



## **Integrated Project - EUWB**

**Contract No 215669**

### **Deliverable**

**D4.3.1**

**Evaluation of requirements for the LT engine implementation (LDR and HDR platforms)**

<b>Contractual data:</b>	<b>M15</b>
<b>Actual data:</b>	<b>M17</b>
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<b>Work package:</b>	<b>WP4</b>
<b>Security:</b>	<b>PU</b>
<b>Nature:</b>	<b>Report</b>
<b>Version:</b>	<b>1.0</b>
<b>Total number of pages:</b>	<b>47</b>

#### **Abstract**

This report presents the main requirements needed for the Location and Tracking engine implementation, to be implemented both at the Low and High Data Rate Platforms, within the scope of the EUWB Integrated Project

#### **Keywords**

EUWB, LT engine, LDR platform, HDR platform, active and passive localization

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## **Abbreviations**

ECMA	European Computer Manufacturers Association
EM	Electromagnetic
EUWB	CoExisting Short Range Radio by Advanced Ultra-WideBand Radio Technology
FPGA	Field Programmable Gate Array
HDR	High Data Rate
HW	Hardware
IP	Internet Protocol
LDR	Low Data Rate
LT	Location and Tracking
MAC	Medium Access Control
OFDM	Orthogonal Frequency Division Multiplex
PHY	Physical Layer
Rx	Receiver
SW	Software
Tx	Transmitter
UWB	Ultra-wideband

## 1 Executive summary

The main objective of this WP is to investigate advanced LT solution for wireless networks characterised by both static and dynamic scenarios. In particular, the research will cover the development of advanced LT techniques to be applied under non-ideal conditions for either Localisation or Tracking.

The main goal of the task 4.3, where this deliverable is included, is the integration and evaluation of the solutions developed by other partners from Work package 4 using the available platforms in EUWB project.

In the scope of the project, three scenarios have been selected to test and evaluated these algorithms on the different platforms.

- Public Transport scenario.
- Automotive scenario.
- Home environment.

This document, which is entitled “D4.3.1 Evaluation of requirements for the LT engine implementation (LDR and HDR platforms)”, is organised into three main parts. Firstly, it provides a general overview of the active localization algorithm and the scenarios defined in the scope of EUWB project, then a short description of the proposed platforms is presented, and finally, the passive localization algorithm, as well as its requirements is presented.

## **2 Introduction**

The purpose of this report is to present the main Location and Tracking engines that are being studied in this work package as well as a brief description, from the point of view of the location engine, of the available platforms in EUWB project.

This document is divided into three main parts, and structured as follows:

The first section provides a general overview of the active location engine currently implemented in PULSERS Phase II project. Also a short description of the three scenarios defined in the different clusters is provided.

Second part of the document includes a brief description of the two available platforms: LDR and HDR platforms.

Passive localization gained importance in some of the scenarios described by the different clusters, so the last section of the document is focused in this issue.

## 3 Active Localization

### 3.1 Description

The main objectives of this task are the integration and evaluation of the location algorithms developed in this work package on the different platforms available.

Considering the nomenclature used in a location engine a blind node or target is a mobile node that has to be located and an anchor node is a fixed node whose position is known.

In order to develop a localization algorithm, the application scenarios described in [4], [6], [8] are simplified as follows. The network, shown Figure 3-1, consists of  $N$  nodes, where  $N_A = N-1$  are anchors, that is with a fixed and known location, while the remaining node is the target whose location is to be determined. For each pair of anchor-target the distance can be measured via the UWB radio interface.

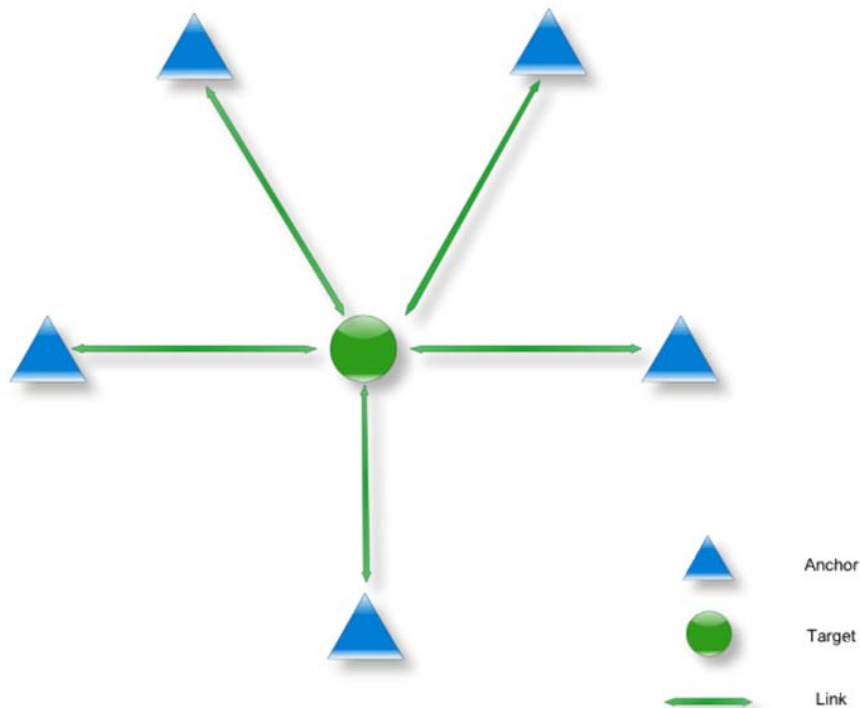


Figure 3-1: Active localization concept

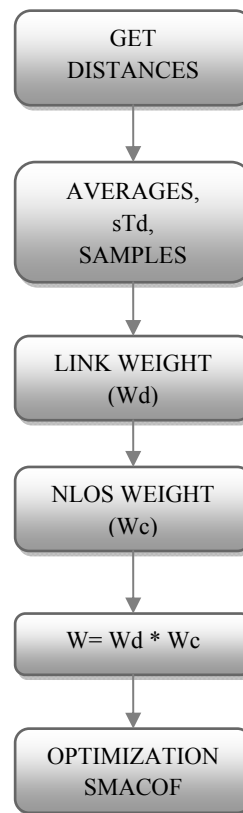
### 3.2 Preliminary Version (PULSERS Phase II)

In project PULSERS Phase II, a first approach of this type of algorithms had been designed and implemented. Following is presented a brief description of that algorithm.

First of all, some input data are requested to the network:

- Ranging information
- Connectivity of the network
- Position of the fixed nodes.

This algorithm can be divided in three main parts. First of all, collect all the required data, then, different weights are calculated to obtain the reliability of the ranging samples and finally, an optimization process is executed. Figure 3-2 depicts this algorithm:



**Figure 3-2: Centralized Algorithm**

The centralized localization algorithm, fully non-parametric, is based on a weighted least squares multi-dimensional scaling (WLS-MDS) approach.

Distance measurements, obtained from the ranging processes amongst the nodes of the network, are collected at a central unit where they will be used by the algorithm to simultaneously localize all the nodes.

In short, the WLS-MDS distance based localization algorithm consists of three major steps.

- First, for each measured link, an aggregated distance estimate is computed from a small set (typical size is between 2 and 5 samples) of measurements. Such an aggregated value is given by the sample mean.
- Second, for each measured link a weight is computed in order to capture the reliability of the ranging samples. Specifically, such a weight consists of a dispersion component, which captures the effect of noise under the assumption of bias-free samples, and a penalty component, which quantises the risk of the latter assumption and penalizes it proportionally. The dispersion weights result from the application of small-scale statistics with reliable optimized under a maximum entropy criterion that “mathematize” the empirical concept of reliability. In turn, the penalty weights are derived from the relationship between the risk incurred by the bias-free assumption and the geometry of 3-node cliques, established by statistical-geometry.

- Finally, the last step required in the WLS-MDS algorithm, is the minimization of a non-convex objective function. To this objective, a low-complexity algorithm based on majorization technique is applied. Specifically, the algorithm is known as SMACOF and it consists of an iterative procedure that attempts to find the minimum of a non-convex function by tracking the global minima of the so-called majored convex function successively constructed from the original objective and basis on the previous solution.

In PULSERS Phase II, the algorithm proposed was designed for mesh networks and not for source localization (as needed in this project).

Indeed, the previous algorithm exploited multiple connections to compute a penalty weight to mitigate the NLOS effect. Now, this method can be neglected.

### 3.3 Enhanced Algorithm (EUWB)

In this project the localization algorithm will include only the dispersion weight. However, for the NLOS mitigation we are investigating some new mechanisms.

A method is proposed by UIL, which in short consists of:

- a) Detection of the LOS/NLOS conditions via hypothesis testing mechanism on the measured noise variance.
- b) Localization via a combinatorial approach, meaning that a LS-based minimization algorithm is repeated several times with different link combinations in order to find the best set of links that minimizes the localization error.

A method is proposed by CWC, which

- a) computes a set of contracted distances
- b) run SMACOF of any other minimization algorithm using the contracted distances

A brief summary of this new method proposed by CWC:

- measure the distances with the UWB radio
- Compute a point in the area formed by the intersection of the circles (feasibility region) of radio " $d_{measured}$ " with centre at the anchors.
- Compute the contracted distances as the shortest distance from each anchor to the aforementioned feasibility region.
- Run SMACOF of any other minimization algorithm (i.e. global distance continuation, steepest descent) using this contracted distances instead of the measurements.

The advantages are:

- non parametric
- No need of sophisticated optimization algorithms since the function becomes convex.
- low-complexity

An idea of this contraction algorithm is presented in the next sections, as well as a possible usage in multihop networks. Also a more robust optimization algorithm is mentioned.

### 3.3.1.1 Contraction concept

In Figure 3-3, a network with 4 anchors and a target is shown. The blue, black and red circles are those corresponding to the true, measured and contracted distances, respectively. The area highlighted with the bold black line indicates the feasibility region. As mentioned above, the new algorithm will compute a point that lies in this area, and using this point, the contracted distances will be computed. (Notice, that the red circles are tangent to the feasibility region.) The circles formed by these distances do not intersect anymore, and they makes the LS- cost function convex. Any minimization algorithm can be employed. The solution is the red-cross (very accurate). Figure 3-4 shows that the contraction algorithm yields localization accuracy close to the theoretical limit shown with the position error bound (PEB). [9]

