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Abstract

Different levels of combining the open EUWB platforms for LDR and HDR are analyzed. After studying the different characteristics of the PHY and the MAC from LDR and HDR UWB platforms, higher layer integration is investigated. The proposed combined LDR/HDR platform combines the strengths of the two UWB systems, the high data rate from the HDR platform and the accurate ranging feasibility of the LDR platform. By hibernating the HDR system and using the LDR system in situations when there is almost nothing to transmit, the combined platform can reduce power consumption. To control and combine the different UWB systems seamlessly an adaptation layer is required. Such a combined system is implemented for a LBS application example with location dependent video streaming. Different combination aspects are investigated, including power consumption and radio co-existence.

Keywords

Co-existence, LDR/HDR combination, power consumption, UWB

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Abbreviations

ASIC	Application-specific integrated circuit
AWGN	Additive white Gaussian noise
DBPSK	Differential binary phase shift keying
BP	Beacon period
DEMUX	De-multiplexer
EUWB	Coexisting Short Range Radio by Advanced Ultra-WideBand Radio Technology
FDS	Frequency domain spreading
FFI	Fixed frequency interleaving
FFT	Fast Fourier transform
FPGA	Field programmable gate array
GPS	Global positioning system
HDR	High data rate
HW	Hardware
IO	Input/output
IP	Internet protocol
LBS	Location based service
LDR	Low data rate
LED	Light emitting diode
LT	Location tracking
LOS	Line of sight
MAC	Medium access controller
MAS	Medium access slot
MBOFDM	Multi-band OFDM
MCS	Modulation and coding scheme
OFDM	Orthogonal frequency division multiplexing
PHY	Physical layer
PLB	Processor Local Bus
PLCP	Physical layer convergence protocol
PPC	Power PC
PPM	Pulse position modulation
QOS	Quality of service
QPSK	Quadrature phase shift keying

RF	Radio frequency
RAM	Random access memory
ROM	Read only memory
SMACOF	Scaling by majorizing a complecated function
SNR	Signal to noise ratio
TDS	Time domain spreading
TFC	Time frequency codes
TFI	Time frequency interleaving
TRX	Transmitter/receiver
TX	Transmitter
UMAC	Upper MAC software component
USB	Universal serial bus
UWB	Ultra-wideband

1 Executive summary

A combined high data rate (HDR) / low data rate (LDR) ultra-wideband (UWB) platform can benefit from the strengths of the two systems, the high data rate from the HDR platform and the accurate ranging feasibility of the LDR platform. Since LDR UWB consumes less power than HDR UWB, if the data rate is low, also the power consumption can be reduced by combining HDR with LDR. The HDR system can be hibernated in situations when there is only few data or only signalling information to transmit. In this case, the LDR system could be used to reduce the power consumption of the combined platform.

For combination of LDR and HDR UWB, the architectural characteristics as well as the specifications for physical (PHY) and medium access control (MAC) layer must be taken into account. The LDR platform uses differential binary phase shift keying (DBSSK) modulation. The receiver relies on a 1.5-bit sub-sampling scheme with low complexity, which is immune against clock drift, does not require any automatic gain control (AGC) or channel estimator and maintains a reasonable clock speed. This allows a low power consumption and accurate ranging feasibility at the same time.

Designed for high throughput transmission of variable data rate up to 480 Mbit/s, the HDR UWB system uses multi-band orthogonal frequency division multiplexing. Comparison with the LDR system show considerable differences in PHY and MAC, making a combination of the platforms on PHY or on MAC challenging. The MAC signalling must be synchronized with the information, mismatch or delays would influence the performance. However, perfectly synchronized operation is difficult because of the superframe structure from LDR and HDR. To control and combine the different UWB systems seamlessly, an adaptation layer is required.

Another possible combination may be on higher layers. Such a combined system has been implemented for a location based service (LBS) application example with location dependent video streaming.

The principle ideas, advantages and applications of a combined LDR/HDR platform is introduced in chapter 2. Chapter 3 summarizes the key characteristics of the LDR and the HDR platforms, which are relevant for combination. The different combination aspects are investigated in chapter 4, including power consumption and radio co-existence. A demonstration example of a combined LDR/HDR platform, which has been implemented for a specific application, is described in chapter 5. Chapter 6 concludes this deliverable.

2 Introduction

Different ultra-wideband (UWB) systems have been introduced within the EUWB project, including the EUWB open platforms for low data rate (LDR) [3] and for high data rate (HDR) [4]. The LDR and the HDR open platforms offer a wide range of applications. For HDR systems, the high data throughput is an essential prerequisite to support applications like multimedia and web services. However, HDR UWB systems suffer from the fact that they show high power consumption compared to LDR UWB systems which are based on impulse radio (IR). In LDR systems, the power consumption and size are important aspects in the overall system performance. LDR applications such as sensors and home, office, and medical automation do not depend on a high data rate. While in pulse-based data transmission the power consumption scales with the data throughput, the power consumption of an HDR UWB system cannot be significantly decreased by reducing the data payload. Another advantage of the LDR platform is the accurate ranging feasibility. At the current state of the technology it outclasses the ranging feasibilities of available HDR platforms. The accurate ranging feature and the operation at very low power consumption of the LDR platform on one hand, and the very high data rate provision of the HDR on the other side, make a combined LDR/HDR desirable. A combined LDR/HDR system could combine advantages of both systems. It was suggested to split the transmitted signal into data traffic and signalling traffic. The data traffic could be transmitted via the HDR physical layer (PHY), whereas the signalling information could be transmitted via the LDR system. However, also other combined operations are possible. Depending on the current traffic load, the combined device could support either pure HDR or pure LDR operation.

Applications of a combined LDR/HDR platform could be location aware routing or resource allocation [6] as well as location based services (LBS), e.g. in museums, exhibition halls or in home entertainment environments. Figure 2-1 illustrates an example from the home entertainment cluster. A high definition (HD) video is streamed from a mobile device onto a display. If the mobile's position is known to the home theatre system, the louder speakers' surround sound parameters could be adjusted accordingly.

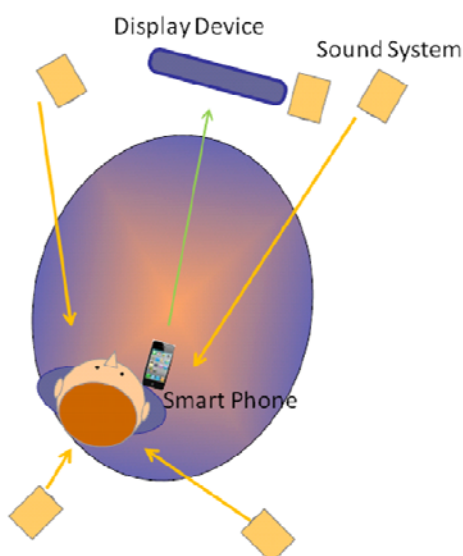


Figure 2-1: An allocation of combined LDR/HDR UWB in home entertainment scenarios [10]

The competitive points of the combined LDR/HDR UWB technologies in this application are high data rate transmission, lower power consumption and location availability. The HDR UWB can support high data rate transmission up to 480Mbps, and it is capability to carrier HD video and audio

data with low compression. The competitive technologies in short range wireless communication, such as IEEE 802.11g and IEEE 802.11n could also provide high data rate, up to hundreds Mbps, supporting a HD video streaming service. However their power consumption is much higher than that of a UWB radio. A brief comparison between UWB radio and IEEE 802.11 WLAN is listed in Table 2-1. To the mobile devices, one of the most critical problems is the power consumption. Normally a video streaming can last more than one hour or even longer. In the case of device keeps transmitting high data rate files with lower power consumption, and therefore UWB technology is more suitable for a mobile device than IEEE 802.11 WLAN. Last but not least, the UWB system provides good location tracking features; this is also the unique strong point in some applications.

Table 2-1: Comparison Short range Wireless Technology

	UWB	IEEE 802.11g	IEEE 802.11n
Peak PHY data rate	480 Mbps	54 Mbps	300 Mbps (two MIMO streams)
Typical PHY data rate	≈ 200 Mbps	≈ 30 Mbps	≈ 100 Mbps
Typical power consumption	40..80 μW < 400 μW	~ factor 10 over UWB	~ factor 20 over UWB
Range in LOS scenarios	Up to 10 m	≈ 40 m	≈ 70 m
LT accuracy	0.30 m	not available	not available

In the UWB networks, the relay is a practical and efficient way to extend the communication range. It has been pointed out that MAC layer of ECMA-368 can hold two level neighbours information. That means in one beacon group.

