Multipath TOA estimation and single-bounce reflection model* within cooperative groups of Impulse Radio transceivers



• **Detection of building's openings:** Indoor-to-outdoor radio signal analysis (e.g. Wi-Fi AP to mobile outdoor MT)

Mobility self-learning for assisted tracking

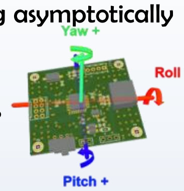
• **Markov chains trained with past estimated trajectories**, Directional Vitterbi, Coupling with location tracking filters

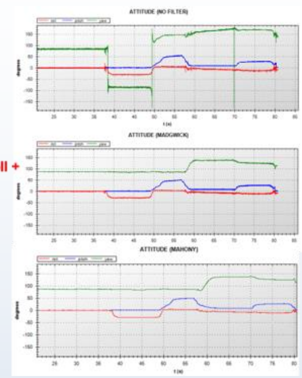


Use of Assisting Non-Radio Means

Inertial data

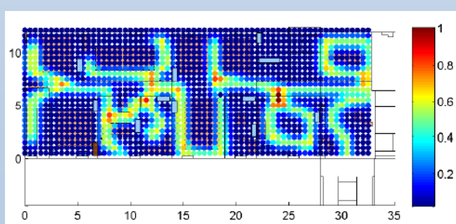
- **Fundamental analysis:**
  - *Performance bounds* illustrating the achievable gains through fusion (e.g. with Wi-Fi TOA),
  - *Adaptive filters* (with unknown state parameters), showing asymptotically optimal solutions (e.g. Expectation-Maximization)
- **Tracking/fusion filter design**
  - *Loosely-coupled fusion EKF* for non-collocated sub-systems (IR-UWB TOA handset + shoe-mounted inertial unit)
  - *Filters detecting changes in the MT's attitude* (e.g. Robert Mahoney's DCM) to assist further tracking (e.g. with Zigbee RSSI)
- **Prototyping and experiments**
  - Selection of commercially available sensors (accelero./gyro./magneto.) for low cost/consumption vs. accuracy
  - Realization of evaluation boards
  - Indoor experiments showing benefits from fusion (e.g. robust pedestrian navigation and MT's attitude detection)





Map knowledge

- **Bayesian Fingerprinting** approaches with map-constrained **likely routes**
- Location-dependent deterministic **compensation of NLOS TOA biases**
- **Extraction of map constraints** through learning (e.g. SVM...)
- **Fusing maps with** other constraints resulting **from radio measurements** (TOA, RSSI, TDOA...) with a unique heterogeneous **geometric** positioning formalism (RGPA)



WP3 Geo-location aided cooperation for future wireless networks

Overview of Main Achievements in WP3

WP3 was in charge of identifying promising avenues for location aided enhancements to wireless communication systems. The wide ranging contributions are organized according to the following targeted systems: cellular networks, mobile ad hoc networks (MANETs) and cognitive radio (CR). Location based approaches are found to alleviate significant signaling overhead in various forms of modern communication paradigms that are very information hungry in terms of channel state information at the transmitter(s) (CSIT). And this at a reasonable cost given the ubiquitous availability of location information in recent wireless standards or smart phones. Location tracking furthermore opens the new perspective of slow fading prediction.

The WP3 results were published in 11 journal papers, 55 conference papers, 2 PhD theses, 1 patent. A WP3-wide joint paper was presented at European Wireless (EW'13). WP3 special sessions were held at EW'13, VTCspring'13, CAMAD'12, Softcom'12, ISCCSP'12, WCNC'12-W4. WP3 was part of a WHERE2 tutorial presented at EW'13, and IEEE ICC'13.

Key Outcomes

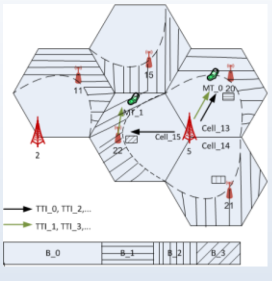
1st outcome: Different partners improved several physical layer methodologies by the aid of location information. The physical layer methods are applicable in coordinated cellular networks, such as LTE-Advanced. Key ingredients here are location aided attenuation prediction and resource allocation such as in relay selection, and location aided multi-antenna beamforming (D3.4 - http://goo.gl/VynGw9).
2nd outcome: The cooperation between mobile terminals is realized through the clustering of terminals aided by geo-location information. This enables improved handover procedures as well as location aided attack detection. A Where2 app demonstrates a secure architecture (D3.5 - http://goo.gl/P1OAgf).
3rd outcome: Location aided cognitive radio techniques with e.g. more robust spectrum sensing aided by geo-location information for weaker signals. This reduced the needed amount of measurement data (D3.6 - http://goo.gl/npiQwT).