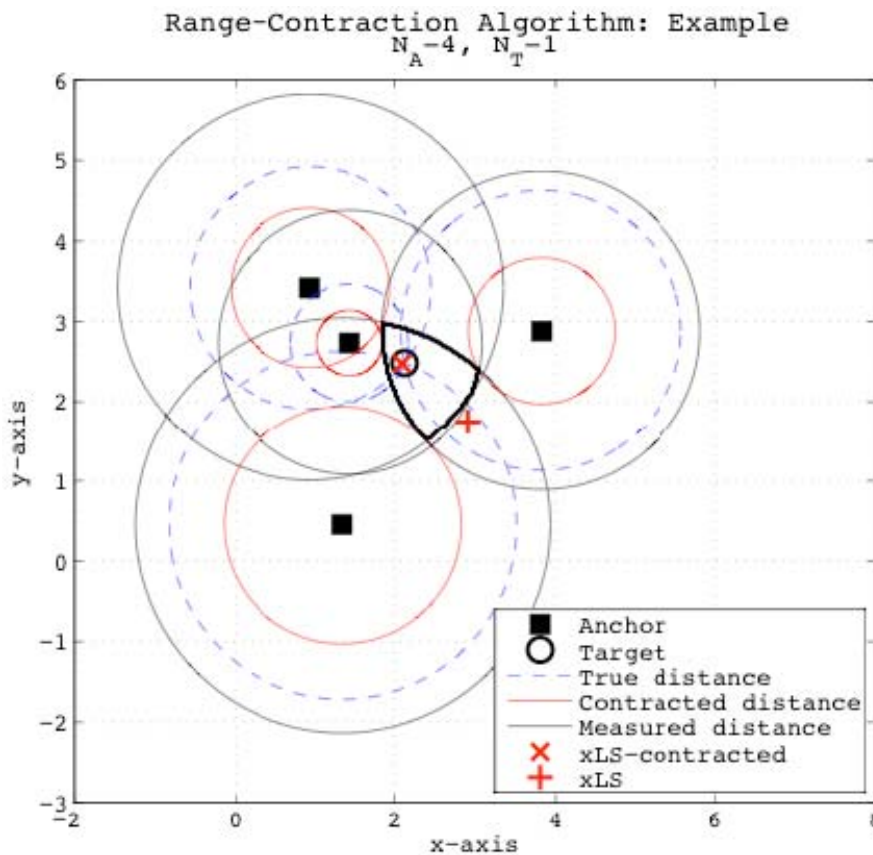


Figure 3-3: Contraction concept

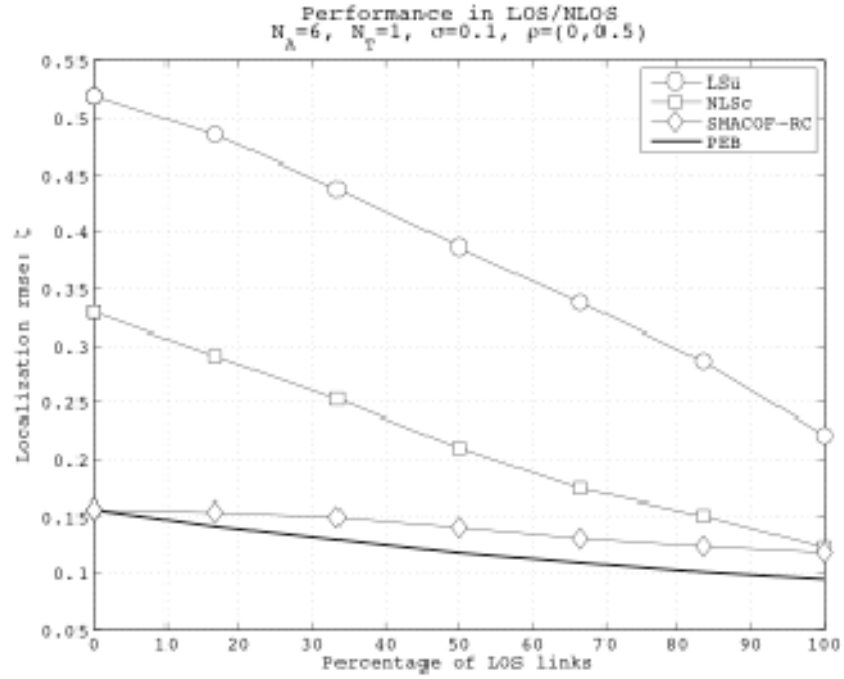


Figure 3-4: Performance in LOS/NLOS

3.3.1.2 Multi-hop Localization with Contraction

The same algorithm can be used to localize a node in a multi-hop network, Figure 3-5 and Figure 3-6. In essence, a tree will be built from the mesh network and the distances to the furthest anchors will be considered. As it can be observed, there is a great improvement in the localization error (Figure 3-7), [10]

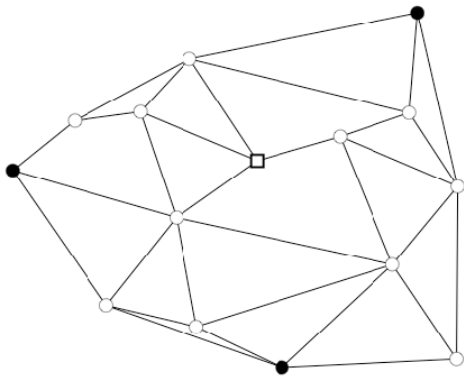


Figure 3-5: Multi-hop network

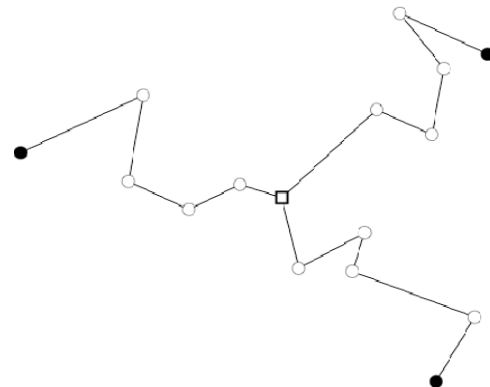


Figure 3-6: Multi-hop Network

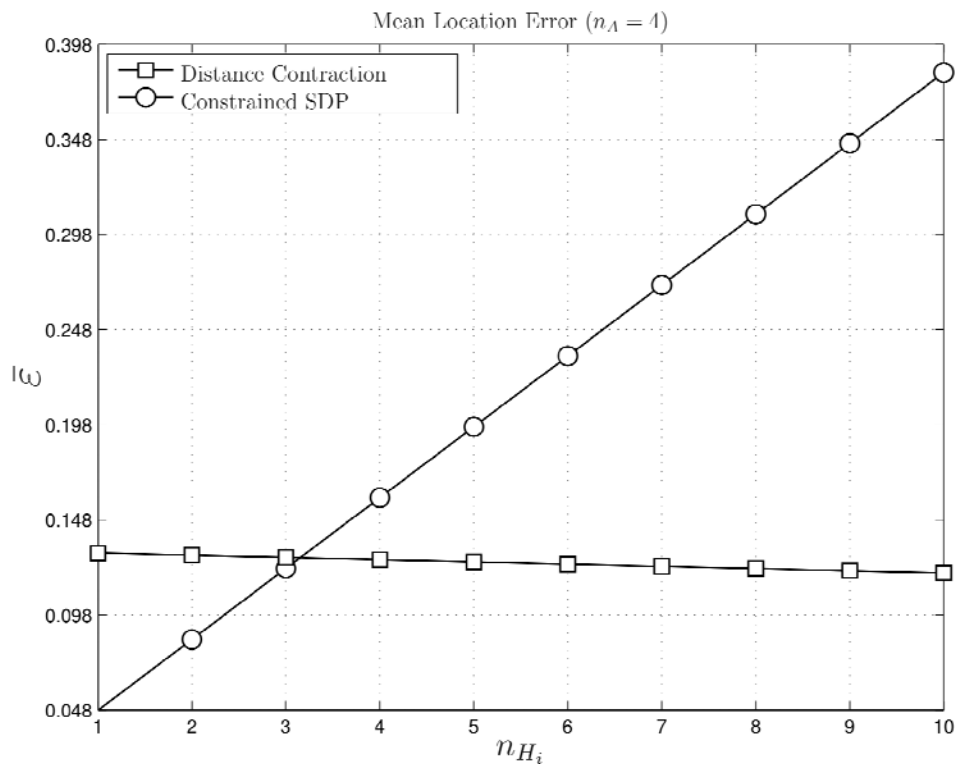


Figure 3-7: Localization error

3.3.1.3 Optimization algorithm

An idea of a more robust optimization algorithm (linear - global distance continuation) that can replace the SMACOF is show in Figure 3-8 and Figure 3-9.

$$\lambda \geq \frac{\sqrt{\pi}}{2} \max_i \{ \tilde{d}_i \}$$

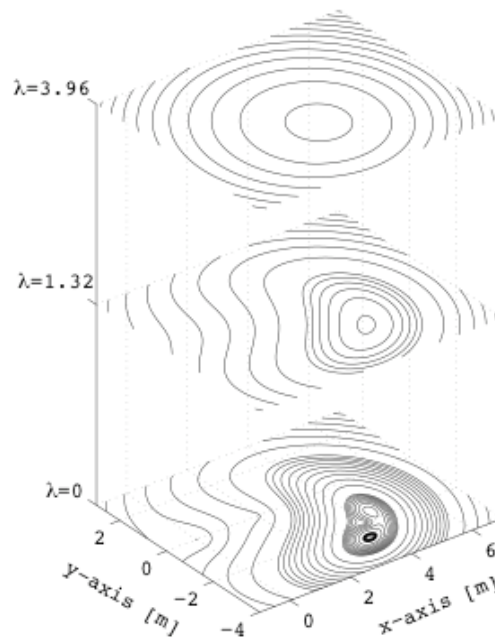


Figure 3-8: Contour plot of the Smoothed Function

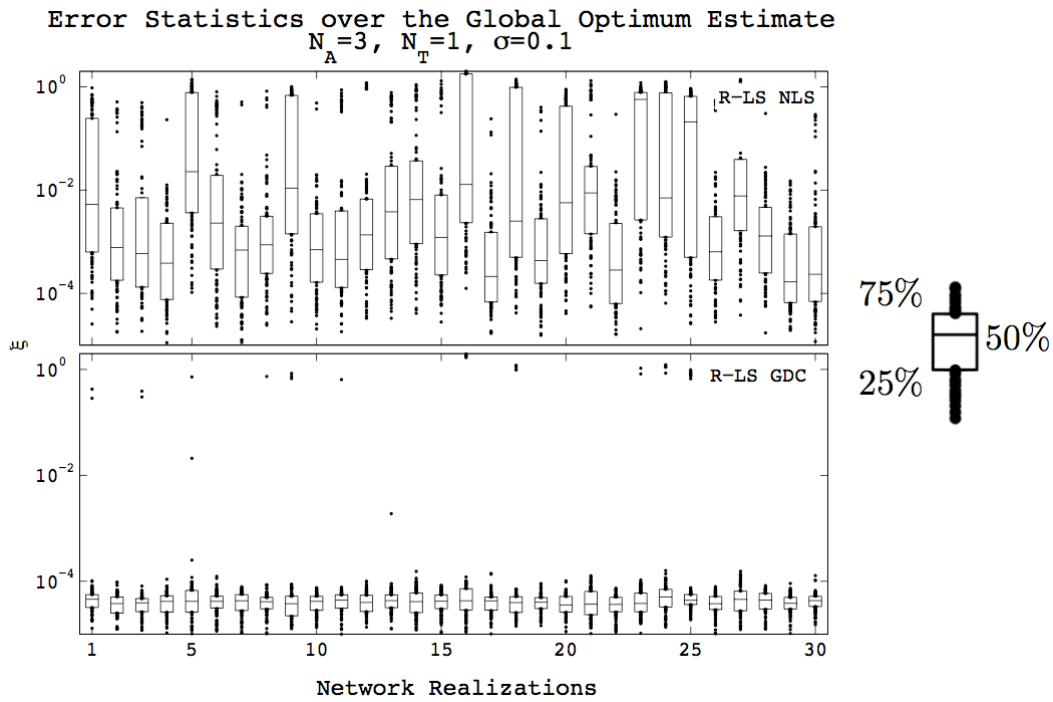


Figure 3-9: Error Statistics

### 3.4 EUWB application scenarios

There are three scenarios defined in the scope of this project. Next subsections present a short description of these scenarios from the point of view of the active localization problem.

#### 3.4.1 Public Transportation

A cell of a wireless network in the aircraft consists of 4 access points with overlapping coverage area [4] and an unknown target. Access points have known location. The localization problem is to estimate the location of a device, which is identified by a code, from a set of distance measurements from the access points. The challenge in this scenario is the high noise level due to the multiple systems coexisting in the airplane.

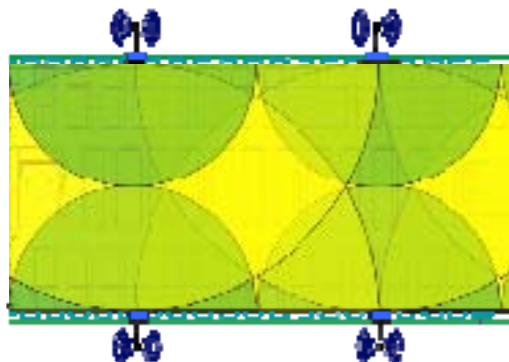


Figure 3-10: Typical scenario - public transportation environment

### 3.4.2 Automotive environment

Consider the wireless network deployed in a car, which consists of 6 access points as shown in Figure 3-11, the localization problem is to estimate the location of a device, which is identified by a code, from a set of distance measurements from the access points. [6]

The challenge in this application scenario is to accurately recognize the location of the car-key (UWB transmitter). In other words, the localization algorithm must be able to recognize, with an error of  $\pm 0.1\text{m}$  if the key is outside or inside the car, and if inside, it is also desirable to identify the location: trunk, engine department, back seats, front-left seat and front-right.