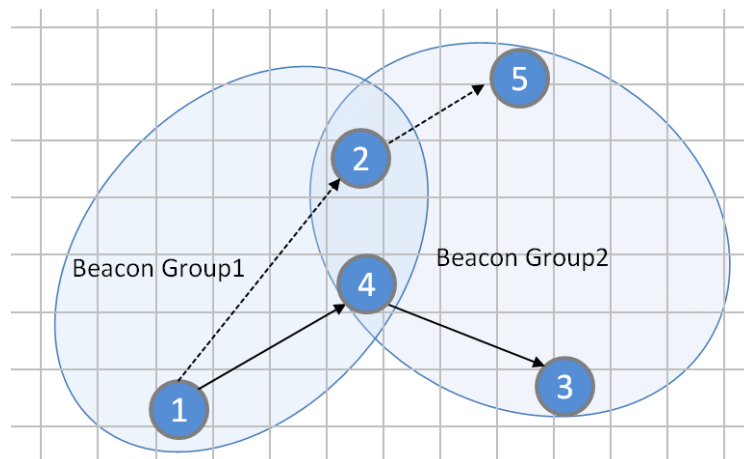


Figure 2-2: Location aided relaying

To support the relaying features, the device should support multiple access ability. The principle of a position based relay is shown in Figure 2-2. The network consists of five UWB devices, and they are in two neighbouring beacon groups. The device 1, device 2 and device 4 are in the beacon group 1, and the device 2, device 3, device 4 and device 5 are in beacon groups 2. Limited to the

communication range, device 1 does not have direct connection to device 3 and device 5. Thanks to the two level neighbours' MAC information supported ECMA-368 standard, the two adjacent beacon groups can therefore be built as an extended beacon groups, and the beacon merging technology makes this possible [8]. This makes the topology of the whole network visible to each device, and MAC layer relaying between the adjacent beacon groups without the upper layer protocol is operable.

Let us assume there are two file need to transfer from device 1 to device 3 and device 5 respectively. From the point of view of device 1, device 3 and device 5 are visible, but there is no direct connection in between. The data can be transferred over one hop relay ether through device 2 or through device 4. However which relaying node shall be chosen? There could be some criterion, such as the link quality indicator between relay and the destination, the distance between the relay and destination. In [17] a geographic information based MAC relay protocol, Geographic Random Forwarding (GeRaF), is proposed. In this demonstration the principle of location aided relaying can be implemented and demonstrated on the combined LDR/HDR open platform.

To understand the location aided relay scheme, the geographical distance between each device in the network is listed in Table 2-2. When choosing the relay depending on the distance, cost of the one hop relay is measured in distance. The minimum cost between device 1 and device 5 is route (device 1->device 2-> device 5) with 6.5m, and that between device 1 and device 3 is route (device 1->device 4->device 3).

Table 2-2: Distance map for relay selection

Device Pair.	Distance	Device Pair.	Distance
1<->2	4m	2<->4	2m
1<->4	3m	2<->5	2.5m
1<->3	out of range	3<->4	3.5m
1<->5	out of range	3<->5	5m
2<->3	5m	4<->5	4m

3 EUWB open platforms

3.1 Overview

This chapter summarizes the key characteristics of the LDR and the HDR platforms, which are relevant for combination.

3.2 LDR UWB

3.2.1 LDR physical layer

The PHY layer of the LDR platform uses a hybrid transceiver architecture, which can benefit from both coherent and non-coherent approaches [10]. Differential demodulation and preamble detection are core parts of the DBPSK receiver (RX). The RX relies on a 1.5-bit sub-sampling scheme, facilitating a low power consumption. The differential demodulation provides immunity against clock drift, even with the large symbol durations that are commonly experienced with LDR scenarios. Channel estimation is not required. The early sub-sampling operation maintains a reasonable clock speed, without significant loss of information in comparison with ideal coherent solutions. The 1.5-bit quantization does not require any automatic gain control (AGC) scheme. Also, it is immune against near-far effects, enabling the exploitation of diversity in the case of pronounced multipath reception [10].

Specific efforts have been consented to decrease the overall system complexity and power consumption [10]. This new feature is mainly authorized by the use of a unique logical gate and the handling of 1.5-bit quantized signals. Another main advantage is the possibility to achieve better compliance with the IEEE 802.15.4a standard. Integration has also been favoured integrating the radio frequency (RF) transceiver (TRX) and the baseband parts into a single application specific integrated circuit (ASIC) [10].

In order to improve the bit energy to noise ratio E_b/N_0 and keep below EMC limits, every symbol is repeated several times. To avoid spectral spikes, the repeated pulses energy is spread using a PN sequences. The resulting data rate depends on the length of the chosen PN code. Table 3-1 lists the data rate parameters.

Table 3-1: Data rate Parameters [7]

	Unit	Min	Typ.	Max	Note
Sampling period	(ps)	125	1000	1000	1 Gsps (lower sample periods for test purposer)
Chip length (CP)	(ns)		120		
Frame (PRP) length (Tf)	(ns)		240		
Symbol length (Ts):	(-)	0.24	2.88	7.44	DBPSK
Modulation order (M)	(-)		2		
Number of chips	(-)		2		
PN code length (PN)	(-)	1	12	217	Limited to 31 due to possible clock drift
Coherent integration (CI)	(-)	1	1	7	CI x ACC = PN
Accumulation (ACC)	(-)	1	12	31	CI x ACC = PN
Synchro PN code length	(-)	1	12	31	Chosen equal to data code PN code length (CI x ACC)
Raw bit rate	(kbps)	134	347	4166	No Position modulation

3.2.2 LDR medium access control layer

LDR UWB MAC layer succeed the protocol used in [10]. It is based on IEEE 802.15.4 standard, with enhancements to meet quality of service requirements and to provide efficient support for ranging and localization with impulse based UWB physical layer. In this MAC protocol, a superframe is defined as a based time unit for all devices in the networks.

There are two periods in one superframe, control period and data period. Control period is a contention free period. In the control period, two parts are identified: the beacon period (BP) slots and the topology management period. Data period is used for data frames, ranging frames, GTS request frames and other command frames. Data frames, ranging frames and GTS request frames are sent in a contention free period whereas other command frames are sent in the contention access period (CAP).

The superframe length is completely flexible and each part in the superframe can have a number of slots up to a maximum value as defined Table 3-2. The maximum number of slots in a superframe is 44.

Table 3-2: Superframe time parameters

Band Group	MAX
BP	12
Topo Mgmt	3
GTS	24
GTS Request	3
CAP	2

3.2.3 LDR platform

The hardware of LDR platform can be divided into four sub-parts, one printed circuit board for each. The MAC board, with ARM9 processor, FPGA, RAM and ROM resources, dedicated to the S/W and H/W MAC and higher software level. The SENS board with the sensors, accelerometer, magnetometer and gyroscope. The PHY board with the UWB radio link base on Leti's TCR ASIC. The IO board with the extensions: Serial port, Ethernet (10BaseT half/full duplex), processor and FPGA JTAG accesses, other LED, push buttons and test points for debug [11].

The organization of the hardware of LDR UWB platform is illustrated in Figure 3-1. MAC board is the main board of the LDR platform. It hosts an ARM9 processor (AT91SAM9261B) with 16Mbytes parallel SDRAM (MT48H8M16), 8Mbyte FLASH (M25P64), 2kByte I2C EEPROM (24LC16). There is also Xilinx FPGA (XC3S1400) on board [11].

SENS board is a daughter board for MAC board and uses a small part of FPGA resources for the ADC management. It is a SPI peripheral for the ARM processor [11].

The PHY board is also a daughter module for the MAC one, and it has two parts: radio part and antenna. Radio part is based on the TCR ASIC including receiver and transmitter and baseband. An on board PLL circuit has in charge of optional 1GHz external sample frequency. A small none volatile memory is available for RF configuration. PHY board is also SPI peripheral for the ARM processor [11].

