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Radio Prototype Specifications

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Editor(s):	Peter CALDERA and Chang-Soon CHOI
Author(s):	Peter CALDERA, Chang-Soon CHOI, Eckhard GRASS, Oliver HOFFMANN
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Abstract

This document is a system requirement document for the radio prototypes delivered by WP2. It reflects the current view of WP2 and is related to current standards and state of the art technology. Currently, WLAN, WPAN-UWP and WPAN-60GHz are considered. The document describes technical requirements for the power amplifier, the RF and the PHY part of the different radios. MAC requirements are described when they are directly related to the radio

Updates due to change request out of the OMEGA consortium or due to technical reasons will be done in accordance with the management handbook.

Keyword list

Prototype, System Requirements, Radio, WLAN, WPAN, UWB, 60GHz, IEEE 802.11n, Power Amplifier, RF, PHY, Baseband, MAC, QoS

Executive Summary

Current und future services and contents in home area networks put diverse demands on the underlying transmission technology. In order to fulfil all the requirements to the desired extent without the need of any new wire and to avoid inefficient and cumbersome solutions with coexistence problems as experienced today, work package 2 (WP2) will integrate various appropriate radio devices into a converged heterogeneous radio network, which meets the customer’s demands with respect to quality of service, reliability, throughput, ubiquity, and self-configuration.

The considered radio technologies comprise enhanced WLAN (IEEE 802.11n), emerging UWB (WiMedia) and upcoming 60 GHz communication (IEEE 802.15.3c, IEEE 802.11ad, ECMA TC48).

In addition to the crucial aspect of convergence at the radio layer, advanced PHY, MAC, and cross-layer mechanisms will be developed, and coexistence will be achieved on system and hardware level. The most promising designs will be prototyped and then integrated into to the OMEGA platform.

This document describes the planed features of the radio prototype delivered by WP2.

For prototyping in WP2 the following roadmap is set up:

1. WLAN (IEEE 802.11n)

- 3x3 Test chip, end of 2008
- 1x1 SoC Chip including baseband processor and MAC, beginning of2009
- 3x3 SoC Chip including baseband processor and MAC, end of 2009

2. WPAN-UWB (WiMedia)

WP2 will investigate WPAN-UWB and develop enhanced methods and mechanisms. However, prototyping of WiMedia devices is not in the focus of WP2. We will show convergence by means of a standard development kit with a state of the art feature set.

3. WPAN-60GHz

- 60-GHz RF and 5-GHz IF super-heterodyne, 1 Gbps OFDM baseband with 500 MHz bandwidth, mid of 2009
- 60-GHz sliding IF, 2 GHz bandwidth OFDM baseband and MAC, mid of 2010

Impact on the other Work-packages

Hardware development will be done in close cooperation with work package 5 "interMAC", because the radio prototype has to be connected appropriately to the interMAC. The features of the radio prototype limit the scope and bandwidth of options of the interMAC.

This deliverable also provides important information for work package 7 "Platform Integration and Demonstration", as the final radio prototype has to be integrated into the overall OMEGA platform.

Insofar, the purpose of this deliverable is not only to provide information about the planed radio prototype, but also to gather feedback from the relevant work packages to assure seamless platform integration.

Protocol, timing and programming issues must be developed according to the standards. Impact on hardware and software implementation must be considered.

List of Authors

First name	Last name	Beneficiary	Email address
Peter	CALDERA	Infineon	Peter.caldera@infineon.com
Chang-Soon	CHOI	IHP	choi@ihp-microelectronics.com
Eckhard	GRASS	IHP	grass@ihp-microelectronics.com
Oliver	HOFFMANN	University of Dortmund	oliver.hoffmann@tu-dortmund.de