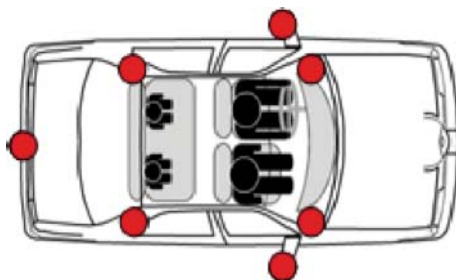


Figure 3-11: Typical scenario - automotive environment

### 3.4.3 Home Environment

Consider the home environment network setup, described in [8], and in particular, consider the scenario of 5 loudspeakers and the remote control. In this application scenario, first, the localization system needs to localize the speakers, and second, use them as anchor nodes to estimate the position of the remote control. In so doing, there are two major challenges. The first one is to develop an algorithm that is anchor-free in order to estimate the location of the speakers up to rotation and mirroring. The second problem is to minimize the localization error of the remote control, given the location of the speakers. In this evaluation-test, we consider only the second problem, since we assume that the anchors (speakers) are already localized.

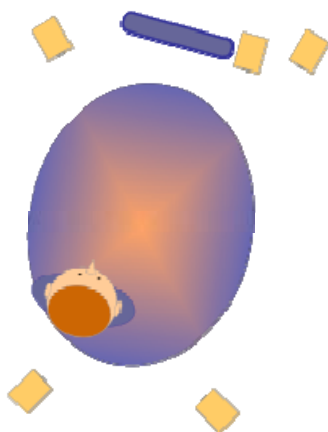


Figure 3-12: Typical scenario - home environment

All of these scenarios have been evaluated in this work package and their results can be looked up in [13]

## 4 Hardware Description

In the scope of this project, two platforms will be available to implement and evaluate the algorithms develop in WP4. This section presents a short description and the location capabilities of each platform.

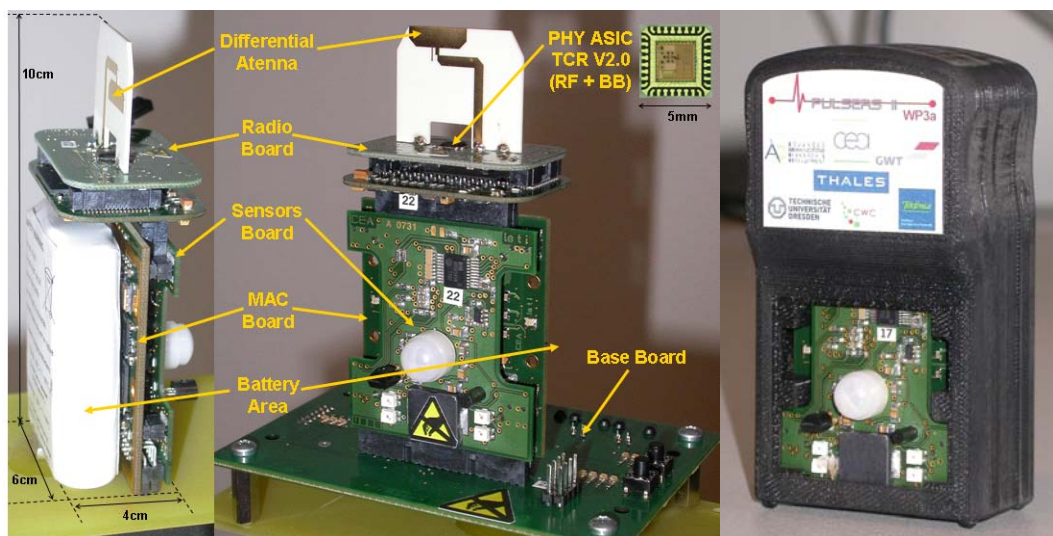
### 4.1 LDR Platform

#### 4.1.1 General Description

The PHY layer proposed hereafter was described in the PULSERS Phase II deliverable D3a3.3 issued in July 2008 [3].

The overall architecture of the LDR-LT platform is shown on Figure 4-1 (physical view). This platform includes a complete protocol stack:

- Application layer (APPL)
- Network layer (NWK)
- Medium Access Control layer (MAC), split into SoftWare MAC (SW-MAC) and HardWare MAC (HW-MAC)
- Physical layer (PHY)



**Figure 4-1 : Physical view of the IR-UWB LDR-LT platform (profile / front / packaged)**

From the implementation point of view, note that the Application, Network, and SW-MAC layers are part of a software package whereas the HW-MAC and PHY layers are part of a hardware package.

The complete stack is implemented into each physical node, including the part of the application in charge of local elementary computations (e.g. for positioning purposes), all except but the part of the application that is hosted on a PC and responsible of advanced tasks (e.g. the Graphical User Interface).

### 4.1.2 General scenario description

Thinking in a common scenario for a location and tracking engine, this section is oriented to describe and make the distinction between anchor nodes and blind/mobile nodes in our LDR platform:

- Anchor node
  - Has fixed known position set by hand
  - Can request or reply to ranging frames (implements proper ranging primitives)
  - Can calculate the range with respect to a blind node
  - Can send its own range measurements to a central point for further processing (i.e. positioning/tracking)
- Blind/Mobile node
  - Has unknown position to be estimated and/or tracked
  - Can request or reply to ranging frames (implements proper ranging primitives)
  - Can calculate the range with respect to a blind node or an anchor node
  - Can send its own range measurements to a central point for further processing or update its own position estimate based on range measurements in the distributed positioning approach (with proper application capabilities for positioning)

Then, as regards to radio management, we make a distinction between:

- PicoNet Coordinator (PNC)
  - Emits beacons
  - Implements resource management and the complete protocol stack
  - Is connected to a Personal Computer (PC) through a serial (or Ethernet).
- Device (DEV)
  - Can get associated to the PicoNet Coordinator (PNC) or a router
  - Can be a simple leaf or become a router and relay beacons
  - Implements the complete protocol stack, all except but the application part hosted by the PC connected to the PNC

Finally, concerning Wireless Sensor Networks (WSN) capabilities, we distinguish:

- Sensor node
  - Can measure one or several environmental parameters (e.g. temperature, acceleration, movement, etc.) at different refreshment rates
  - Can relay environmental measurements to a collecting point in the network
- Actuator node
  - Can react to an injunction delivered by a central or neighbouring entity by modifying its own status or setting off a particular action (e.g. light or sound alarm)

In order to ease design and implementation efforts on demonstration boards, note that all the nodes are implemented and hosted onto identical physical platforms with similar HW/SW capabilities.

#### **4.1.2.1 *Embedded Sensors and Actuators***

In addition to the LT capabilities, each is also endowed with a set of functional sensors and actuators, as follows:

- Sensors:
  - 3D accelerometer
  - 3D magnetometer
  - thermometer
  - Passive Infra-Red (PIR) movement detector
- Actuators:
  - four high-power LED
  - buzzer

Embedded 3D magnetometers and 3D accelerometers are analogue components, respectively from Honeywell and STMicroelectronics.

The thermometer is also an analogue component, from National Semiconductors.

The PIR detector is based on an Infra Red (IR) sensor with suitable Fresnel lens, both from Murata, followed by an analogue high-gain amplifier and a band pass filter (0.01-10Hz). The main output information is a Boolean accounting for movement detection. However, further information (typically a 16 bits word) can be optionally obtained for qualitative or quantitative processing.

The audio actuator is a piezoelectric buzzer with programmable sound frequency and duration.

The light actuators use four Light-Emitting Diodes (LED) with programmable activity and global light level.

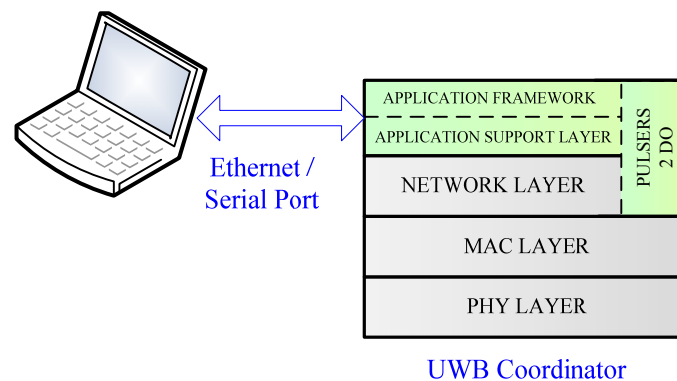
#### **4.1.2.2 *Functionalities/capabilities***

- Location and Tracking applications
  - Peer-to-peer or broadcasted ranging (including Blind-to-Anchor ranging and Blind-to-Blind ranging)
  - Distributed positioning
  - Centralized positioning
  - Potentially Centralized tracking
  - ...
- Radio and network management
  - Peer-to-peer communications
  - Association and disassociation
  - PicoNet (PN) synchronization
  - Beacon relaying
  - Mesh networking
  - Network discovery
  - Network scheduling
  - Optimal routing

- Topology control
- Low Duty Cycle (LDC) and activity control
- ...
- Sensor/actuator-oriented applications
  - Relay of heterogeneous data flows
  - Relay of critical alarms or instructions
  - Environment monitoring and context awareness
  - Adaptative and autonomous networking
  - ...

### 4.1.3 Interfaces

The interface between the wireless sensor network and the graphical user interface is represented in the following picture:



**Figure 4-2 : Interface between the GUI and the network**

As it is depicted in the previous figure, the communication between the PC (where the GUI is implemented) and the coordinator is made through a serial port interface.

### 4.1.4 Location engine - software environment

LDR software oriented to the localization are divided in three main parts: All the configuration done by the user through the GUI, all the measurements done by the boards, and all the calculations needed implemented embedded on the boards and also in the GUI (main operations for the centralized algorithm).

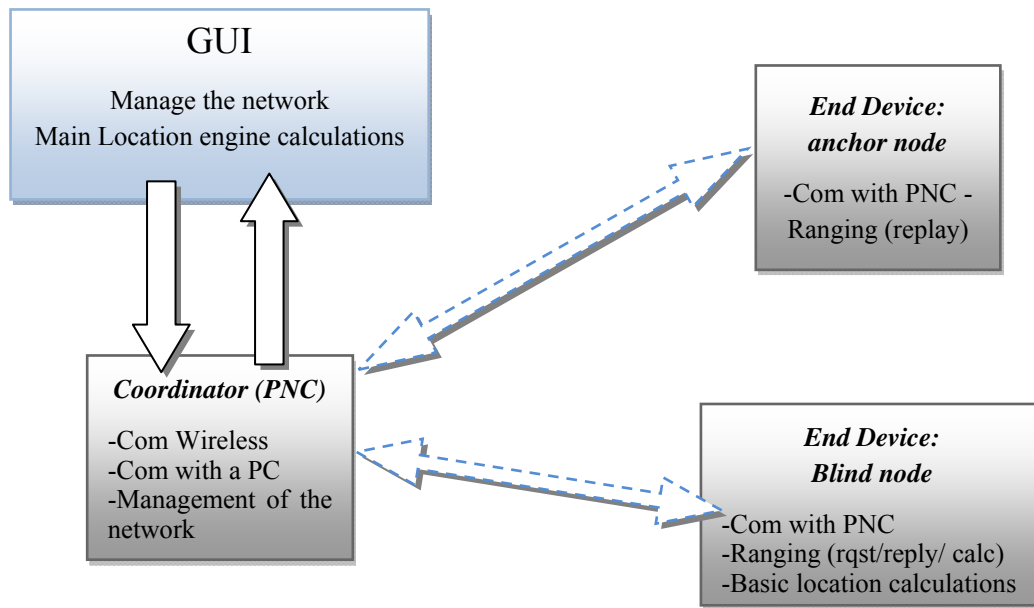


Figure 4-3: Infrastructure of LDR Software

### 4.1.5 Ranging Functionality

All the layers in the stack implemented in the LDR platform take part in the ranging procedure, the most important requirement for the location engine.

#### 4.1.5.1 PHY layer – Ranging functionality

Fine resolution ranging module is the one in charge of performing the fine resolution search of the beginning of the received channel impulse response. A coarse estimation (with a precision of about 8ns) of the time of flight is already performed by time-stamping the frame detection event.