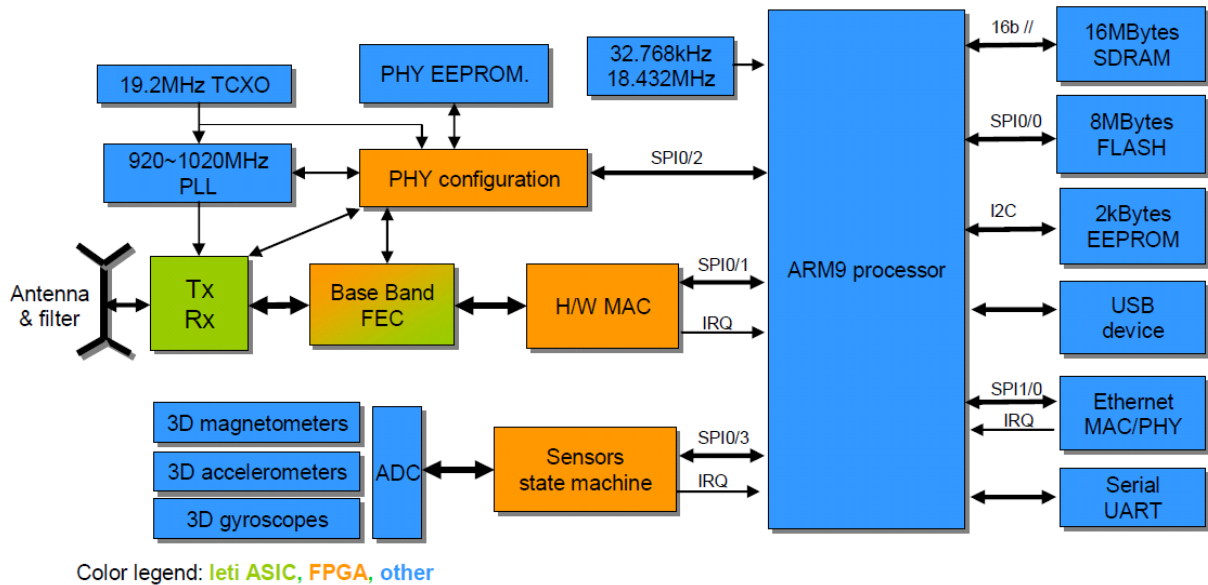


Figure 3-1: Block diagram of LDR-TR hardware [10]

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 MAC layer for its software part (called SW/MAC) takes place in an embedded LINUX operating system running on the embedded ARM9 processor. The embedded Linux operating system and whole software stack are pre-installed in SPI flash.

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. The software package is hosted on a Linux file system running on random access memory (RAM). Each software layer is an independent Linux process running in the user memory space. All drivers reaching the hardware platform are running in the kernel memory space [10].

3.2.4 Ranging with LDR UWB

In the LDR UWB PHY, detection of an arrival ranging packet is through two steps, coarse ranging measurement and fine resolution ranging. The coarse ranging measurement is realized by preamble detected, it has a time resolution with 8 ns. To get precise results, received signal shall be sent to the fine resolution module. This fine resolution module is 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 8 ns) of the time of flight is already performed by time-stamping the frame detection event as mentioned in the previous section. The signal processing performed on the incoming samples is using incoming signal chunks of 1 ns. Further details of the ranging of LDR UWB can be found in [10].

3.2.5 Energy efficiency of the LDR system

The LDR UWB system is very suitable for low data rate applications like sensors networks due to its low power consumption. This fact is referred to the nature of device operation where the devices have less data to exchange and need to transmit more than they receive. The average energy overhead consumed during acquisition is fixed for a packet [12]. Thus, the shorter the payload, the greater the overhead energy per bit as the overhead energy is amortized over fewer bits.

Also for the RF part, the employment of modulation schemes such as DBPSK and PPM leads to a power efficient data transmission. In this section, an investigation on the power consumption of LDR UWB transceivers is presented.

The LDR UWB PHY implemented on TCR chip has two operating modes, stand-alone and baseband active. Table 3-3 summarizes the power consumption in the different parts of the UWB PHY.

Table 3-3: Power consumption [5]

Operating Mode	Digital	TX	RX	I/O
Standalone	10 mW	0.4 mW	8 mW	11 mW
Baseband active	35 mW	0.4 mW	8 mW	2 mW

3.3 HDR UWB

3.3.1 HDR physical layer

The HDR UWB system is based on MB-OFDM technology, and it is designed for high data rate transmission for short range communication. It is considered as a technology that enables short range, low power, high-speed wireless connectivity of up to 480 MBit/s by using the UWB spectrum from 3.1 GHz to 10.6 GHz. Due to different modulation and coding schemes (MCS) 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. There are some application scenarios for the HDR UWB, for instance, wireless USB in office environment, wireless HDTV signal transmission for home entertainments, etc. The HDR UWB can support such a high data rate transmission, which benefit from the use of MB-OFMD technology. This also introduces complexity of implementation. Table 3-4 shows the data rates, which are supported by the HDR platform on PHY.

Table 3-4: PHY data rates, supported by the HDR platform

	Date Rate /(Mbit/s)							
PHY	53.3	80	106.7	160	200	320	400	480
MAC	49	72	94	134	162	235	276	313

For a HDR UWB device, the bandwidth from 3.1 to 10.6 GHz is divided into 14 bands, each with a bandwidth of 528 MHz. As shown in Figure 28 in [8] and in Table 3-5, 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. A sixth group is defined within the spectrum of group three and four, consistent with usage within world wide spectrum regulations.

Every of the 528MHz wide bands consists of 128 sub-carriers with 4.125 MHz intervals. There are 100 data sub-carriers, 10 guard sub-carriers, 12 pilot sub-carriers for coherent detection and 6 null sub-carriers, which are left free for guard bands. A block diagram of the OFDM modulator is shown in Figure 3-2.

Table 3-5: WiMedia Frequency band plan [8]

Band Group	BAND_ID	Lower Frequency [MHz]	Center Frequency [MHz]	Upper Frequency [MHz]
1	1	3168	3432	3696
	2	3696	3960	4224
	3	4224	4488	4752
2	4	4752	5016	5280
	5	5280	5544	5808
	6	5808	6072	6336
3	7	6336	6600	6864
	8	6864	7128	7392
	9	7392	7656	7920
4	10	7920	8184	8448
	11	8448	8712	8976
	12	8976	9240	9504
5	13	9504	9768	10032
	14	10032	10296	10560
6	9	7392	7656	7920
	10	7920	8184	8448
	11	8448	8712	8976

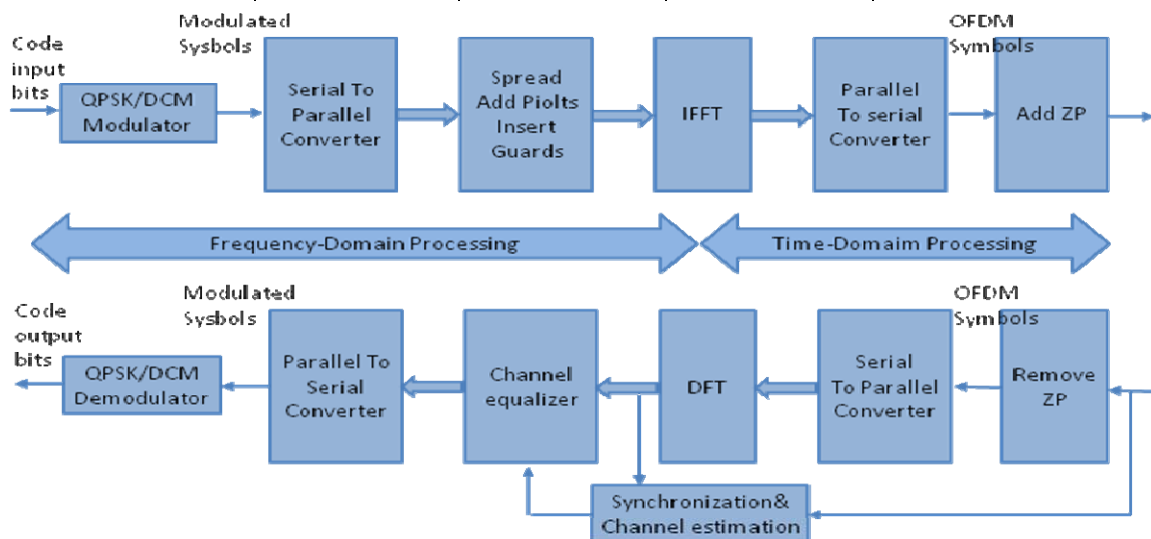


Figure 3-2: Diagram of WiMedia OFDM baseband

Two sub-carrier modulation schemes are employed: quadrature phase-shift keying (QPSK) and dual carrier modulation (DCM). The quality of the UWB link and the transmission data rate depends on the deployed modulation scheme. For a high quality link, for data rates of 320 Mbit/s or higher, the DCM scheme, which is more robust against multipath fading channels, is preferred in order to maximize the data rate, whereas the lower quality link, for data rates of 200 Mbit/s or lower, employs the QPSK scheme using lower code rates. Nevertheless, in an AWGN scenario, both modulation schemes behave identical. In the QPSK mode two bits are mapped to each sub-carrier whereas in the DCM mode four bits are mapped to two sub-carriers [8].