List of Acronyms

Acronym	Meaning
BP	Beacon Period
DAA	Detect And Avoid
DFS	Dynamic Frequency Selection
DRP	Distributed Reservation Protocol
ECC	Electronic Communications Committee
FCC	Federal Communications Commission
FEC	Forward Error Correction
HDTV	High Definition Television
IEEE	Institute of Electrical and Electronics Engineers
LOS	Line Of Sight
MAS	Medium Access Slot
MCS	Modulation and Coding Scheme
MGWS	Multiple Gigabit Wireless Systems
MIMO	Multiple-Input Multiple-Output
MPDU	MAC Protocol Data Unit
MSDU	MAC Service Data Unit
NAS	Network Attached Storage
OFDM	Orthogonal Frequency Division Multiplex
PCA	Prioritized Contention Access
PLCP	Physical Layer Convergence Protocol
PPDU	PLCP Protocol Data Unit
QoS	Quality of Service
SAP	Service Access Point
SME	Small and Medium Enterprises
SOHO	Small Office – Home Office
UWB	Ultra Wide Band
WLAN	Wireless Local Area Networks
WPAN	Wireless Personal Area Networks
WWRF	Wireless World Research Forum

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1 Radio Prototype Specification

1.1 WLAN

1.1.1 Description of System Requirements

The WLAN Radio comprises power amplifier (PA), RF module and baseband (BB) processing. Beside the support of IEEE 802.11n, this device shall also be backward compatible with IEEE 802.11a/b/g.

It shall be possible to derive a RF only device from the WLAN Radio by a simple bond-out option.

The WLAN Radio supports the 2.4 GHz band only. The silicon supports the 5 GHz band as well but neither the additional pads which are necessary to support the 5 GHz band will be made available in the planned packages nor any effort for debugging and testing on system level is planned.

<u>**Architectural Principles**</u>

High MAC shall be implemented in software on an external NWP (Network Processor)

The architectural split is as follows:

- PA, RF, BB-PHY and Low-MAC shall be integrated on one silicon
- High-MAC shall be implemented in software on an external network processor (NWP)
  - Host load for complete WLAN functionality @ 150 Mbit/s air rate for any kind of data transmission and reception (including small A-MPDU subframes aggregated to 64 kbyte A-MPDU):
    - Target: 60 MIPS
    - Maximum: 100 MIPS
- Buffer queues shall be held in the RAM of the NWP
- The data buffer integrated in the WLAN Radio shall be minimized such that its size, together with the maximum latency(ies) of any of the system interfaces, guarantees that minimum reaction times according to 802.11n are met.

The Low-MAC comprises only those time critical functions which an external controller connected to the WLAN Radio via any of the system interfaces is not able to handle.

<u>**Collaborative BT Coexistence**</u>

Collaborative Bluetooth (BT) coexistence shall be supported (BT device connected to WLAN Radio on same board)

Synchronized BT coexistence shall be supported according to 802.15.2. RF Frontend control for BT coexistence shall not be supported.

<u>**Non Collaborative Coexistence**</u>

Non collaborative coexistence shall be supported (device not connected to WLAN Radio) for:

- Microwave oven
- DECT
- Bluetooth
- Amateur radio
- Cellular radio

20/40 MHz Autosensing

Autosensing of the 20 and 40 MHz bands shall be supported

- Receive direction: Detect if counterpart transmits in 20 MHz or 40 MHz band
- Transmit direction: Detect if band is already occupied. If only the upper 20 MHz of the 40 MHz band is occupied, transmission shall be done in the lower 20 MHz band.

Ethernet Frame Length

The maximum Ethernet Frame Length of 2000 bytes according to [1] shall be supported

Jumbo frames (up to 64 kB) without fragmentation cannot be handled by .11 because the MSDU size is limited by the standard to 2304 bytes.

Ambient Temperature Range

The ambient temperature of the package must be in the range of 0 to 85oC

- Required: 0 to 85oC @ 2 years life time

VLAN Support

Ethernet with VLAN tags shall be supported

It shall be foreseen that the MAC firmware has access to the VLAN tag in order to follow standard extensions which are under discussion. The following access methods shall be supported:

- Stripping of VLAN tags
- Adding of VLAN tags
- Change of VLAN tags

Code of Conduct

Compliance to the Code of Conduct on Energy Consumption of Broadband Equipment of the EU

The WLAN Radio based WLAN system shall be fully compliant to the Code of Conduct on Energy Consumption of Broadband Equipment of the European Commission. This is reflected in the following power limits for the complete WLAN system:

- On state: < 1.2 W
- Off state:
  - 0 W with external power switch
  - < 1 mW (Leakage only) with power down pin according to requirement Power Down
- Standby: < 100 mW
  - Only transmission of beacons at lowest beacon period allowed by .11 standard

Note: The appropriate use cases for fulfilment of this requirement have to be defined

To minimize power consumption in every operation mode clock gating shall be utilized wherever possible.