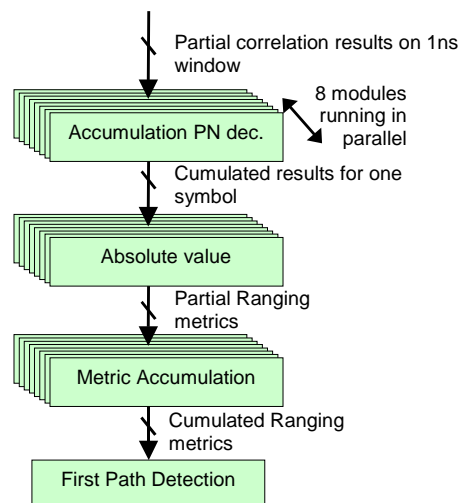


Figure 4-4 : Fine resolution ranging module architecture

Basically, the signal processing performed on the incoming samples is the same as the one performed in the demodulation block, but using incoming signal chunks of 1ns (1 sample in our case) instead of 8ns. To do this, the 8 partial correlation results corresponding to the related 1ns incoming signal chunks are provided by the correlator used in the demodulation module and are then processed by 8

parallel PN decoding and accumulation modules similar to the one used in the demodulation branch. A second stage of accumulators performs additional accumulations on the absolute values of the resulting metrics in order to reach the required processing gain. Once these accumulations are performed, the first significant path is detected and its index gives the fine grain resolution required for precise ranging. In order to reduce the complexity, this module processes only the signal chunk for which the first detection event occurred and the 2 or 3 previous ones. It is to be noticed that this simple approach allows using any data frame for ranging measurement.

More details can be found on [14]

#### **4.1.5.2 MAC layer - Ranging functionality**

A ranging frame is introduced for the purpose of ranging transactions.

Issued by the PHY, each end of ranging frame – Tx and valid Rx – gives the timer results. There are 6 different timer values according to the ranging frames, as described below:

- TTx-Req the time stamp of the request ranging frame on the initiator side,
- TRx-Req the time stamp of the request ranging frame on the destination side,
- TTx-Resp the time stamp of the response ranging frame on the destination side,
- TRx-Resp the time stamp of the response ranging frame on the initiator side,
- TTx-Drift the time stamp of the drift ranging frame on the destination side,
- TRx-Drift the time stamp of the drift ranging frame on the initiator side.

Ranging mode also depends on the number of contiguous time slots dedicated to ranging in the GTS descriptor:

- One slot only allows one way ranging with only TTx-Req and TRx-Req available,
- Two slots for two way ranging with also TTx-Resp and TRx-Resp,
- Three slots for three ways ranging with all the six timer values.

More details can be found on [14]

#### **4.1.5.3 Network Layer - Ranging functionality**

The ranging is organised by means of separate primitives to be used by the higher layers. There is a request primitive for requesting a ranging procedure between a source device and one or more destination devices. Within the network layer a decision is made to perform the ranging (source address is the own network address, alternatively in case of reception of a range request network command) or to transmit a network command frame to the source device to force that device to range. After ranging, a range confirm network command resp. a range confirm primitive is generated.

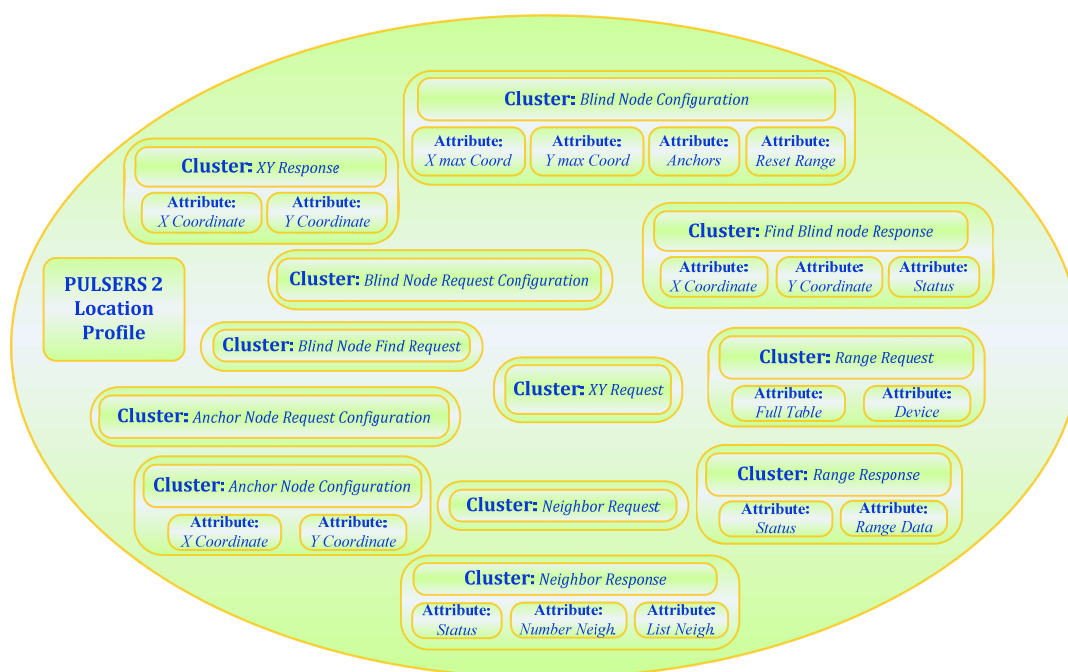
#### **4.1.5.4 Application point of view**

LDR platform upper layer design is based on ZigBee Stack. Following this standard, the application layers need a profile to define all the commands and attributes of the Localization Communication, [14].

Application profiles are agreements for messages, message formats and processing actions that enable applications to create an interoperable, distributed application between applications that reside on separate devices. These application profiles enable applications to send commands, request data and process commands and requests.

A profile is defined by means the device objects involved in it and the clusters implemented in that profile:

- Device Object: set of possible application objects that can be used inside a profile. For example, in the location profile defined, the device object list is formed by a monitor (to show the data to the user), anchors (fixed node with known position) and blind nodes (nodes that are going to be located).
- Clusters and attributes: The communication between all the device objects inside a profile is defined by the cluster (commands), and their attributes (parameters). Figure 4-5 displays all the clusters and attributes implemented in PULSERS Phase II location profile.



**Figure 4-5 : PULSERS Phase II Location Profile**

This profile embedded the basic command needed for the previous location engine, but this profile can be modified with new requirements.

#### 4.1.6 Graphical User Interface

LDR platform available offers the possibility to have a sensor network as well as the location engine developed.

The GUI should offer the possibility to manage the complete network (different sensor and actuators included).

Thinking in the location engine the GUI should offer to the user the possibility to manage different aspects of the location algorithm to test it on the different scenarios defined in this project.

## 4.2 HDR Platform

The HDR platform follows a modular approach with a split at the MAC / PHY interface. The MAC is implemented on a commercial ‘off the shelf’ FPGA development platform, whilst the PHY module (including both RF and Baseband functionality) is provided as a daughter card. The MAC layer offers the ability to interface higher protocol layers above the MAC layer interface, however an IP based interface is provided to allow IP based application scenarios to be developed directly with the development platform interface, [22].

Release E01935R01.0 of the ‘Open Platform’ is provided on the Xilinx ML507 Virtex-5 FPGA development platform as shown in Figure 4-6. Here it is shown with the Wisair 532 PHY module integrated as a daughter card on the TES MAC-PHY interface adapter card,[23].



Figure 4-6: HDR “Open Platform” on a Xilinx ML507 Virtex-5

### 4.2.1 General Description

#### 4.2.1.1 Physical layer description

The (V)HDR Open Platform is considered as a platform that enables short range, low power, high-speed wireless connectivity of up to 480 MBit/s by using the ultra wideband spectrum from 3.1 to 10.6 GHz. Due to different modulation schemes and spreading methods the platform supports data rates of 53.3 MBit/s, 80 MBit/s, 106.7 MBit/s, 160 MBit/s, 200 MBit/s, 320 MBit/s, 400 MBit/s and 480 MBit/s, [22].

The UWB bandwidth from 3.1 to 10.6 GHz is divided into 14 bands, each with a bandwidth of 528 MHz greater than the minimum bandwidth 500 MHz of the UWB signal, so that the definition of UWB is satisfied. These 14 bands are grouped into 5 band groups with 3 bands in each band group excepting the last group which has only two bands. The sixth group is also defined within the spectrum of group three and four, consistent with usage within world wide spectrum regulations.

The MultiBand Orthogonal frequency Division Modulation (MB-OFDM) scheme is specified in the ECMA standard in order to transmit information with UWB. Each band consists of 128 sub-carriers with 4.125 MHz intervals: 100 data sub-carriers, 10 guard sub-carriers, 12 pilot sub-carriers for coherent detection and 6 null sub-carriers.

Two modulation schemes are employed for the data sub-carriers: QPSK (quadrature phase-shift keying) and DCM (dual carrier modulation). The quality of the UWB link and the transmission data rate depends on the deployed modulation scheme. For a high quality link (for data rate 320 MBit/s or higher) the more efficient DCM scheme is preferred in order to maximize the data rate, while the lower quality link (data rate 200 Mb/s or lower) employ the less efficient QPSK scheme but with lower code rates. In the QPSK mode two bits are mapped to each sub-carrier while in the DCM mode four bits are mapped to two sub-carriers.

In order to improve the BER (bit error rate) two types of redundancy are used: Frequency-domain spreading (transmitting the same data on two separate sub-carriers within the same OFDM-symbol) and time-domain spreading (transmitting the same data over two bursts). Together with forward error correction (FEC) convolutional codes with code rates of 1/3, 1/2, 5/8 and 3/4 the transmission data rates can be adapted.

The coded OFDM symbols is then spread by hopping across the bands in each band group according to a hopping sequence which is predefined and called TFC (time frequency code). It should be noted that this hopping can be executed only within one band group. A hopping among several band groups is not possible. 10 TFCs are supported for each band group. Three types of TFCs are specified in ECMA standard: a) the OFDM symbols are hopped across all the three bands within one band group, referred to as Time-Frequency Interleaving (TFI); b) The OFDM symbols are interleaved over two bands within one band group, referred to as two-band TFI or TFI2; and c) only one single band of a band group is utilized during transmission, referred to as Fixed Frequency Interleaving (FFI).

In the case of data rate 53.3 Mb/s the QPSK modulation as well as FDS, TDS and FEC with a code rate of 1/3 are employed. The following calculation indicates how to achieve this data rate: deploying QPSK modulation, 200 bits are mapped on 100 data symbols forming the payload part of one OFDM symbol. The FDS and TDS reduce the throughput in half respectively and 50 bits/symbol are obtained. The FEC works on six-symbol intervals, therefore six symbols times 50 bits/symbol result in 300 raw bits. Considering the FEC code rate 1/3 only 100 coded bits will be transmitted in six symbol intervals, i.e. 1.875  $\mu$ s. Thus, the throughput equals 53.3 Mb/s. To achieve a data rate of 480 Mb/s DCM is employed together with no FDS and no TDS. The FEC coding rate is 3/4. The calculation is analogue: The DCM mapping results in 200 bits/symbol. Due to no FDS and TDS these bits will be input to FEC without redundancy. FEC works on six-symbol intervals, hence, six symbols times 200 bits/symbol equals 1200 raw bits. The FEC code rate 3/4 reduces the raw bits to 900 coded bits which will be transmitted in 1.875  $\mu$ s resulting in a data rate of 480 Mb/s, [22].