In order to improve the bit error ratio (BER) 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 [8].

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 time frequency code (TFC). Three types of TFCs are specified in the 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) [8].

Table 3-6: Data rate parameters

Info. Data rate	53.3Mbps	80Mbps	106Mbps	160Mbps	200Mbps	320Mbps	400Mbps	480Mbps
Modulation	OFDM/ QPSK	OFDM/ QPSK	OFDM/ QPSK	OFDM/ QPSK	OFDM/ QPSK	OFDM/ DCM	OFDM/ DCM	OFDM/ DCM
FFT Size	128	128	128	128	128	128	128	128
Coding Rate (K=7)	R = 1/3	R = 1/2	R = 1/3	R = 1/2	R = 5/8	R = 1/2	R = 5/8	R = 3/4
Spreading Rate	4	4	2	2	2	1	1	1
Data Tones	100	100	100	100	100	100	100	100
Info. Length	242.4 ns	242.4 ns	242.4 ns	242.4 ns	242.4 ns	242.4 ns	242.4 ns	242.4 ns
Zero Padding Suffix	70.08 ns	70.08 ns	70.08 ns	70.08 ns	70.08 ns	70.08 ns	70.08 ns	70.08 ns
Symbol Length	312.5 ns	312.5 ns	312.5 ns	312.5 ns	312.5 ns	312.5 ns	312.5 ns	312.5 ns
Channel Bit Rate	160 Mbps	160 Mbps	320 Mbps	320 Mbps	320 Mbps	640 Mbps	640 Mbps	640 Mbps

With different coding rate and spreading in time and frequency domain, eight information data rates are possible for a HDR UWB. Three of them are mandatory. They are 53,3Mbps, 106,7Mbps and 200Mbps. The data rate parameters are listed in Table 3-6. 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. Each of FDS and TDS reduce the throughput by a factor of two, yielding 50 bits/symbol. 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 μ 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 μ s resulting in a data rate of 480 Mb/s.

3.3.2 HDR medium access control layer

MAC layer protocol of HDR UWB complies with the standard ECMA-368 [8]. It is a distributed MAC layer protocol and is designed for peer-to-peer, ad hoc networking. No like a centralized MAC, there is no master device, each device must maintain its own database of information about the neighbors and need also a scheme to cooperate with each other. Comparing to a centralized MAC, such as WLAN and mobile cellular networks, the ECMA-368 MAC is much more complicated. The advantages of the distributed MAC are that, devices can organize themselves in ad hoc manner, should any node in network fail to operate, the rest of the network can still work.

In ECMA-368 standard, medium access sharing is through a TDMA scheme. Within this TDMA protocol, four time resolutions are defined: Superframe, MAC Access Slot (MAS), Beacon Slot, and Backoff Slot. As shown in Figure 3 of [8], a Superframe is a fixed periodic duration of approximately 65.5mSec (256 MASs). In the beginning of a Superframe are Beacon slots. In Beacon slots only Beacon frames are sent, and the set of Beacon Slots of a superframe make up a Beacon Period. All MASs that fall outside of the Beacon Period maybe used for data, command, or control frame transfers. No data/command/control frames may be transmitted during the Beacon Period.

Table 3-7: WiMedia Superframe parameters

Band Group	Duration	Note
Superframe	65,5ms	256 MASs
Beacon slots	85um	About 1/3 of a MAS
BP	flexible	
MAS	256us	

3.3.3 HDR platform

The hardware of HDR platform consists of two boards, the main board and PHY board. The main board is a Xilinx ML507 Virtex-5 FPGA development board, as shown in Figure 3-3. The MAC core is implemented in a combination of software written in ‘C’, targeted at a PPC embedded processor, and digital hardware implemented in VHDL [14]. The MAC PHY interface defined in ECMA-369 standard is also implemented on FPGA [9].

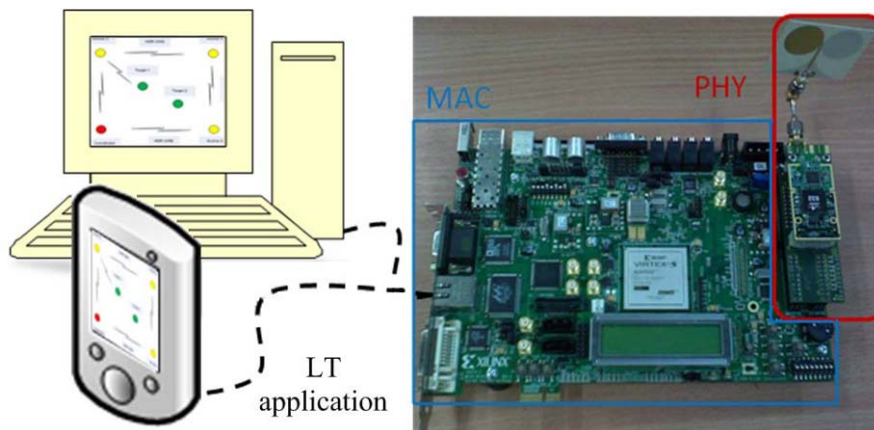


Figure 3-3: HDR ‘Open Platform’ (right side), with potential application clients [15]

The PHY card can be the Wisair 612 chipset or a Realtek 7012 module. Both modules comply with ECMA-368 PHY specification, and support 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. The ranging functionality is only supported by the Wisair 612 PHY module [14].

The MAC hardware (HMAC) is a VHDL design that provides the hardware sub-system that compliments an embedded software design. The HMAC and software subsystem implement a WiMedia medium access controller that supports an ECMA-369 MAC-PHY interface.

The MAC is running on a Xilinx ML507 FPGA development board, whereas the PHY is implemented on a separate daughter card. These cards are connected by XGI expansion headers. The PHY/MAC interface protocol is defined in ECMA-369 standard [9]. The installation of the open platform is illustrated in Figure 3-3, a host computer can be connected to the RJ-45 Ethernet port, and an RS232 cable can be connected to the serial debug port.

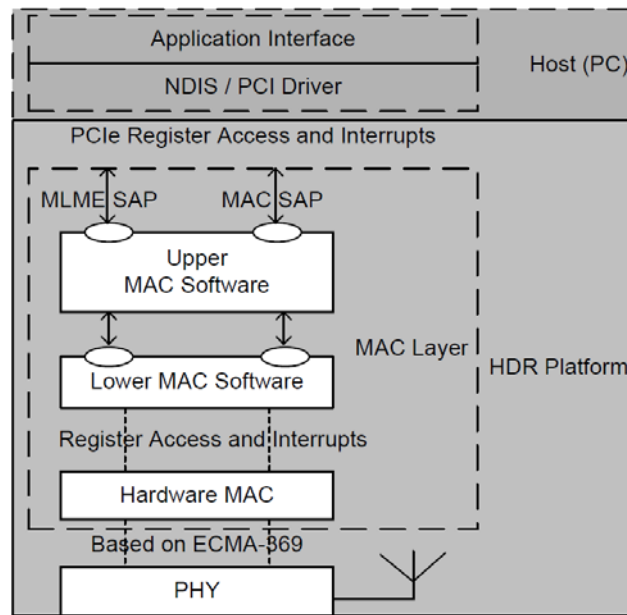


Figure 3-4: Layer structure of the HDR platform [14]

The overall structure of the HDR part of the open platform is shown on Figure 3-4. It can be seen that the MAC layer is partitioned into three parts, namely, the HW MAC (HMAC), the lower MAC (LMAC) and the upper MAC (UMAC). The HMAC manages small-scale transactions on the medium. It is implemented using a HW description language on an FPGA. LMAC and UMAC are implemented on a UML-based operating system running on the Power PC [14]. The LMAC manages multiple streams of frames to be sent to and received from the medium, together with immediate control of the HMAC. The UMAC manages protocol exchanges with peer MAC entities. The natural interface between the UMAC and the LMAC is internal, in the sense that they require access to common data structures. Moreover, they share access to common helper functions, for example for access to hardware registers [14]. The WiMedia Link Layer Protocol (WLP) is also implemented to support IP data running on WiMedia MAC. It makes the transparent TCP/IP transmission over WiMedia devices possible.