Overall Power Limit for WLAN

The overall power for the complete WLAN system shall not exceed 2 W

The WLAN Radio based WLAN system (AP or NIC) shall not exceed 2 W under all conditions, e.g.:

- VDD = 3.0 ... 3.6 V

- Aggregation
- 150 Mbit/s air rate
- maximum Tx power of the integrated PA
- System interface
  - PCI for AP
  - SDIO+SPI for AP
  - PCI for NIC
  - SDIO for NIC

Table 1 Estimated Power Break Down @ 2.4 GHz

	VDD = 3,3 V		VDD = 3,0 V		VDD = 3,6 V	
	I[mA]	P[mW]	I[mA]	P[mW]	I[mA]	P[mW]
Tx Direction						
RF	98	323.4	98	294	98	352.8
PA	300	990	272.7	818.2	327.3	1178.2
AFE+BB-PLL	79	260.7	79	237	79	284.4
BB+MAC+Interfaces	51.3	169.3	51.3	153.9	51.3	184.6
Rx Direction						
RF	79	260.7	79	237	79	284.4
PA	-	-	-	-	-	-
AFE+BB-PLL	72	237.6	72	216	72	259.2
BB+MAC+Interfaces	404.6	1335.2	404.6	1213.8	404.6	1456.4

Note:

1. The power supply range for WLAN is based on the (mini) PCI specification (Chapter 4.3.4.1 of [2])
2. The overall power limit for WLAN is based on the mini PCI specification (Chapter 2.3 of [3])
3. The power supply range for SDIO is specified to 2.6 V to 3.6 V (Chapter 14.4 of [4])
4. According to chapter 14.3 of [4] the current limit for SDIO is specified to 500 mA @ 2.7 ... 3.6 V

Channel Selection

Auto and Manual Channel Selection

Auto and manual channel selection shall be supported. In auto channel selection mode the channel with the least RF interference shall be selected.

Power Down

Power Down Mode by Pin

If enabled, the WLAN Radio shall be forced statically into power down mode by the appropriate GPIO pin. In power down the complete chip including clock generation and oscillator shall be shut-down. Release of power down shall be possible without firmware download.

Power Modes

Different Power Modes shall be supported

The following power modes shall be supported:

- Normal Operation
- Listen Mode
- Power Down Mode
- Sleep Mode

Supported PHY Standards

Support of IEEE 802.11a/b/g/n and j

Table 2 Supported PHY Standards

Standard	F0 [GHz]	Transmission method	Modulation	Data sub-carriers	Bandwidth [MHz]	Coding Rates	Air Rate [Mbit/s]
802.11a	5	OFDM	BPSK, QPSK, 16-QAM, 64-QAM	48	20	1/2, 2/3, 3/4	<= 54
802.11b	2.4	DSSS	DBPSK, DQPSK, CCK		22		1 2 5.5 /11
802.11g	2.4	OFDM	BPSK, QPSK, 16-QAM, 64-QAM	48	20	1/2, 2/3, 3/4	<= 54
802.11n	2.4/5	OFDM	BPSK, QPSK, 16-QAM, 64-QAM	52 or 108	20 or 40	1/2, 2/3, 3/4, 5/6	<= 150

The standard shall be negotiated with each station.

Supported Frequency Bands

Support of the 2.4 GHz ISM band (including channel 14) and the 5 GHz unlicensed band

Table 3 Frequency Bands for 2.4 GHz and 5 GHz

Frequency Band		
Spectrum [GHz]	Number of non-overlapping channels	Comments
4.915- 5.091		
5.15 – 5.25	4	4
5.25 – 5.35	4	4

5.470 – 5.725	11	11
5.725 – 5.825/5.850	4/5	4/5
2.4 – 2.497	3/4	Channel 14 supported