Selected Results

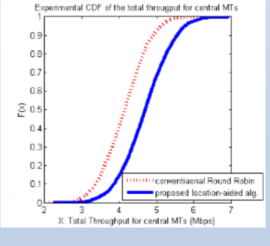
Relay Selection

Reducing signaling overhead

- **Location-aided** relay node planning
- Location-aided **Round Robin Scheduling** in FFR-aided LTE-A Relay Network
- Location-aided **CSIT feedback**



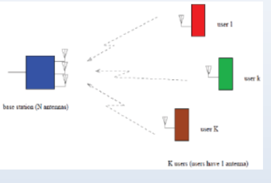
- Optimize **relay locations** based on **traffic demand maps**
- **Reducing** CSI feedback **overhead**



Spatial Division Mulitple Access / Multi-User MIMO / Multi-Cell

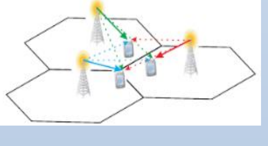
Location Aided SDMA

- **Location** aided **more precise** compared to **DoA** based
- **Resolves ambiguities**
- **Select users** that go well together



Location Aided Multi-Cell Processing

- **Reducing feedback**
- Identifying which interference is relevant at a certain SNR
- **Massive MIMO** exploiting **slow fading (e.g. pathwise)**

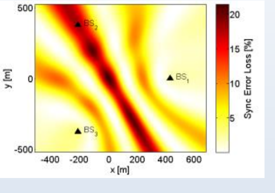


Location Aided Physical Layer Algorithms

Location Aided Synchronization

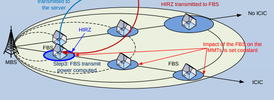
- Synchronization at cell edges is challenging due to interference
- Use of **sync signals** from **adjacent base stations**

→ **turn interference** into **useful signal**



Location Aided ICIC

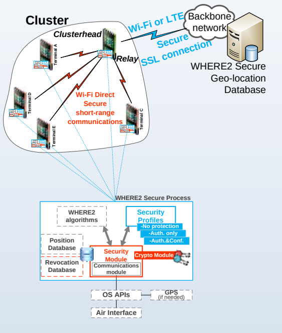
- Definition of **high-interference zones**
- **Location** aided information about **interference, shadowing and slow fading**
- Significant **improvement** at **cell edges of macro- and femto-cells**



Location Aided Clustering

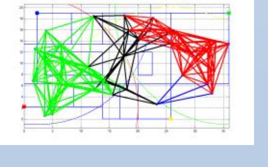
Scalable Clustering for MANETs

- Use clusterheads as authenticators that exploit authenticated Diffie-Hellman exchanges to perform secure key distribution operations



Location Aided Channel Allocation for 2ndary Users

- Creating **map of coverage** of **primary** users to determine which channel is being used and which **locations** should **be avoided**.



WHERE2 Project– December 2013

WP4 Heterogeneous test bed for location and communications

Key outcomes: Evaluation of mobile radio systems and integration in WP4 to show cooperative positioning and communications for an indoor scenario. Implementation and validation of multiple location algorithms. Preliminary measurement campaign and full measurement campaign executed and documented (data available – D4.5 http://goo.gl/EbYPLF). Measurement campaign data post-processed to identify radio models and test location algorithms. Different scenarios/applications concepts presented and partially evaluated with real data.