3.3.4 Ranging with HDR UWB

Although mainly oriented to high data rate applications, the ECMA-368 standard defines the ranging feature in full, including PHY layer measurement definition, controlling protocol and message formats. Similar to the LDR platform, the time of arrival (TOA) measurements for ranging is proposed. The signal propagation time τ is used to estimate the distances between two UWB devices.

The time of generation and detection of a ranging frame is recorded by a counter, pRangingTimer, of 32 bits. The start of the first channel estimation symbol in the physical layer convergence protocol (PLCP) preamble is taken as the timing reference point. The pRangingTimer is driven by a clock on the PHY. Due to quantization errors, the ranging accuracy is limited by the resolution of the used timing clocks. According to ECMA-368, the clock rate f_T of the ranging timer, measuring the propagation time, shall be 528 MHz (minimum if ranging is implemented), 1056 MHz (optional), 2112 MHz (optional) or 4224 MHz. With the speed of light c , these clock rates yield ranging resolutions in the range of $\Delta s \approx c/f_T$, i.e. 56.8 cm, 28.4 cm, 14.2 cm or 7.1 cm. Furthermore, the timing may be biased in a known system through modification to allow for PHY processing delays. There are two registers to amend transmit and receive processing delays respectively to improve the ranging precision. More details of the ranging can be found in [8]. However, ranging is defined as an optional feature and was not considered to be of major significance during development of the standard.

shows the overall ranging measurement blocks and feature scope at the WiMedia PHY layer. The ranging measurement block consists of a counter and two latching stages, the latter of which has two separate 32-bit registers for RX measurement and for TX measurement.

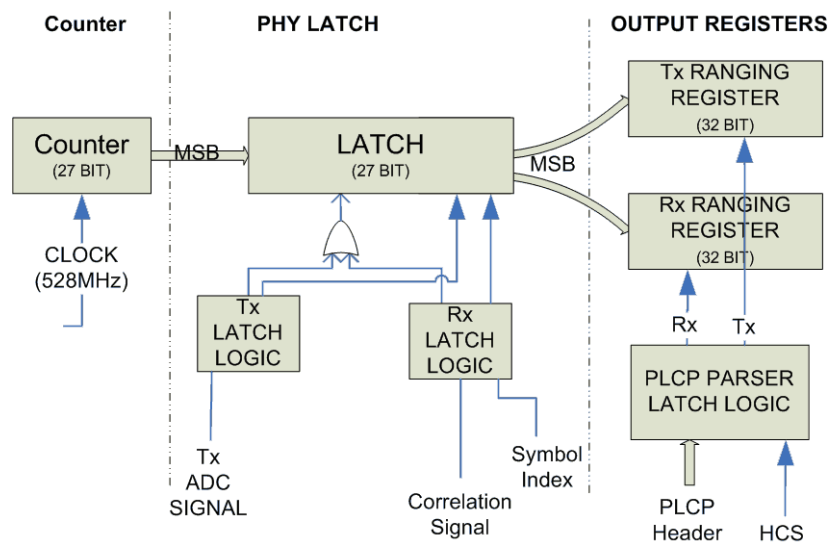


Figure 3-5: Ranging Blocks and system [4]

The counter is a free running counter with no reset or initial value, which runs at 528MHz, equivalent to about 60cm of ranging resolution. The ranging disable is not described, however, the counter may start from any value once 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.

The second latch operates on desired frame formats only. A desired frame is determined according to a bit encoding added 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 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 path with low probability of miss-detect and errors.

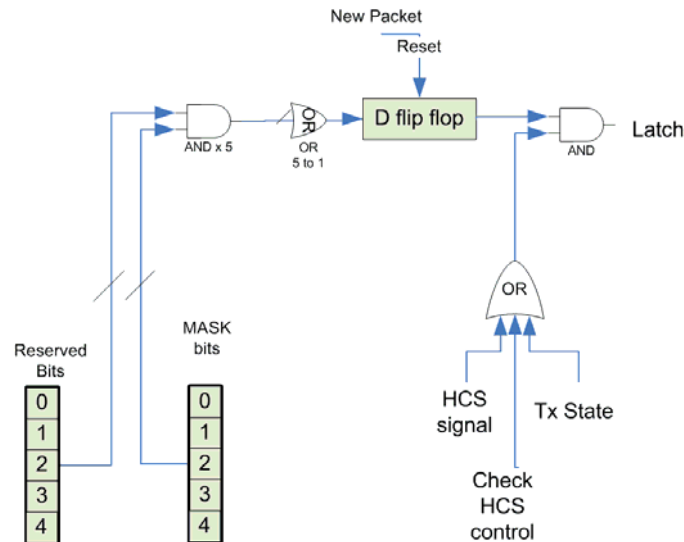


Figure 3-6: Output registers latch logic [4]

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.

Converted to meters, the ambiguity of one symbol is approximately $93.6\text{m} / 2 = 46.8\text{ m}$ (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.

The ranging ambiguity will not be resolved by the PHY. It is proposed that the ranging ambiguity would be resolved through the use of averaging in the case of point-to-point applications, and further improved through the use of triangulation in the case of point-to-multi-point systems. Such functionality is considered to be application level and is beyond the scope of the open platform MAC and PHY.

3.3.5 Energy efficiency of the HDR system

Energy in HDR UWB high power consumption often imposes a limitation on the use of UWB for applications where low power is desired, or sometimes required. Although the MAC and higher layers significantly affect the overall power consumption of the system, they generally have little impact on the design of the hardware system. The physical layer specification, however, is directly related to the operation of the hardware and needs to be fully comprehended in order to achieve a hardware design with optimal power consumption.

Table 3-8: Power consumption for a MB-OFDM system [5]

Process node	PHY data rate (Mbit/s)	Active transmit power	Active receive power	Clear channel assessment	Power save (deep sleep mode)
90 nm	110	93 mW	155 mW	94 mW	15 μ W
	200	93 mW	169 mW	94 mW	15 μ W
	480	145 mW	236mW	94 mW	15 μ W
130 nm	110	117 mW	205 mW	117 mW	18 μ W
	200	117 mW	227 mW	117 mW	18 μ W
	480	180 mW	323 mW	117 mW	18 μ W

4 LDR/HDR combination

4.1 Feasibility of combined LDR/HDR systems

Comparison of the characteristics of the LDR and the HDR system, introduced in chapter 3, shows considerable differences in PHY and MAC, making a combination of the platforms challenging. In particular the physical layer specifications are directly related to the operation of the hardware and need to be fully comprehended in order to achieve a hardware design with optimal power consumption [12]. A combined physical layer, supporting both the pulse based LDR modulation and the multiband OFDM modulation of HDR UWB at the same time seems disadvantageous. Possible combinations may be on MAC or on higher layers.

If interfacing on MAC layer, several aspects shall be considered. MAC signalling is critical for performance and must be synchronized with the information. Further, the signalling duration and timing or delay is critical to the HDR performance or throughput. In fact, the MAC layer protocols of LDR and HDR UWB have significant differences, including the superframe structure and length. Since the superframe of the distributed MAC from LDR and HDR UWB need strict synchronization and both have different structure and length, a combined MAC, being standard conform to both LDR and HDR, becomes difficult. Therefore it is rather challenging to design a low layer integration of the two existing UWB systems. To manage such a combination anyway, an adaptation layer concept has been proposed [13]. The different combining aspects are extensively discussed in this chapter.

A simply combined platform may also benefit from the advantages of LDR and HDR UWB, if interfacing on higher layers. This shall be more practical than lower layer interfacing. Considering that LDR UWB requires less power for operation, and provides somewhat better ranging, and HDR UWB provides higher data rates and lower energy per data bit, the solution could be to utilize LDR only when there is practically nothing for the HDR to transmit, e.g. signaling on standby for fast wake-up. Furthermore, LDR UWB could be used for accurate location tracking, if the LT feature of the HDR system is insufficient. Demo applications for higher layer combined LDR/HDR platforms are proposed in chapter 5.