Number of Streams

In the first version, only 1x1 system shall be supported

Other supported Standards

Support of all relevant Standards according to Table 4

Table 4 Supported Standards

Standard	Topic
802.1x	Authentication
802.11k	Radio Resource Measurement of Wireless LANs *
802.11w	Protected Management Frames *
802.11h	Spectrum Management in 5GHz range
802.11j	5 GHz operation in Japan
802.11e	MAC enhancements QoS Software Package 1: EDCA+WMM Software Package 2: TSPEC and HCCA
802.11i	Enhanced Security Mechanisms
802.15.2	Coexistence of WPANs and WLANs
CCX v1-5	Cisco Compatible Extensions Client: * AP: Not required
WiFi Alliance	WPA/WPA2, WMM, WMM-PS, WMM-AC, WPS
GB 15629.11- 2003GB 15629.11-2003	**Wired Authentication and Privacy Infrastructure (WAPI)** WAPI shall not be implemented but the concept shall be finalized and the design shall be prepared such that the functionality can be easily implemented in a potential redesign step)
802.1 AVB	Audio/Video Bridging (802.1 AVB shall not be implemented but the concept shall be finalized and the design shall be prepared such that the functionality can be easily implemented in a potential redesign step)
* Note: Will be available in the end of 2009.	

Air Throughput

The maximum air throughput of 150 Mbit/s shall be supported

Antennas

Up to 2 antennas shall be supported on chip level

Selection of 1 antenna out of 2 shall be supported for diversity purposes as depicted in Figure 1.

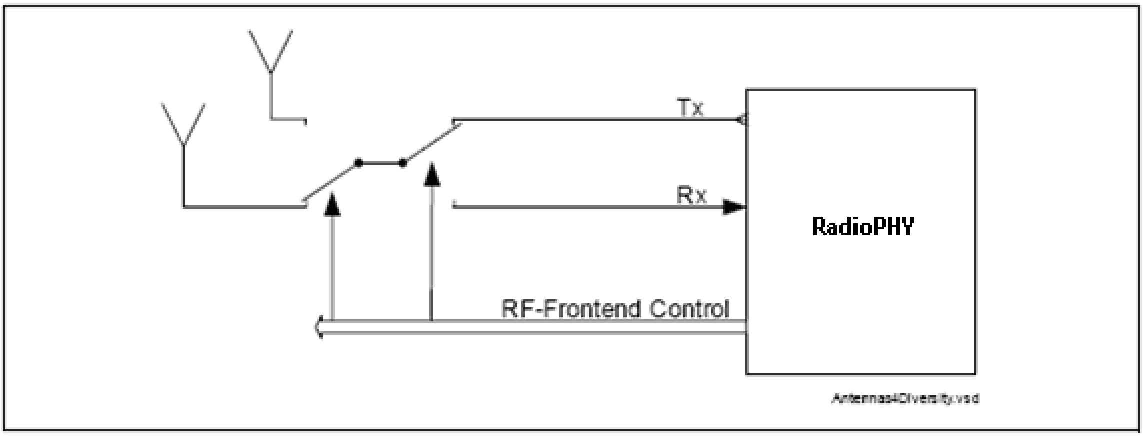

Figure 1 Antenna Diversity with 2 Antennas

Operation modes

Operation mode configurable by bond option

The following operation modes shall be supported:

- .11b/g only WLAN Router
- .11b/g/n WLAN Router
- .11a/n WLAN Router (to be supported on marketing request only)

Support of external LNA

Configurable Internal/External LNA

The following LNA modes shall be supported:

- Internal LNA
- External LNA

The LNA mode is configurable. The different AGC settings controlled by the PHY have to be taken into account.

Front End Control Pins

Eleven Frontend Control Pads

The silicon of the WLAN Radio shall support ten Front End control pads (RF_FE_CTL[9:0]) in the analog power domain.

Because of pin count constraints only six control pins are bonded out in Package 2 (PCI 3.0 + I2C, Single Band).

For supporting dual band applications with different kinds of front end modules two additional GPIOs shall be supported which can be utilized as front end control lines in addition to RF_FE_CTL[9:0].

This functional multiplexing shall be possible by configuration only, i.e., without the need of specific SW and/or FW versions.

Front end control variants supported by Package 2:

- External PA and antenna diversity but no external LNA
- External LNA and PA but no antenna diversity
- External LNA and antenna diversity but no external PA
- External PA, external LNA and antenna diversity with Skyworx like double switch only

Front end control variants supported by silicon:

- External PA, external LNA and antenna diversity

Integrated Oscillator

The integrated oscillator shall support 36 MHz and 40 MHz

Selection of the frequency shall be done by the external circuitry, i.e., neither a mode pin nor a configuration register shall be required for the oscillator.