#### 4.2.1.2 MAC layer description

The MAC is the lower sub-layer of the data link layer defined in OSI basic reference model. The MAC service is provided by the MAC service access point (MAC SAP) to a single MAC service client, usually a higher layer protocol or adaptation layer. The PHY provides service for the MAC by the PHY service access point (PHY SAP). The MAC sub-layer requires the following features:

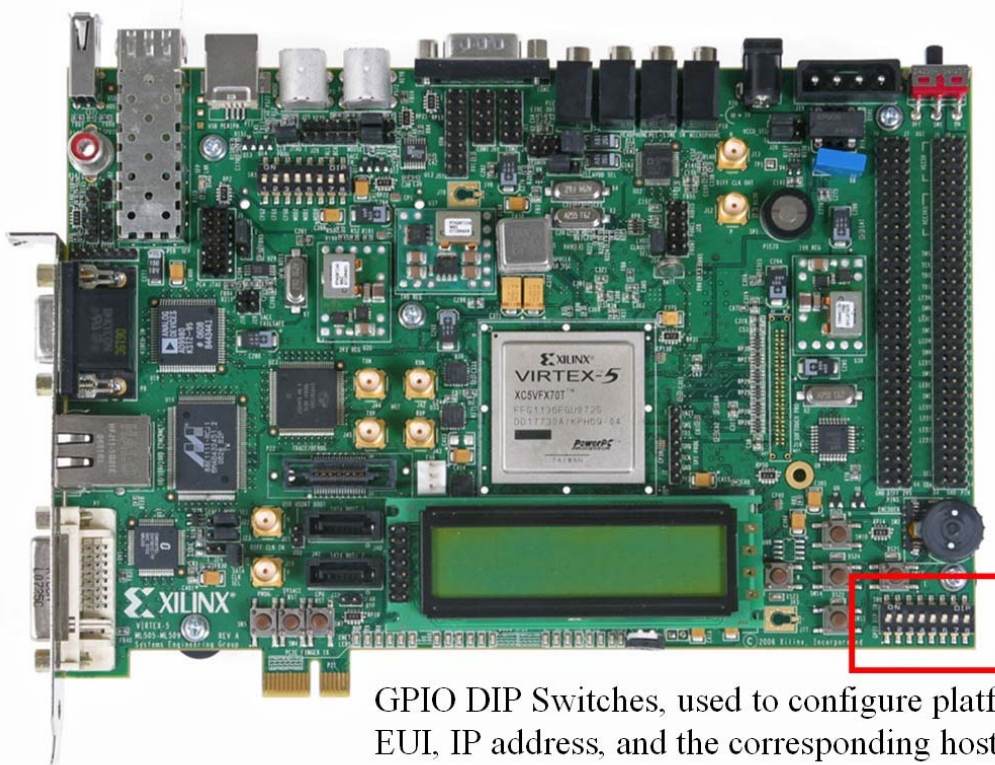
- Frame transmission in both single frame and burst mode
- Frame reception for both single frame and burst mode transmission

- PLCP header error indication for both PHY and MAC header structures
- Clear channel assessment for estimation of medium activity
- Range measurement timestamps if MAC range measurement is supported.

The exchange of parameters between the MAC sub-layer and the PHY makes the frame transmission and reception possible. In single frame transmission the MAC sub-layer controls the frame timing fully, while in burst mode transmission the MAC sub-layer has only the control of the first frame timing and the PHY provides accurate timing for the remaining frames in the burst, [22].

#### 4.2.1.3 Network information requirements

The first release of the HDR ‘Open Platform’ supports an Ethernet based host interface. Each platform has a unique EUI and internal IP address. The EUI and IP address of the platform are configured by setting the top three GPIO DIP selection switches (6 to 8), which are shown in Figure 4-7, [22].



GPIO DIP Switches, used to configure platform EUI, IP address, and the corresponding host IP address

**Figure 4-7: Configuring EUI and IP Addresses**

There are eight internal IP options, which can be configured by the selection switches (6 to 8):

- 0: {0x00, 0x11, 0x22, 0x33, 0x44, 0x11}, {192, 168, 23, 11}
- 1: {0x00, 0x11, 0x22, 0x33, 0x44, 0x22}, {192, 168, 23, 22}
- 2: {0x00, 0x11, 0x22, 0x33, 0x44, 0x33}, {192, 168, 23, 33}
- 3: {0x00, 0x11, 0x22, 0x33, 0x44, 0x44}, {192, 168, 23, 44}
- 4: {0x00, 0x11, 0x22, 0x33, 0x44, 0x55}, {192, 168, 23, 55}

5: {0x00, 0x11, 0x22, 0x33, 0x44, 0x66}, {192, 168, 23, 66}

6: {0x00, 0x11, 0x22, 0x33, 0x44, 0x77}, {192, 168, 23, 77}

7: {0x00, 0x11, 0x22, 0x33, 0x44, 0x88}, {192, 168, 23, 88}

Switch 6 is MSB and switch 8 is LSB. It assumes that there are two HDR platforms. Each platform must have a unique host IP address, which can be the external IP address of the connected PC. The host IP address is configured by setting GPIO DIP selection switches (3 to 5) as shown in Figure 4-7. There are also eight options for the configuration of host IP:

0: {192, 168, 23, 1}

1: {192, 168, 23, 2}

2: {192, 168, 23, 3}

3: {192, 168, 23, 4}

4: {192, 168, 23, 5}

5: {192, 168, 23, 6}

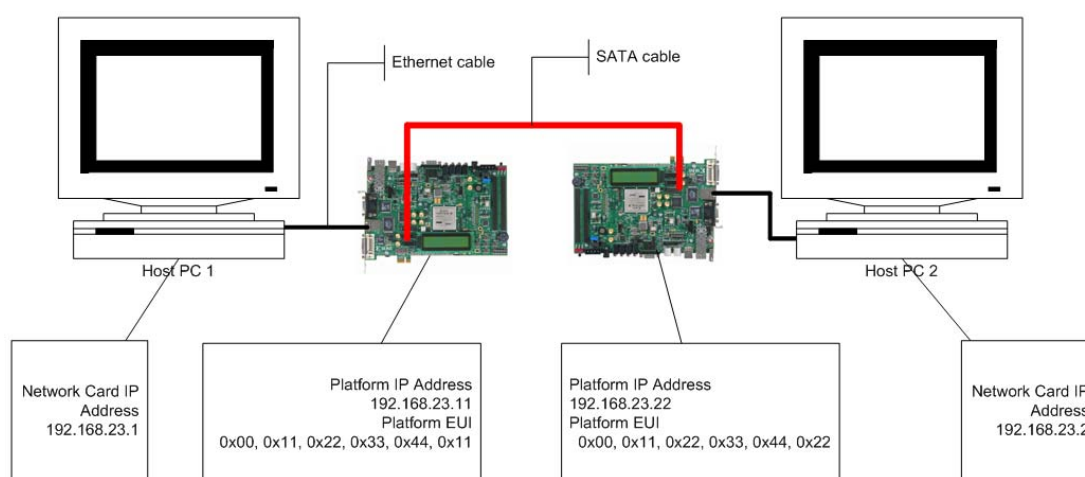
6: {192, 168, 23, 7}

7: {192, 168, 23, 8}

It is also necessary to add a persistent route to the route table on both the PCs which are connected to the platforms. This can be done from the MSDOS command prompt as follows.

```
route -p ADD <remote host ip> <local board ip>
```

- Where <remote host ip> is the IP address of the remote host PC connected to the other board.
- And <local board ip> is the IP of the local platform.



**Figure 4-8: Configuring IP Host Routing Tables**

This figure shows the method of configuring the IP Host Routing Tables. Two platforms are connected with the SATA cable due to the lack of the PHY module from Wisair, [23].

## 4.2.2 Interfaces

### 4.2.2.1 Physical MAC interface

As agreed in the EUWB project, the PHY MAC interface information shall be provided to TES only in a separate document.

### 4.2.2.2 MAC and Higher Layer Interface

The key capabilities of the MAC core that will be available on the HDR open platform are:

**Table 4-1: MAC Core High-level Features Supported by HDR Open Platform**

Attribute	Supported (Y/N)
PCA	N <sup>1</sup>
Hard DRP	Y
Soft DRP	Y
Block ACK	N <sup>1</sup>
Explicit DRP Negotiation	Y
Hibernation Anchor	N
Probe	N
Link Feedback	Y
Range Measurement	Y-TBD
Security levels M0	Y
Security levels M1	N <sup>1</sup>
Security levels M2	N <sup>1</sup>

All messages (events) provided in the MAC core interface take the form of a variant to a service primitive, using the common '*req*', '*cfm*', '*ind*', '*rsp*' notation where;

- A '*req*' is a request message received from a higher component layer.
- A '*cfm*' is a confirmation message sent to a higher component layer as a result of processing a '*req*'. All '*req*' messages have a corresponding '*cfm*' message i.e. '*req*' and '*cfm*' are messages symmetrical.
- An '*ind*' is an indication message sent to a higher component layer.

---

<sup>1</sup> These features are available in the MAC core, but there are no plans to make this available on the open platform

- A 'rsp' is a response message received from a higher component layer as a result of processing an 'ind'.

Not all 'ind' messages require a 'rsp' message i.e. 'ind' and 'rsp' messages can be asymmetric,[22].

#### 4.2.2.3 Service Primitives for the Upper MAC

This section describes the messages that may be used at the service interface to the MAC Core by a client software component.

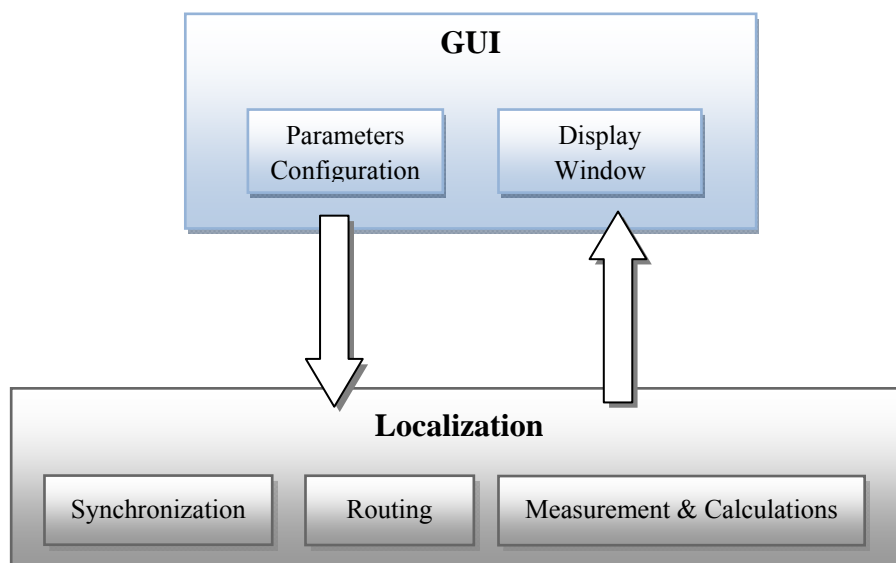
The service interface provided in this document has been derived from analysis and high-level design of the component layer based on the specification versions listed in the references section, found at the end of this document, [22].

The primitives rely on three categories of data types:

- Types that apply specifically to the MAC core.
- Types that apply to the software protocol stack as a whole are global types.
- Base types such as bool (boolean) and u8 (unsigned 8-bit integer) are TMKii Kernel Types.

#### 4.2.3 Location Engine - Software environment

HDR Software consists of three parts: Parameters Configuration, Localization and Display window. The relationship among them can be illustrated as follows:



**Figure 4-9: Infrastructure of HDR Software**

As can be seen from the Figure 4-9, the graphical user interface includes Parameters Configuration and the Display Window. The localization engine consists of Synchronization, Routing and Measurement Calculation.

A ranging feature is desired for some of the HDR applications in the EUWB project. This optional feature was defined by the ECMA standard, but has not been implemented by any manufacturer so far.

This document describes the ranging feature to be added to the MB-OFDM open platform of the EUWB project.

A single ranging measurement is based on measuring the propagation time of two consecutive messages in alternating directions. Each of the two devices measures the transmission time and the reception time, and the differences provide the propagation time.

The definition of the ranging feature in the ACME standard, [20] and [21], was not thorough enough for a simple implementation. The definition is vague on the exact timing definition of the reception signal and is very demanding from the MAC perspective.

A slightly modified approach for this feature is suggested in this document. The suggested approach resolves the timing ambiguity in the Rx and relaxes the MAC requirements.

#### **4.2.3.1 Measurements concepts**

The ranging feature measures the points in time of transmitted and received messages and calculates the time differences and therefore the signal propagation delays and the distances between nodes. These distances are the basis for localization.

According to the standard, the time measurement is done with a counter (pRangingTimer) of up to 32 bit, with the LSB running at 4224MHz as a maximum, or setting bits [2:0] (LSBs) =0 and counting from bit 3 at 528MHz,[24].