4.2 Combination concept

4.2.1 Overview

In this chapter, combination concept and the platform implementation are presented. The co-existence of LDR and HDR UWB radio of the combined LDR/HDR open platform is also studied.

The combination of HDR and LDR UWB open platforms can be separated into two categories. Full combined and half combined [5]. The full combined system can operate as HDR UWB system and LDR UWB system at the same time. The half combined system is operating as HDR UWB system and utilizing LDR-UWB TRX to enhance system performance. When considering the layer of the interfaces between a LDR UWB platform and a HDR UWB platform, the combined LDR/HDR UWB open platform could be PHY layer combination, MAC layer combination and higher layer combination.

Two different integration levels of a combined LDR/HDR UWB platform can be considered, full combined and half combined [5]. The full combined system can operate as HDR system and LDR

system in the same time. The half combined system is operating as HDR system and utilizing LDR-UWB TRX to enhance system performance.

4.2.2 PHY and MAC layer integration

A full combined LDR/HDR UWB platform with interfacing on PHY and MAC, may be used to transmit the data traffic via HDR and signalling information over via LDR. Furthermore it could also be used as cooperative system or as either HDR or LDR system, yielding four system operation states:

1. LDR UWB system,
2. HDR UWB system,
3. HDR/LDR system, where the two interfaces are not working simultaneously,
4. HDR/LDR system, where the two interfaces are working simultaneously.

In the HDR system the power consumption is high and generally related to the OFDM modulation scheme. Also power consumption does not change significantly with throughput. Moreover, the high throughput in the HDR system comes from the size of data frames and is not affected by signalling frames. The power used for sending signalling information is in the same level of that used to send data information. From this point of view we can send HDR signalling information using LDR physical layer since its power consumption is low and does not need high data rate transmission. The MAC frames can be split into data and signalling frames where data sent via HDR-PHY to maintain data rate requirements. The signalling is sent over LDR-PHY layer for saving power. In order to coordinate operation of the two physical layers, an adaption layer is required and shall be designed. This layer deals with routing, synchronization, and power control issues [5]. The adaption layer protocol coordinates the operation of two different devices using different protocols. It allows having both system functionalities on the same device. The adaption layer protocol starts with a data-analysis, where the received MAC frames are separated in data- and signalling frames defined in accordance to the classification given in chapter 3. Based on the frame type a de-multiplexer (DEMUX) switches its output to the next stage. The coverage for both systems should be identical to decrease the multipath and interference effects especially for the LDR TRX part. Since the LDR coverage is higher than HDR system the transmission power should be minimized to not fall behind the receiver. At this point, the adaption protocol computes the required power to transmit the LDR frames using power-distance relation in HDR and LDR TRXs. The computation starts with observation of the throughput, distance and power relation in the HDR system that will be stored in HDR/LDR conditioning stage. Then from the HDR power consumption value it will choose the LDR data rate and power needed to transmit the signalling frame to the same distance used for HDR TRX. At the final stage the protocol will route the signalling frame to be inserted as payload for LDR MAC frames and send it over the interface. In the data frame case, the adaption protocol forwards the frames to the HDR physical layer with the data rate and power defined through HDR-MAC layer. The transmission and receiving over the LDR part should be invisible for the HDR system. This implies that all the switching and transmission process should be done in the reserved HDR medium access slot (MAS) to maintain the timing for the main system, i.e. the HDR system. The operation states for both parts are controlled by the adaption layer in the proposed concept. In the data traffic mode, the HDR forwards HDR-MAC layer frames and changes the HDR-PHY layer state from sleep to ready and then to transmit or receive state and turn LDR PHY to sleep state. Also in signalling traffic mode the adaption layer inform LDR to switch the LDR-PHY to ready state to prepared for transmit or receive state. Table 4-1 shows the states of the

two layers. One of the two systems is allowed to be in active state and this is a direct result of using HDR MAC frames contents as controller for switching process.

Table 4-1: Combination HDR/LDR operation states [5]

Traffic	LDR PHY	HDR PHY
Data	SLEEP	READY
Signalling	READY	SLEEP

Advantages of the lower layer combined LDR/HDR UWB system with PHY and MAC interfaces are the sharing of common resources. Also a common MAC structure is possible. However, the LDR and HDR are differently designed and optimized to their specific specification and features like the MAC and the PHY packets, making lower level combination impractical. The MAC signalling is critical for performance, and must be synchronized with the information data. Furthermore, the signalling duration and timing or delay is critical for the HDR performance or throughput.

4.2.3 High layer integration

Each of the open EUWB platforms consists at least of a UWB radio and a controlling processor. The controller part of the HDR open platform is a Xilinx ML507 board including FPGA and PPC. The controller part of the LDR open platform is an ARM9 microcontroller. One possible integration approach is to share the controlling part for two different radios, a LDR and a HDR UWB radio. To integrate the PHY modules, it could be possible to adapt the LDR UWB PHY board onto the controller board of the HDR platform. Alternatively both complete platforms could be connected to an additional controller unit. For a feasibility study, this additional controller unit may be a PC.

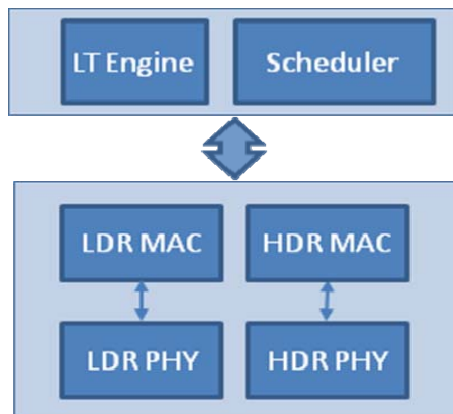


Figure 4-1: Higher layer integration

The modular approach using an additional controller unit assures the stable work for both LDR and HDR radio, and benefits from the high resolution ranging service from LDR and the high throughput from HDR. An adaption layer shall schedule dispatch data according to the size and the required data rate and control the hibernation of the two UWB radios, ensuring an efficient and energy saving operation. Another task of the adaption layer is the control of the LT service.

4.3 Co-existence of LDR and HDR UWB

The combination of LDR/HDR platform faces the co-existence problem of the two systems. The LDR spectrum is centred around 4.1 GHz and overlaps with band 2 and band 3 of the WiMedia UWB,

which are centred at 3.9 GHz and 4.2 GHz. When the HDR UWB radio is working on band 2 or 3, there will be interference between the two UWB systems [10].

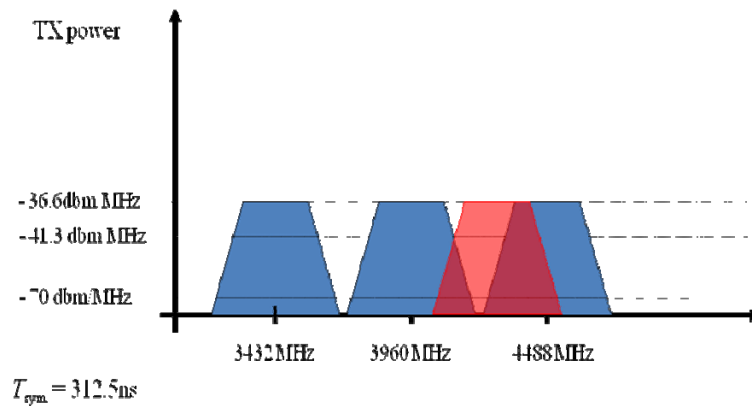


Figure 4-2: Spectrum of the LDR (red) and the HDR (blue) UWB systems

There are several approaches to avoid interference. They are:

1. Avoidance of band 2 and 3 for the HDR system. This frequency division multiple access (FDMA) scheme is the most simply way to solve the co-existence of the LDR and HDR system. However this also limits the usable frequency space.
2. Iteratively switch over between LDR and HDR in a time division multiple access (TDMA) scheme. It is noticed that, both the LDR UWB and HDR UWB have hibernation feature to save energy. Therefore the combined LDR/HDR could apply such a way, that when LDR is active, the HDR goes into sleep, and inversely when the HDR is active, the LDR should go to sleep mode. This can be implemented by a scheduler in Figure 4-1. However, problems may occur, when there are several devices in the network. A strict synchronization between the combined LDR/HDR UWB device would be necessary. Otherwise, the radio from the other combined devices will also introduce interference, even if there is no interference between the local LDR and the local HDR system.