System Interfaces

System Interfaces to be supported mutually exclusively

The appropriate system interface for any application shall be selected by pin-strap.

Driver for disabled interfaces shall be disabled such that neither an internal nor an external pull-up or pull-down resistor is necessary. If disabled the driver shall not consume any power.

- PCI Rev. 2.3 (Endpoint), covered by PCI Rev. 3.0
- PCI Rev. 3.0 (Endpoint) [2]. Slave and Master mode shall be supported
- Mini PCI Rev. 1.0 (Endpoint) [3], form factor of PCI Rev. 3.0

  Power Management required:

  - According to PCI BUS POWER MANAGEMENT INTERFACE SPECIFICATION, REV. 1.2 [6] (including utilization of PME# for requesting a change of its power state or for indicating a PME)
  - According to PCI Mobile Design Guide [8] (CLKRUN# based)

- CardBus [5], mainly form factor of PCI Rev. 3.0

  Power Management required:

  According to PC Card Standard - Electrical Specification, Volume 2 [7] (CCLKRUN# based, including utilization of PME# for requesting a change of its power state or for indicating a PME)

- Standard SDIO (for Windows-Mobile)

  CRC error handling as follows:

  - CRC is generated in transmit direction
  - After reset the CRC is evaluated in receive direction but data shall be forwarded independent of the result of the CRC evaluation.

  SDIO interface can be configured via the vendor specific register of CCCR such that the data is not forwarded in case of receiving defective data.

- SDIO + SPI.

SPI is utilized for accessing the control and status registers while SDIO is utilized for the data flow and the interrupts coming along with the data flow.

SDIO to be optimized for connecting Amazon-SE:

- Block Mode with configurable block size from 1 - 2k
- High Speed Mode (up to 50 MHz clock frequency) and Default Mode (up to 25 MHz clock frequency) supported
- CRC errors are handled as in Standard SDIO mode.

System Interfaces, Latency

Latency for data transmission via the System Interfaces

SDIO Latency with NWP connected:

- Condition 1:
    - Block Mode applied
    - No processor load of the NWP for other tasks
    - Code is running from cache, i.e., no cache miss is taken into account
    - Clock speed: 25 MHz
    - 4 data pins
    - Average of 100000 transactions of the same packet length
    - Formula for transaction time: $t = t_0 + b*p$

      b: time to transmit a single byte

      p: packet length in byte
- Condition 2:

Table 5 SDIO, Latency

	Read From WLAN	Write to WLAN
Condition 1		
t_0 [µs]	18.36	11.27
b [ns/byte]	83.27	79.92

BB <=> RF Data Interface

Data interface between BB and RF shall be analog

A2D for data (One A2D for I, One A2D for Q):

- I and Q shall be sampled with the same clock edge
- Differential input, full scale: 1.4 VPP @ 0.7 V input VCM
- Latency (Sampling Instant to interface): < 8 sampling clock periods
- Switching from .11b to .11g and vice versa: < 0.5µs

- Wake up from standby: < 1 µs
- Wake up from shutdown: < 2 µs
- Overall (RF+AFE) static I/Q Mismatch at AFE->BB PHY interface after calibration:
    - Gain < 0.3 dB
    - Phase < 3 degree
- Overall (RF+AFE) dynamic I/Q Mismatch at AFE->BB PHY interface after calibration:
    - Gain < 0.2 dB
    - Phase < 2 degree

Maximum Air Rate supported by System Interface

Maximum air rate to be supported by all System Ineterface flavors

The continuous air rate of 150 Mbit/s for back-to-back transmission of aggregated packets of maximum size shall be supported by PCI utilized as system interface.

The throughput for SDIO as system interface shall only be limited by the overhead specified in the SDIO specifications [9] [10]. This holds for the 25 MHz and 50 MHz options.

Point-to-point interfacing assumed for both cases.

Throughput limitations on the system interface should not lead to a drop of the air rate, i.e., packets received without error shall be acknowledged no matter if the Rx buffer overflows.

Rate Configuration

Manual and Auto Rate Configuration shall be supported on a per station basis.