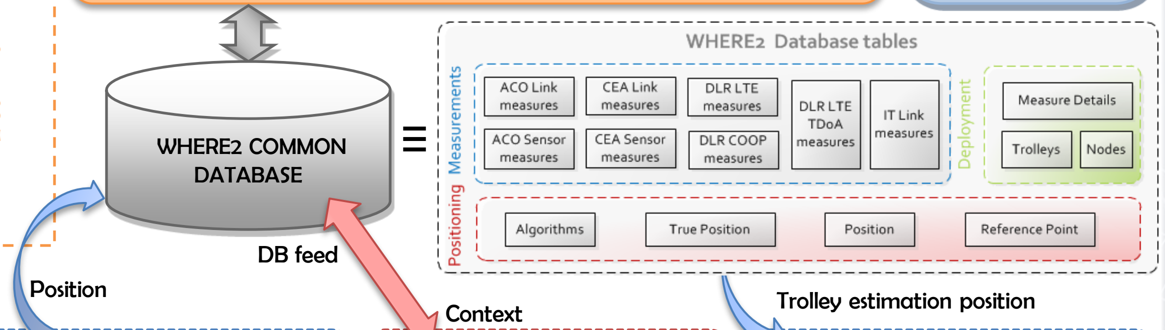
Trial Platform Architecture:

Where2 Platforms

	ZIGBEE PLATFORM	IR-UWB PLATFORM	RTD –LTE PLATFORM	OTHER PLATFORMS
Radio Access Technologies	• 2.4 GHz ISM Band • Bandwidth: 5 MHz • Data rate: 250kbps • Tx power: -1.9dB • 30mA@3V • Modulation: OQPSK	• RF/BB 130nm IC • 4.5 GHz center freq. • Bandwidth: 500 MHz • DBPSK modulation • 1mW Tx / 15mW Rx • 802.15.4-like MAC	• 2.4 GHz + 5.2 GHz ISM Band • Bandwidth: 20 MHz and 40 MHz • Flexible algorithm prototyping/verification	• 0.3 – 6.5 GHz, BW 28MHz. Up to 4x4 MIMO, TDD & FDD • Wi-Fi custom access points and computers • Wi-Fi smartphones and 1.9-2.1 GHz licensed band (3G) • 3.4-3.6GHz WiMAX • 2.1 GHz licensed band (3G), 2.6 GHz licensed band (LTE preview)
Location Features	• Sensor integration • Inercial data • Location estimation • RSSI data	• Round-Trip-Delay ranging (0.3m res.) • RSSI, BER, CIR • Inertial sensors data	• TDoA/RSSI with 3GPP-LTE • Round-Trip-Delay for cooperative nodes	

WHERE2 Common Framework

– Multithreading acquisition middleware
– Report of Node/link measures
– Handling of synchronization issues
– Burst or event based data acquisition
– Low level platforms integration via USB/Ethernet



REAL SCENARIO TRIALS

WHERE2 analysed technologies such as WLAN, LTE, ZigBee, UWB and OFDM (based FPGA programmable card with Wi-Fi transceivers) have been used to acquire data related to different radio communication metrics (RSS, RTD, ToA) and inertial sensor measures. Two scenarios have been evaluated to obtain the analysed measurements: an office at *DLR's premises* and a corridor placed in one *PTIN building*. Those measurements have been documented and stored using the WHERE2 Common Framework in the WHERE2 Common Database which have been defined and full developed for this project. This database is one of the main outputs generated by this WP http://goo.gl/9CQuLF

POSITIONING ALGORITHMS EVALUATION

The data store in WHERE2 database is provided to the partners who have worked in the production of various positioning algorithms in order to estimate location information from an heterogeneous set of ranging metrics. In the measurement campaigns the error between the estimated and the actual location is evaluated to conclude for the most appropriate technology or combination of technologies and algorithms to be used in indoor environments (message passing algorithm, RGPA, ML, WLS, EKF,...) - http://goo.gl/RfFuxB

ADITIONAL SCENARIOS / APP

Vertical Handover between Wi-Fi and WiMAX technologies based on two dominant decision metrics: the position of the user in an indoor environment and congestion in the Wi-Fi access points

RSSI fingerprinting algorithm tested in the indoor office environment of the OTE Labs building (build Android app that scans RSSI, show status and find devices).

Context Location Based app, considering user's location and schedule (Google Calendar).

Other applications were evaluated: Android app for secure localization data exchange, Outdoor 3D geo-map construction system for indoor devices location, public demonstration of context location based scenario at FuNeMS'13