A register should be latched to this timer at times corresponding to the transmission and reception of the first bit of the first CE symbol (reference signal). The timing may be biased in a known quantity:

1. RANGING\_TRANSMIT\_DELAY = the time from the generation of the reference, triggering the pRangingTimer capture, to the time this signal reaches its own antenna,
2. RANGING\_RECEIVE\_DELAY = the time from the arrival of the reference signal at the antenna to the time this signal is first detected in the PHY, triggering the pRangingTimer clock capture.

The timer should start and stop according to instructions from the PHY/MAC IF, [24].

#### **4.2.3.2 Actual PHY Implementation for Ranging**

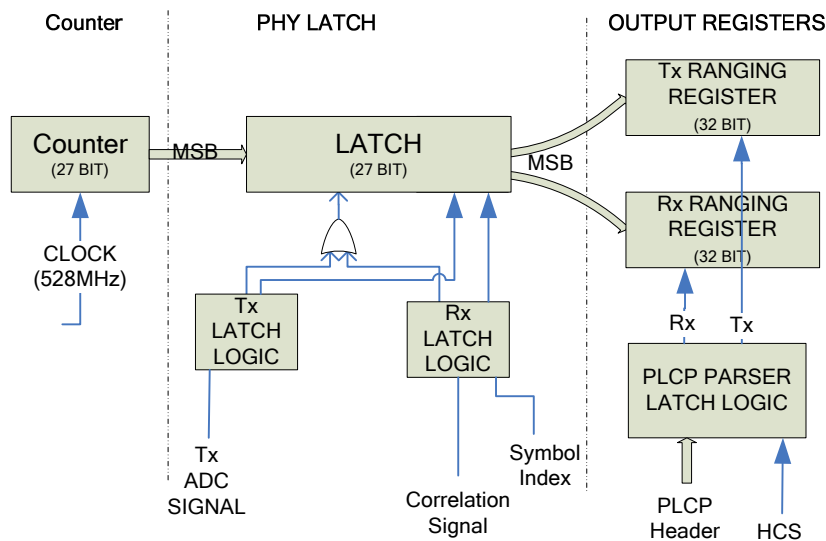
The ECMA standard defines the ranging feature in full, including PHY layer measurement definition, controlling protocol and message formats. However, ranging was not considered a major standard feature already while being written, and while this definition could work, it is very problematic, once actual design takes place, as explained below.

As will be shown below, some of the definitions are ambiguous, but have a clear resolution for correct results. Other definitions require the MAC control over the PHY to be tighter, to a level that forces specific architectures and is more restrictive in implementation, compared to the communications requirements.

The system designed, and specified was modified from the ranging as defined in [20], in order to relax the MAC requirements in a way which would enable the MAC to manage the ranging operation without being designed especially for it. This is even more important for the open platform, since the MAC of the EUWB open platform runs on FPGA, [24].

## 4.2.3.2.1 PHY Block Diagram

Figure 4-10 Shows the overall Ranging measurements blocks and feature scope at the PHY, [24].



**Figure 4-10: Ranging Blocks and system**

The PHY architecture is constructed of a counter, and two latching stages, the latter of which with two separate registers one for Rx measurement and one for Tx measurement.

The counter is a free running counter (no reset or initial value) running at 528MHz, equivalent to about 60cm of ranging resolution (and maximal error). The ranging disable is not described, however, the counter may start from any value once activated \ re-activated.

The first latch stage should latch the counter value for both Tx and Rx operations. The Tx latch timing is generated by the signal arriving to the ADC. The Rx latch timing is derived from the received signal as explained below.

The second latch operation is designed to latch only desired packets. A desired packet is determined according to a bit code added (by the MAC \ higher layer) to reserved bits in the standard ECMA PHY header (for both Rx and Tx), provided there was no header error in the reception (only in Rx). According to the current operation, the secondary stage loads the value to either the Tx or Rx register. The bit selection for the code is programmable, see Figure 4-11.

For additional feature control, each of the output ranging registers will be reset on read operation, [24].

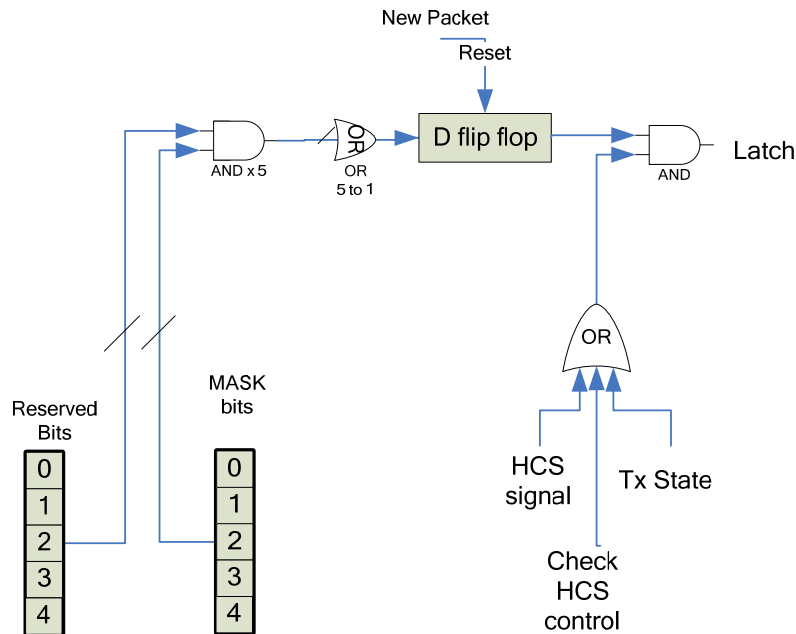


Figure 4-11: Output registers latch logic

4.2.3.2.2 Rx Latching algorithm and limitations

The Rx latching is done during the acquisition of a newly received signal, the ECMA\WiMedia signal at the acquisition is a time domain correlation sequence, and the latch requires the acquisition to reach a particular symbol after the signal has been detected and then check the receiver calculated correlation surpasses a threshold for the first time. This way enables catching the first wave-front\path with low probability of miss-detect and errors.

The suggested Rx latching algorithm has one major problem – the symbol in which the Rx is latched is counted from the preliminary signal acquisition, and not from the CE. The preliminary signal acquisition might start at a later symbol, instead of the first one, and then, the timing measurement result would suffer from ambiguity, of integer symbol number. This ambiguity will not be resolved by HW, because it is easy to solve it by the ranging application SW. Converted to meters, the ambiguity of one symbol is approximately  $93.6m / 2 = 46.8m$  (range conversion requires averaging of both directions). The ranging ambiguity value is much larger than the expected communication and ranging range. Hence the ranging application SW can easily resolve this ambiguity, [24].

4.2.3.2.3 PHY ranging parameters

Table 4-2 lists the parameters for the ranging; the two main parameters are the Cor value threshold and the start symbol post detection, [24].

**Table 4-2: PHY ranging parameters**

<b>Parameter</b>	<b>Comments</b>
Ranging Cor value threshold for Rx	Integer value to be optimized
Ranging start symbol for Rx	1 to 15, value should be optimized.
Ranging PLCP MASK bits [bit 6, bit 7, bit 8, bit 14, bit 15]	-
Check HCS	1 bit
Ranging Feature enable	1 bit

#### **4.2.4 HDR Platform GUI**

The Graphical User Interface (GUI) consists of parameters configuration and the display window. From them the input parameters can be configured and the result of the measurement can be displayed in the display window.

## 5 Passive localization

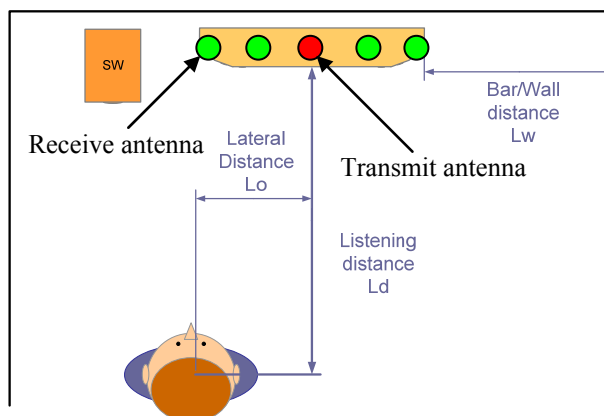
Passive localization gained importance in the EUWB project especially for the applications in home entertainment and automotive environment scenarios. Here, information about e.g. listener's position in the home entertainment environment or about the intruder detection in the automotive environment helps to improve the overall performance of the audio resp. car-security UWB systems. In these scenarios people are localized passively only by the reflection of electromagnetic waves scattered back from their body. In what follows, we will describe the passive localisation scenario in more details. We will present major challenges related to the passive localisation and impose requirements on the HW that should be used for the demonstration and/or evaluation of the passive localization.

### 5.1 Scenario description

Scenario for the demonstration of passive localization was selected with respect to the deliverable D8c.7 [12]. This deliverable describes application scenarios for localization application in home audio systems. It proposes three application scenarios that provide the focus of EUWB's location tracking activities within the home environment cluster. These scenarios include:

- Multiple speakers Home Theatre Systems
- Two-point Ambisound Systems
- Single-point Ambisound (Sound bar)

The single-point ambisound has the advantage that some parameters are fixed / known on beforehand by the design. Therefore, we have selected this scenario for the demonstration of passive localization. An example of the scenario is given in Figure 5-1. Parameters that are a priori known and simplify the demonstration are e.g. coordinates of antennas situated within the sound-bar.



**Figure 5-1: 1-point Ambisound ideal setup**

Now, we will describe the application scenario and the propagation of EM waves in it in more details. The purpose of it is to demonstrate challenges imposed on HW and SW for passive localisation. Finding a solution for the propagation of electromagnetic waves is generally a very difficult task. It depends strongly on the whole scenario, i.e. on the position of transmit and receive antenna, on geometrical and material properties of the whole propagation environment. In order to solve this problem it is necessary to combat direct scattering problem by solving the Maxwell equations. This is, however, not within the scope of this chapter. Here, we will give only basic equations describing the

receive power of electromagnetic waves in basic scenario consisting of one transmit antenna, one receive antenna and a person that should be detected and localized as shown in Figure 5-2. If we assume an omni-directional transmit antenna with an antenna gain  $G_0$  transmitting a signal with the power  $P_t$  than the power density of transmitted wave at distance  $R$  from the transmitting antenna in a lossless material is

$$(1) \quad S = \frac{P_t}{4\pi R^2} G_0.$$

If there is a receive antenna with the identical antenna characteristics than the power measured at the output of this antenna is described by the following equation known in the literature [15] as the Friis formula

$$(2) \quad P_r = P_t \frac{G_0^2 \lambda^2}{(4\pi)^2 R^2}.$$

This formula shows that the power of the received electromagnetic waves in a lossless medium (air) decreases with the power of the distance between transmit and receive antenna.