For the auto rate configuration at least the following parameters shall be evaluated for the rate setting of the appropriate STA:

- SNR
- PER

Certification

Certification in all relevant certification labs

Certification according to the following:

- WHQL
- WiFi Alliance
    - WPA/WPA2/WiFi protected set-up
    - WMM
    - WMM-PS (Software Package 2)
    - WPS (Software Package 2)
    - WMM-AC (Software Package 2)
    - Extended EAP (Software Package 2)
- Connection with Centrino

- WinXP (for driver)

MAC Functions

- Counter for received good packets
- Counter for received bad packets
- Time measurement for scan and connect (to be implemented in software)
- Throughput measurement (to be implemented in software)
- Rx from air -> Tx to air loopback (MACLBIG1 and MACLBIG2, Figure 2)
- Transmission of framed continuous ONEs
- Transmission of framed predefined pattern (1010..., 100100...)
- Transmission of framed pattern from file (to be implemented in software)

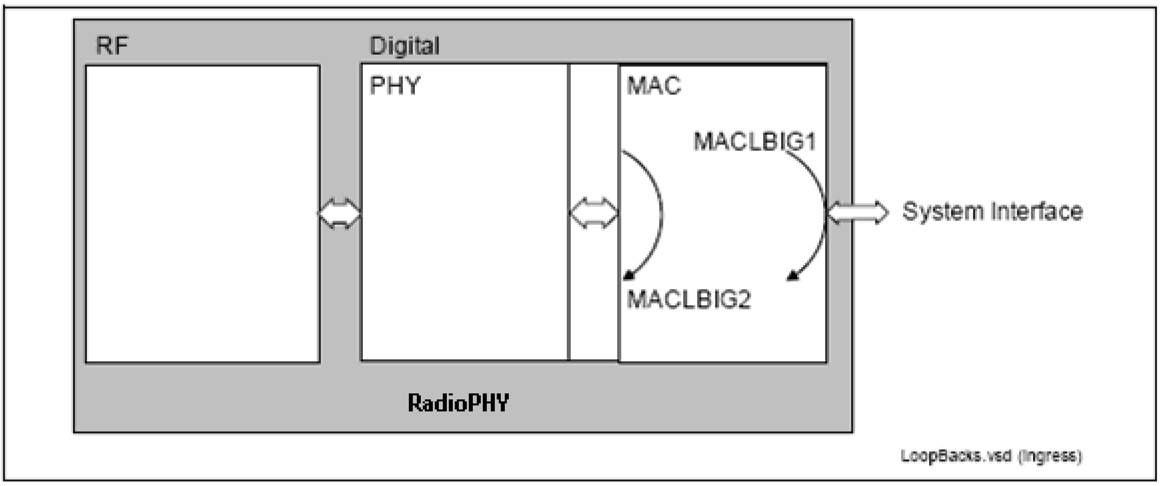

Figure 2 Ingress Loop-Backs

1.1.1.1 Special Requirements for the RF and PA

This chapter lists the requirements for the RF which are either beyond the supported standards or which limit the options of the supported standards.

Transmit Power of the integrated Power Amplifier

The typical output power of the PA shall be different for 2.4 GHz and 5 GHz

- 2.4GHz:
  - Typical output power of integrated PA at the output pin @ 64 QAM, 11g (48 tones):
    - Mode 1: >14.5 dBm @ TBD mA
    - Mode 2: >12.5 dBm @ <300 mA
    - Mode 3: Support of external PA
  - Typical output power of integrated PA at the output pin @ 64 QAM, .11n (108 tones):
  - 2,5 dB less compared to .11g in all modes

- The output power at the RF TX output shall be adjustable in 1 dB steps in the range -20 dBm ... 16 dBm
- Output power reduction implies reduction of power dissipation by the same factor
- The WLAN Radio shall be configurable such that an external PA can be utilized instead of the integrated one. The output shall be differential supporting the possibility to connect one out of the two pins of the differential output via an inductive impedance to VDD.

- 5 GHz: Shall be supported with an external PA

Note: The WLAN Radio product is optimized for for 2.4 GHz only. 5 GHz shall be supported by the silicon but pins are not available on planned packages and no effort planned to be spent for debug and test.