4.4 Implementation

4.4.1 Overview

The combined LDR/HDR is implanted on higher layers as suggested in 4.2.3. The LDR platform is dedicated to do localization tracking as well as low load data transfer, whereas the HDR platform transfers the high data rate traffic. The common controller part must implement two main tasks, the ranging control and the LT algorithm exploiting the ranging results from the LDR platform (cf. 4.4.2), and the traffic control over the HDR platform (cf. 4.4.3).

4.4.2 Location tracking

An advanced location tracking algorithm shall be implemented as introduced in [15]. It has the following main steps:

- Measure distances between communication nodes,
- Compute contracted distances to mitigate none line of sight (NLOS) drawbacks,

- Estimate the mobiles location by applying a distance based localization algorithm like scaling by majorizing a complicated function (SMACOF).

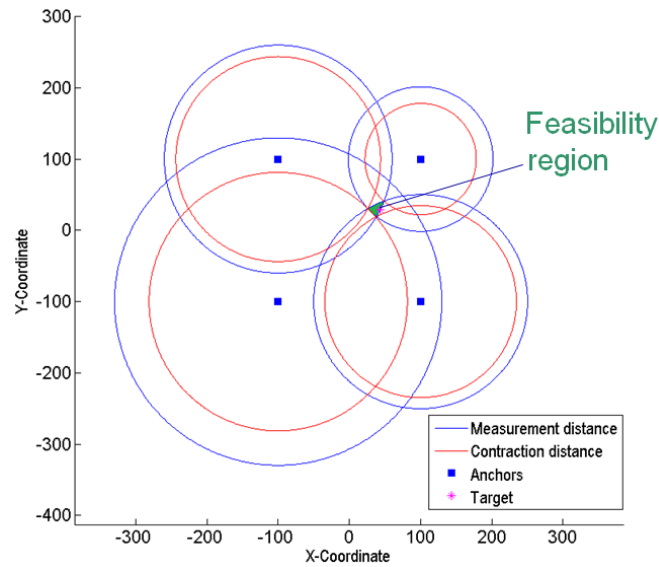


Figure 4-3: Distance contraction concept

Figure 4-3 illustrates the distance contraction method in a network with 4 anchors and one target. The blue markers represent the anchors. The blue circles around the anchors represent the measured distances. The green marked area, called feasibility region, is the area, which is within all blue ranging circles. The red circles are tangent circles to the green feasibility region. They represent the contracted distances. Since they do not intersect anymore, they make the least squares (LS) cost function convex, which simplifies the optimization problem. Principally any optimization algorithm can be employed.

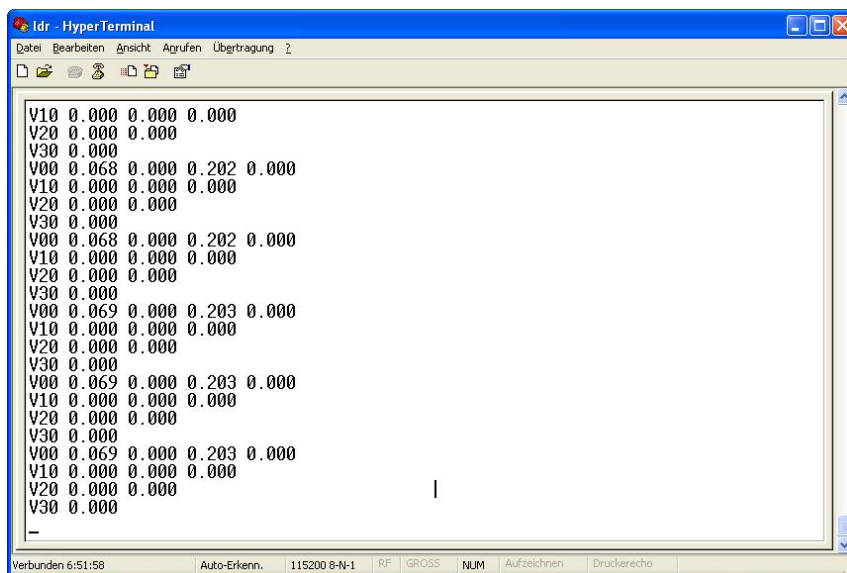


Figure 4-4: Distance matrix to LT engine

The collection of the ranging results, the measured distances, is done by a LT coordinator. The collected distances are stored into a distance matrix and sent to the localization engine. In case of the LDR platform, the distance matrix can be retrieved e.g. via the serial interface of the platform. Figure 4-4 shows the ranging output in a terminal program with connection to the LT coordinator platform. In the example shown in Figure 4-4, there are 5 nodes. The distance matrix includes all distances measured between each pair of nodes in the networks. The table to ranging results build an upper

triangular matrix which contains totally 10 distances in the case of 5 network nodes. The GUI of the Accorde implementation of the LT application for the LDR platform is shown in Figure 4-5.

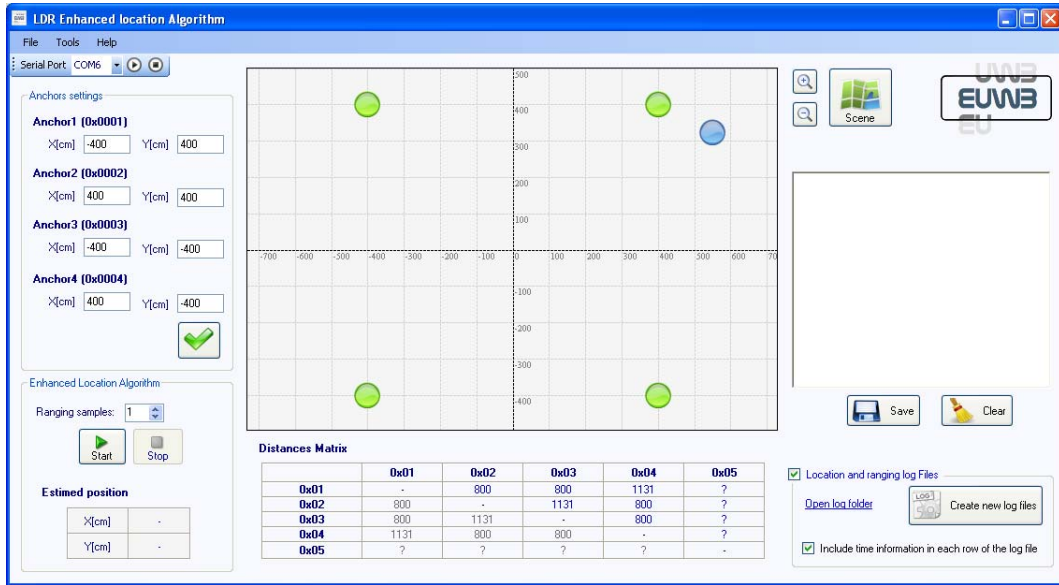


Figure 4-5: GUI of localization and tracking application

The collected ranging results are passed to the LT engine, and the distance contraction localization is carried out. On the upper left of the GUI, the coordinates of the anchors can be configured by the user. The estimated coordinates are shown on the lower left area of the GUI. All the devices are displayed on the map in the centre of the GUI.

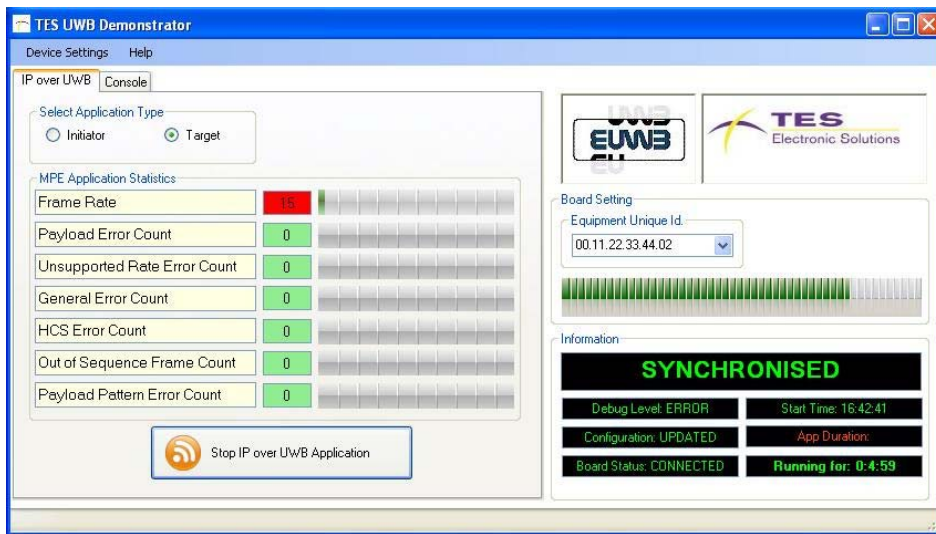


Figure 4-6: GUI of IP over UWB application

4.4.3 IP over UWB

The IP over UWB (IPoUWB) is realized by an implementation of the WiMedia link layer protocol (WLP), which ties the WiMedia communication radio platform to a common internet protocol (IP) interface. The WLP is implemented on the platform. The IPoUWB application demonstrates TCP/IP connectivity using the MAC on the Xilinx ML507 Virtex-5 FPGA development platform. To enable IPoUWB, the MAC layers of communication partners must be synchronized. To connect and

synchronize pairs of HDR platforms, there is a demo implementation with GUI, which uses the open WLP application programming interface (API) of the HDR platform as shown in Figure 4-6 [16].