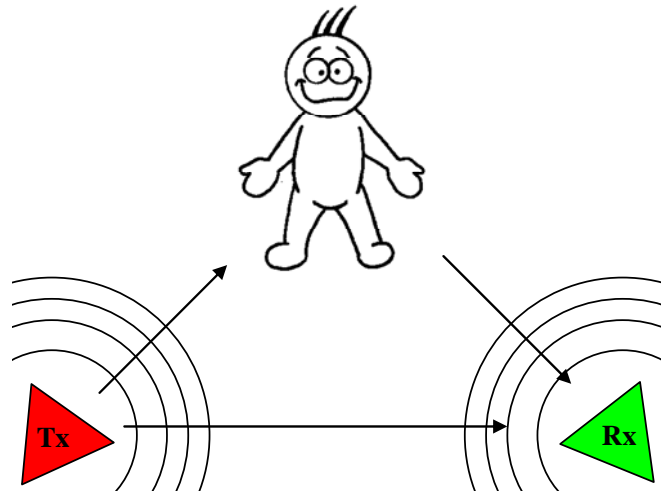


Figure 5-2: Propagation of electromagnetic waves

If there is a person at the distance  $R_t$  from the transmit antenna than the power density of the transmitted wave at this position is given by (1). As transmitted electromagnetic waves reach the person it becomes the source of reflected electromagnetic waves and their power transmitted back towards the receiving antenna is

$$(3) \quad P_z = \frac{P_t G_0}{4\pi R_t^2} \sigma,$$

where  $\sigma$  is the radar cross section of the person. It describes the ability of an object to reflect electromagnetic waves. It is equivalent to the antenna gain, which describes the ability of the antenna to transmit electromagnetic waves of certain frequency to a particular direction. Radar cross section  $\sigma$  is angle and frequency dependent. The power density of electromagnetic waves reflected from the object towards the receive antenna at distance  $R_r$  from the object is

$$(4) \quad S_o = \frac{P_t G_0 \sigma}{4\pi R_t^2} \frac{1}{4\pi R_r^2}.$$

The power of a signal which is possible to measure at the output of receiving antenna caused only by the reflected electromagnetic waves from the person is

$$(5) \quad P_r = P_t \frac{G_0^2 \sigma \lambda^2}{(4\pi)^3 R_r^2 R_t^2}.$$

The total power obtained from the receive antenna is a combination of the direct wave propagating from the transmit antenna directly to the receive antenna and the electromagnetic wave reflected back from the object. Thus, the total power measured by the receive antenna in this simple scenario is

$$(6) \quad P_r = P_t \frac{G_0^2 \lambda^2}{(4\pi)^3 R^2} + P_t \frac{G_0^2 \sigma \lambda^2}{(4\pi)^3 R_r^2 R_t^2}.$$

However, only the second term related to the reflected electromagnetic waves is significant for the detection and localization of persons. Therefore, localization systems based on the passive approach must be able to detect weak signals at the presence of the strong signal – a direct wave. Thus, the dynamic range of UWB sensors for passive localisation must be much higher in comparison to localization systems based on active approach. This represents one of the biggest challenges in the passive localization.

## 5.2 Passive localisation algorithm

Algorithm that is intended to be implemented for the online demonstration of passive localisation should consist of three basic steps:

- detection,
- localization and
- tracking

In following sub-chapters, we will focus on the detection and localization step. Tracking algorithms just improve results of the localisation step taking into account time correlation of computed coordinates.

### 5.2.1 Detection of persons

As demonstrated by (6), the most challenging part in the positioning of persons is their detection. The detection of persons strongly depends on following conditions:

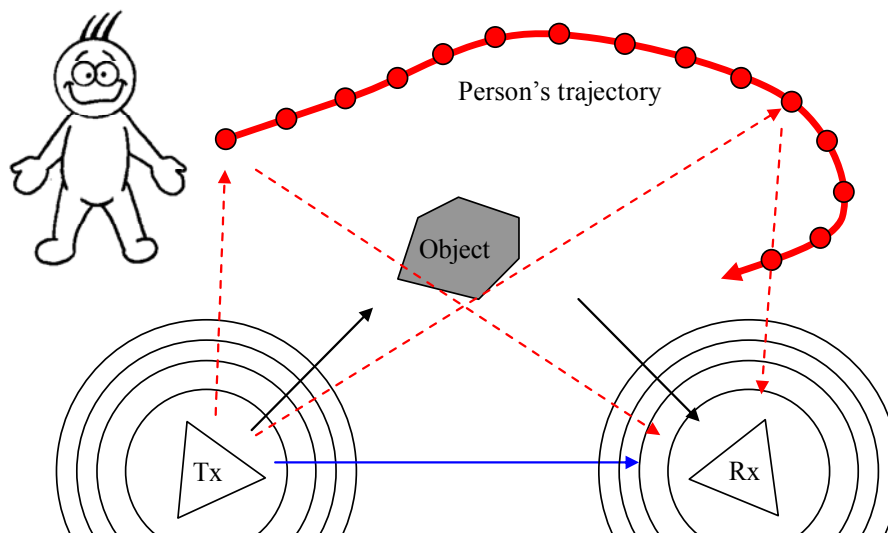
- the number of persons,
- their activity,
- environmental conditions.

Person's activity is related to the kind of its movement. A person can walk, or sit quietly. This influences its detection. A moving person is easily to detect in comparison to the sitting or laying person. In the latter case, the person can be detected only according to its respiratory or heartbeat activity. Detection of the respiratory and/or heartbeat activity is, however, a challenging task. Small

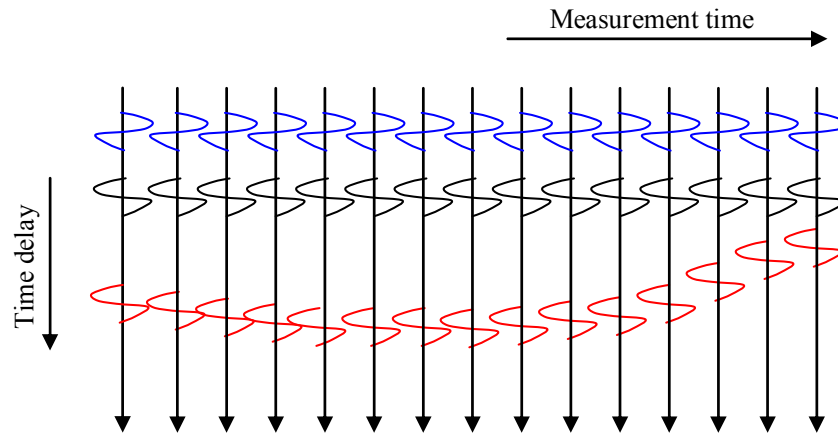
movements of the human chest evoke only very weak signals. This imposes tough requirements on the dynamic of HW intended for passive localization.

Environmental conditions also determine the degree of complexity of the person's detection. If all objects in the person's surroundings are static then the detection of a moving person is relatively easy. In this case, the moving person can be differentiated from other static objects according its movement. However, if the scenario is time-varying with various moving objects (windows, machines), the person detection is a challenging task. In this case, the detection step must be followed by target recognition.

Figure 5-3 describes the application scenario related to the detection task. Here, we assume one person moving along the trajectory illustrated by the red line and one static object. Further, we assume an UWB sensor transmitting a stimulation signal at a certain measurement rate. Transmitted electromagnetic waves propagate, firstly, directly towards the receive antenna (blue line). They are also back scattered from the static object (black line) and from the moving person (dashed red lines), which appears to the UWB sensor at certain time as a static object. Red circles situated along the person's trajectory represent subsequent positions of the moving person that are related to time instants when the UWB sensor transmits impulses. Impulse responses recorded by ultra-wideband localizer that are related to this scenario are schematically shown in Figure 5-4. Impulse responses are aligned to each other creating so a 2 dimensional picture, where the vertical axis is related to the time delay of one impulse response and the horizontal axis is related to the measurement time. Direct waves propagating from the transmit antenna Tx to the receive antenna Rx are illustrated by blue impulses, scattering from the static object is shown as a black impulse and the waves scattered from the moving person are depicted by the red impulse.



**Figure 5-3: Detection of a moving person in case of a static scenario**



**Figure 5-4: Impulse responses related to the measurement scenario from the previous figure**

From the figure, it is obvious that the direct wave and the scattering from the static object create horizontal lines parallel to the time axis. In practical measurements these usually strong static signals overlay time variant echoes. An approach separating static signals from time-variant reflections is known in radar signal processing as a background subtraction [16]. Since it was described in details in the deliverable D4.1.1a (Initial Localization and Tracking Algorithm) we just summarize its basic idea. Background subtraction eliminates or at least reduces disturbing static signals. Static signal components result from direct Tx-Rx feed-through and from wave scattered at dominant static reflectors, e.g. walls, furniture or metallic devices. Background subtraction considerably enhances the detection of weak time variant signal features. A simple background subtraction approach starts with stacked averaging of the sequence of measured impulse responses. This way, the static background scattering is estimated which is in the next processing step subtracted from the time variant sequence of impulse responses.

For the demonstration of the passive localization within the frame of this project, a background subtraction based on the exponential averaging will be implemented for on-line processing in the HW. A key advantage of the exponential averaging is its simplicity. For the computation of the result, it takes a fraction of the previous output  $y_k$  and a fraction from the current input  $x_k$  according to

$$(7) \quad y_k = \alpha y_{k-1} + (1 - \alpha)x_k \quad .$$

where  $\alpha$  is the weighing factor and is between 0 and 1. If the weighing factor  $\alpha$  is equal zero, then the output is a copy of the input and is without any averaging. By increasing the factor  $\alpha$ , the input values are more and more averaged. Thus, this simple formula is capable to emphasize recent events, or smooth out high frequency variations and reveal long term trends. This approach has an advantage over the simple averaging of all measured impulse responses since it is also able to suppress slow time-variations of the background in comparison to the movement of persons.

The background subtraction algorithm is followed by a ranging algorithm. The goal of this step is to estimate time-of-arrivals (ToAs), i.e. a time necessary for the transmitted impulse, which is reflected from a moving person, to arrive to the receive antenna. The ToA estimation can be a very simple maximum search algorithm, or more sophisticated algorithm based on the adaptive threshold detection. For the demonstration of the passive localisation within the frame of this project, we will program different ranging algorithm. The performance of these algorithms can be so compared in a real-time.

### 5.2.2 Localization of persons

In the case of the passive approach, the person (at an unknown position) acts as a reflector and the localization unit works in a radar-type mode without any cooperation with the person. In these conditions the round trip time transmitter-person-receiver is measured and this information gives access to the person's position.

The problem description of the simplest case of 2D passive localization is illustrated in Figure 5-5. Firstly, the localization system estimates ToAs as discussed in the previous chapter. Estimated ToAs  $\tau_{p1}(t)=s_I(t)+s_2(t)$  and  $\tau_{p2}(t)=s_I(t)+s_3(t)$  determine two ellipses those focal points are determined by the locus of the transmit antenna and the loci of the corresponding receive antennas. Thus, the target position results from the intersection of both ellipses described by following equations

$$(8) \quad \left( \frac{x(t) + \frac{D}{2}}{a_1(t)} \right)^2 + \left( \frac{y(t)}{b_1(t)} \right)^2 = 1$$

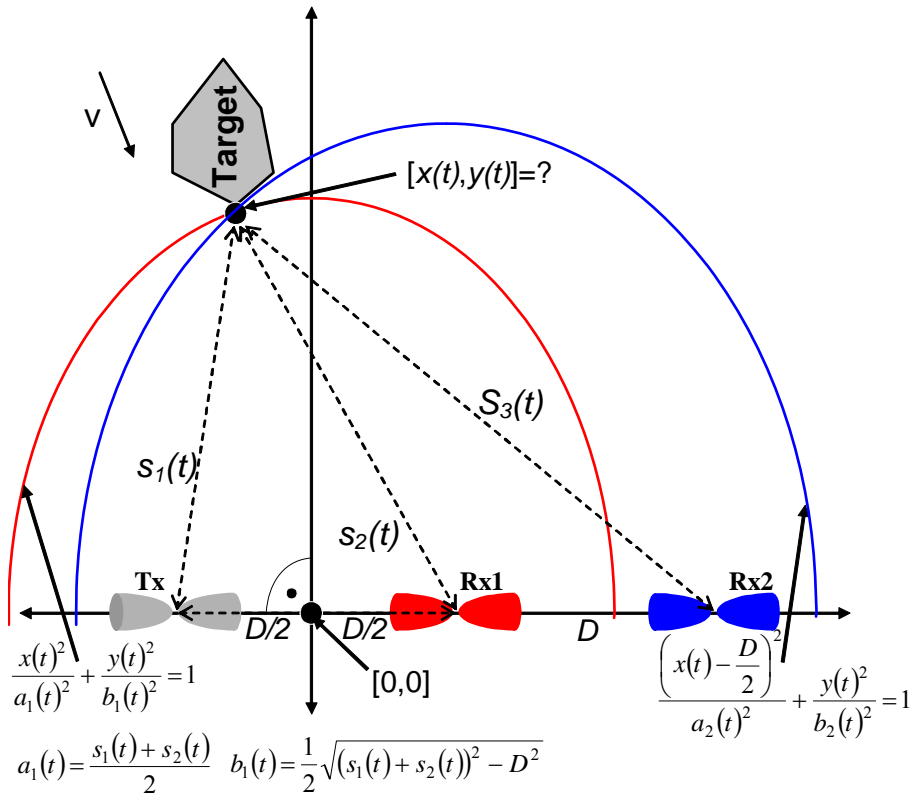
$$(9) \quad \left( \frac{x(t) - \frac{D}{2}}{a_2(t)} \right)^2 + \left( \frac{y(t)}{b_2(t)} \right)^2 = 1$$

The length of the main axis  $2a_i$  is given by the corresponding ToA  $\tau_{pi}$

$$(10) \quad 2a_i(t) = s_0(t) + s_i(t) = c \tau_{pi}(t)$$

and the length of the minor  $2b_i$  axis calculates from

$$(11) \quad \left( \frac{D}{2} \right)^2 + b_i^2(t) = a_i^2(t)$$



**Figure 5-5: Localization of a moving person**

From equations given above and from Figure 5-5, it is apparent that the precision of the position estimate depends strongly on

- the antenna arrangement
- actual position of the target,
- the precision of the ToA estimator,
- and also on the design of the localizer unit, which has to provide a stable ultra-wideband sounding signal.