5 Demonstration setup

5.1 Overview

In this chapter location aided applications based on the combined LDR/HDR platform is demonstrated. The demonstration is made to show a location sensitive application, whereas the location information is obtained by the LDR, which is more adequate in localization and tracking because of the high resolution pulse. And the video streaming is over HDR, which is can transmit high data rate data with rang of 10 meters. The advantage of the combined platform is, it can be easily get the location information from the LDR UWB by using its functionality, at the mean time, high data rate service are available. The combination of the LDR and HRD is not a physically piece two deceives together, it is a dynamic integration. For instance, the combined device can be sensible to the location information, and make use of the location to aid relaying, routing or other high layer applications.

5.2 Location depended video streaming

The demonstration consist of four different LDR UWB and two HDR UWB. As illustrated in Figure 5-1, there are four devices in the UWB networks, with notation from 1 to 4. The device with name 1 and 4 is a combined LDR/HDR one, both LDR UWB and HDR UWB are available. Device 1 is supposed to be a fixed device, and it works as a video streaming server. Device 4 has low mobility; it has a video streaming client running. Device 2 and 3 are fixed LDR UWB devices that work as anchor nodes. Also the device 1 works as an anchor node.

The principle of the demonstration is, the mobile device can receive different video data from the server.

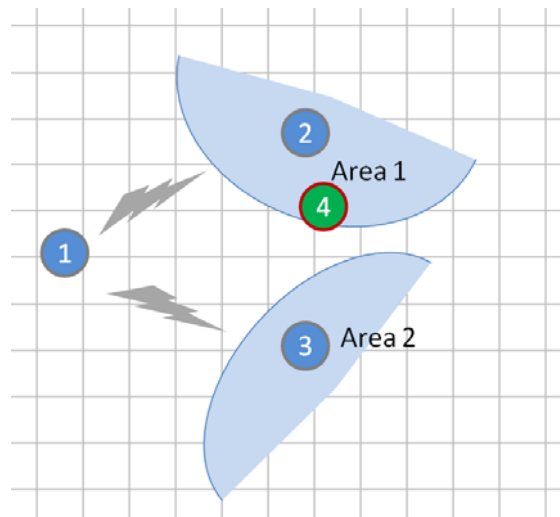


Figure 5-1: Demonstration of location dependent video streaming

On the server side, the video source is switched by the location of the mobile tag. For instance, as shown on Figure 5-1, the mobile tag (device 4) is in the area 1, which means the device expects receiving video 1. Alternatively, when the mobile tag is in the area 2, another video is streamed from the server to mobile.

The implementation of the location dependent video streaming service on the combined LDR/HDR is quite simple. The diagram of the location based video streaming is illustrated on Figure 5-2. On the left hand side of the diagram, blocks of the video server side is shown. The LT engine collects useful ranges between the target video clients and the other localization anchors and estimate the position of client with the method describe in chapter 4.4.2. As the position of the video client is estimated, the area detector will judge the geographical area where the target currently is. This area can be understood as the area 1 or area 2 shown in Figure 5-1. The Video server then switches the streaming content. The GUI of the implementation is shown in Figure 5-3.

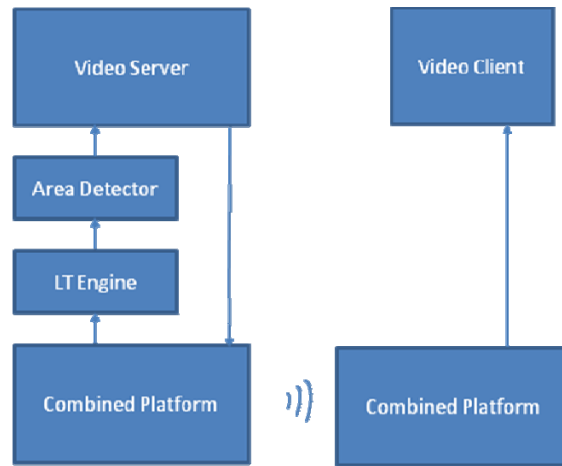


Figure 5-2: Diagram block of the location based video streaming service

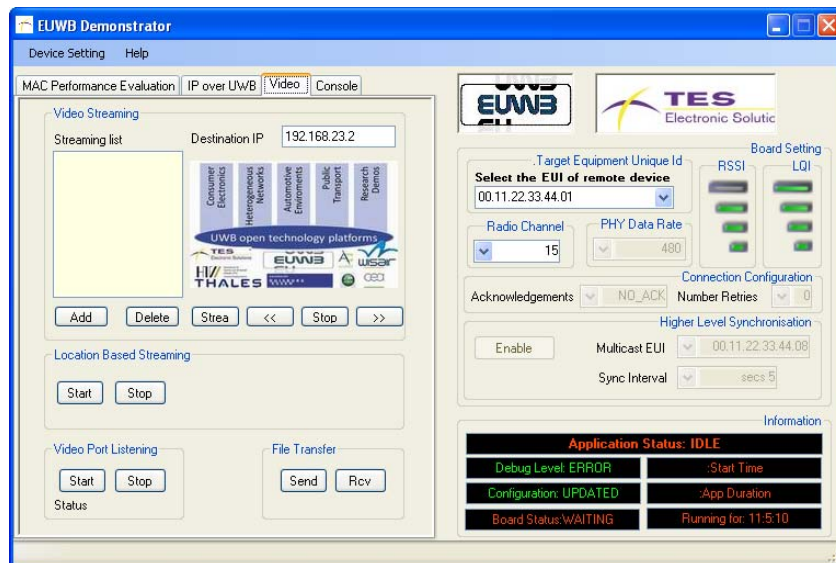


Figure 5-3: GUI of location dependent video streaming service

This combination of location and high data transfer service is useful in many scenarios, for example in a museum or in an exhibition hall. Such a system is more economy and makes tourists feel more convenient. Advantages are that, all the introduction information is stored in the service side and it is more flexible to configure the system to adapt different scenarios.

6 Conclusion

After analysis of the different EUWB open platforms for LDR and HDR, several integration schemes for the combined LDR/HDR platform have been investigated. For the application scenario described in chapter 5, a demonstrator of a combined LDR/HDR platform has finally been implemented, where different video contents are streamed from a fixed UWB video server to a mobile client. The streamed content depends on the location of the mobile node. Combining the different strengths of the platforms, the HDR system is used to transfer the audio and video data, while the LDR system is used for location tracking. Different issues of the combined platform have been taken into account. Interfacing of on PHY and MAC layer has been considered and theoretically elaborated. However, for the demonstration, interfacing on higher layers has been accomplished. The combined platform has been tested and the coexistence of LDR and HDR has been investigated. Several coexistence solutions are feasible. Since the spectrum of the LDR system overlaps with two frequency bands of the HDR system, and because both systems of the proposed demonstrator shall be able to operate at the same time, interferences may occur. However, since the LDR system emits short UWB impulses with comparable high power density, the LDR system can in most cases operate while the HDR system is transmitting. And because of the large impulse period of the LDR signal, the channel code of the HDR system allows operation in parallel to the LDR system. If operating on overlapping frequency bands, the MCS of the HDR shall be reduced. To avoid interference the HDR system of the combined platform shall use a frequency band, which does not interfere with the LDR spectrum.

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