These parameters can be more or less tuned by the design of the localization system. However, we have to take into account that passive localization cannot reach much better precision as is the size of the localized person. It is due to the fact that the localized person is an extended target. It has not a unique scattering centre. Therefore it reflects electromagnetic waves from different scattering centres at different times.

### 5.3 HW requirements on the passive localisation system

Requirements imposed on HW and SW of passive localization system depend on the application scenario and the processing algorithm. Both were described in previous chapters. The following list of requirements summarizes challenges mentioned above:

- HW and SW must be capable to detect in measured impulse responses weak signal components that are reflected from moving persons in the presence of strong signal components (static objects),

- person's detection is based on the detection of time variances in measured signals. Thus, HW must be stable enough to enable SW this detection.

The first requirement is related especially to the dynamic range of the UWB sensor. This reflects its ability to measure a weak signal in the presence of a strong signal. In order to obtain a realistic analysis of this requirement, we have analysed data measured by a real-time channel sounder available at Ilmenau [17], [18] during the measurement campaign performed in the home-entertainment environment. More details about this measurement campaign performed at LUH can be found in the deliverable 3.1.2b [19]. In Figure 5-6 we can see impulse responses measured by directional Vivaldi antennas arranged in a sound-bar constellation. Impulse responses are horizontally aligned forming so a 2D image. The vertical axis is related to the ToA, horizontal axis is related to the measurement time. It is evident that the time-varying signal components reflected from a moving person are almost invisible as far as the person does not stand in front of antennas. The reflection from a moving person can be brought into the front by the background subtraction algorithm.

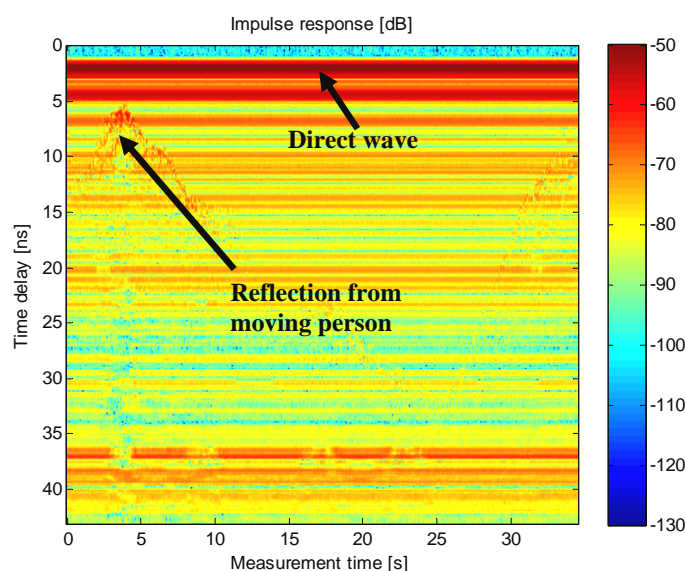
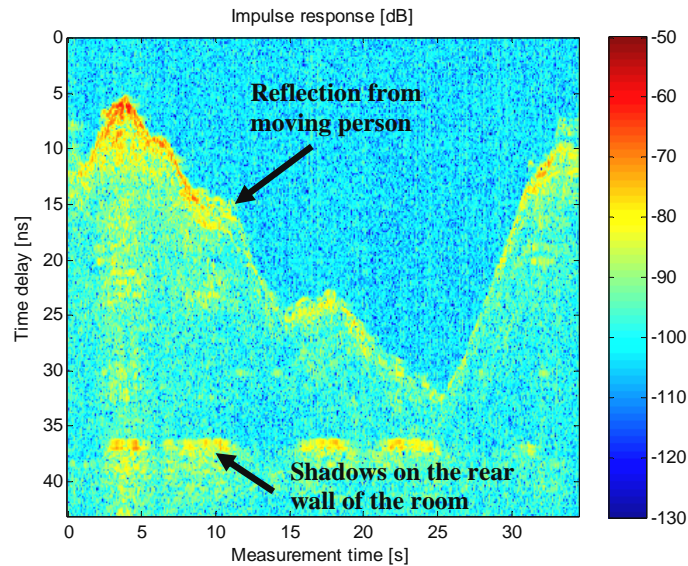


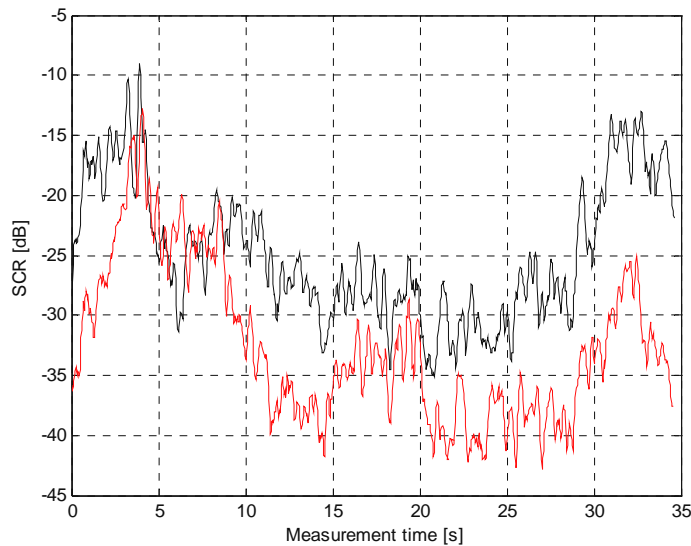
Figure 5-6: Measured impulse responses in the home-entertainment environment

Figure 5-7 illustrates the result of the background subtraction. It reveals time varying signal components stored in measured data. As shown in the figure, these are not only the reflections from a moving person but even “electromagnetic shadows” on the rear wall of the room. As far as there is no person in the room, electromagnetic waves are reflected or scattered from a number of objects present in the room. As a person enters the room it shadows some of these reflections from objects. It prohibits the propagation of electromagnetic waves between the transmit antenna, object and the receive antenna. Since the person moves, it shadows always different objects, or its parts. Thus these shadows that are related to the movement of the person are also time-variant signal components. Background subtraction makes them visible in processed data, too.



**Figure 5-7: Data processed by the background subtraction algorithm revealing movement of a person**

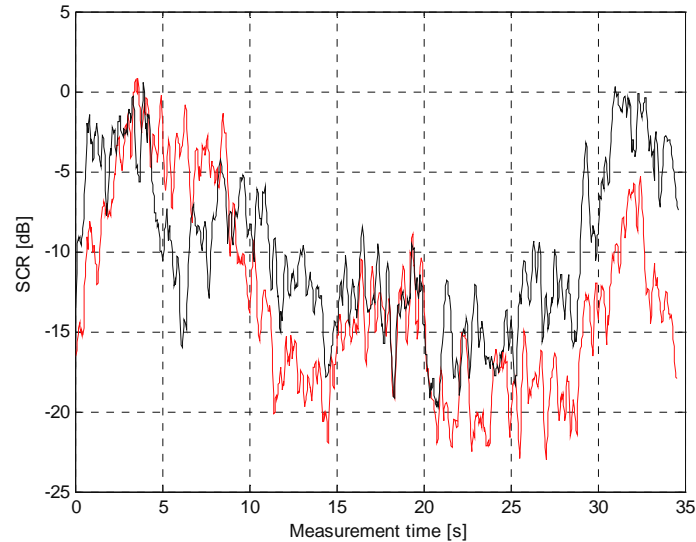
In order to evaluate the necessary dynamic range of the UWB system, we have compared the signal strength of signals reflected from a moving person to the signal strength of the direct wave propagating from the transmit antenna to the receive antenna. Figure 5-8 shows the result of this comparison – signal to clutter ratio (SCR) for 2 different receive antenna positions. The first receive antenna was at the distance of 37cm from the transmit antenna. In this case, the measurement system for the demonstration of passive localization must offer at least 43 dB of dynamic range. If the receive antenna is at the distance of 71cm, the necessary dynamic range is about 35dB.



**Figure 5-8: Signal strength of signal reflected from a moving person related to the signal strength of the direct wave**

*(black – distance Tx to Rx is 71cm,  
red - distance Tx to Rx is 37cm)*

If the UWB system is capable of gating the strongest signal component (direct wave) out from the measurement, then the dynamic range requirements are even looser. Figure 5-9 illustrates SCR for the same measurements constellation as in Figure 5-8, but the direct wave was gated out from measured impulse responses. It is evident that in this case, the required dynamic range is approximately equal for both antenna distances and is about 23dB.



**Figure 5-9 Signal strength of signal reflected from a moving person related to the maximum signal strength of static components**

*(black – distance Tx to Rx is 71cm,*

*red - distance Tx to Rx is 37cm)*

We have to take into account that the presented analysis considers a person moving in the room. If the person sits in a sofa in front of TV, it must be localized just by its breathing activity. In this case the requirements imposed on the dynamic range of the UWB system will be even tighter. More detailed analysis on this topic can be found in the EUWB deliverable 3.1.[19].

The dynamic range of UWB system is not the only one requirement that must be fulfilled by a system intended for the passive localization. Another important requirement is the stability of the system. This requirement is due to the background subtraction algorithm. It presumes that the environment is static and reflections from objects within the environment come always at the same ToA. This requires a stable UWB system. Otherwise the system jitter will corrupt this assumption. Measurements made by the UWB channel sounder from Ilmenau are not suitable to quantify this stability requirement. The UWB channel sounder is driven by a dielectric resonance oscillator. Moreover, there is a wired synchronization between the transmitter and receivers. Thus, its jitter is in an order of femto-seconds ( $10^{-15}$ s).

## 6 Conclusions

As it has been mentioned in this document, the main issue of this task is the implementation and evaluation of the different localization solutions developed.

Taking this into account, in this deliverable two different location engines have been presented,

- a) Active localization: In PULSERS Phase II a preliminary centralized algorithm was developed and implemented and tested. This algorithm was designed for mesh networks and not for source localization (as is required for this project). In EUWB project the localization algorithm will include only the dispersion weight. However, for the NLOS mitigation some new mechanisms are being investigated. The three scenarios proposed mainly by WP8 partners [4], [6], and [8] have been studied and considered for the improvement of the active localization. [13]
- b) Passive localization: This type of localization has gained importance in the EUWB project especially for the applications in home entertainment and automotive environment scenarios. Information about e.g. listener's position in the home entertainment environment or about the intruder detection in the automotive environment helps to improve the overall performance of the audio resp. car-security UWB systems. This deliverable has been focused on home entertainment scenario. The basic steps of the algorithm commented here, are:
  1. Detection of persons,
  2. localization of persons

The other important aspect is the hardware where these algorithms are going to be implemented. In the scope of EUWB project two platforms will be available: Low Data Rate (LDR) and High Data Rate (HDR) platforms.

A general description of each platform has been presented. Also the main interfaces with the user and the localization aspect, like the ranging functionality has been exposed. Besides, the software involved in the location engine has been introduced. LDR software is based on ZigBee stack. In this stack, the communication between all the devices is performed by the profiles. A location profile has been defined for our LDR platform, and it can be modified taking into account new requirements.

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## **Acknowledgement**

The EUWB consortium would like to acknowledge the support of the European Commission partly funding the EUWB project under Grant Agreement FP7-ICT-215669 [1],[2].