Support of .11j (4.9 GHz to 5 GHz operation in Japan)

11j shall be supported by hardware

Additional effort for .11j support, e.g. for firmware or test, will only be spent on strong marketing request. For the time being no additional efforts beside hardware implementation are spent for .11j.

Support of 10 MHz channel spacing

The 10 MHz channel spacing shall be supported.

Aggregation and fragmentation

Frame aggregation and fragmentation shall be supported

Aggregation of MAC service data units (MSDUs), known as A-MSDU aggregation, as well as aggregation of MAC protocol data units (MPDUs), known as A-MPDU, shall be supported as defined in the standard. Necessary features of block acknowledgment shall also be supported.

Fragmentation of MSDUs shall be supported as defined in the standard.

1.1.1.2 Special Requirements for the PHY

This chapter lists the requirements for the PHY which are either beyond the supported standards or which limit the options of the supported standards.

STBC Support

STBC in receive direction shall be supported.

LDPC Support

LDPC not supported

LDPC not supported because of small gain versus high cost at higher bit rates.

MCS support.

In the first version, the MCSs according to Tables 8 and 9 shall be supported.

The optional short guard interval (GI) shall be supported

Table 6 Symbols used in MCS parameter tables

Symbol	Explanation
N_{SS}	Number of spatial streams
R	Coding Rate
N_{BPSC}	Number of coded bits per single carrier (total across spatial streams)

$N_{BPSCS}(i_{SS})$	Number of coded bits per single carrier for each spatial stream, $i_{SS} = 1, \ldots, N_{SS}$
N_{SD}	Number of complex data numbers per spatial stream per OFDM symbol
N_{SP}	Number of pilot values per OFDM symbol
N_{CBPS}	Number of coded bits per OFDM symbol
N_{DBPS}	Number of data bits per OFDM symbol
N_{ES}	Number of BCC encoders for the DATA field
N_{TBPS}	Total bits per subcarrier

Table 7 Supported MCSs for mandatory 20 MHz bandwidth, $N_{SS} = 1$, $N_{ES} = 1$

MCS Index	Modulation	R	$N_{BPSCS}(i_{SS})$	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate (Mb/s)	
								800 ns GI	400 ns GI see NOTE
0	BPSK	1/2	1	52	4	52	26	6,5	7,2
1	QPSK	1/2	2	52	4	104	52	13,0	14,4
2	QPSK	3/4	2	52	4	104	78	19,5	21,7
3	16-QAM	1/2	4	52	4	208	104	26,0	28,9
4	16-QAM	3/4	4	52	4	208	156	39,0	43,3
5	64-QAM	2/3	6	52	4	312	208	52,0	57,8
6	64-QAM	3/4	6	52	4	312	234	58,5	65,0
7	64-QAM	5/6	6	52	4	312	260	65,0	72,2

Table 8 Supported MCSs for optional 40 MHz bandwidth, $N_{SS} = 1$, $N_{ES} = 1$

MCS Index	Modulation	R	$N_{BPSCS}(i_{SS})$	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate (Mb/s)	
								800 ns GI	400 ns GI
0	BPSK	1/2	1	108	6	108	54	13,5	15,0
1	QPSK	1/2	2	108	6	216	108	27,0	30,0
2	QPSK	3/4	2	108	6	216	162	40,5	45,0
3	16-QAM	1/2	4	108	6	432	216	54,0	60,0
4	16-QAM	3/4	4	108	6	432	324	81,0	90,0
5	64-QAM	2/3	6	108	6	648	432	108,0	120,0
6	64-QAM	3/4	6	108	6	648	486	121,5	135,0
7	64-QAM	5/6	6	108	6	648	540	135,0	150,0

1.1.1.3 Special Requirements for the MAC

This chapter lists the requirements for the MAC which are either beyond the supported standards or which limit the options of the supported standards.

HCCA

HCCA supported supported by software package 2.

HCCA is not required by Wifi. Hardware including memory shall support HCCA.

APSD/PSMP

APSD / PSMP supported by software package 2.

APSD / PSMP is not required by Wifi. Hardware including memory shall support APSD/PSMP.

CCX

CCX supported by software package 2.

CCX is only relevant for NIC applications. Hardware including memory shall support CCX.

Bluetooth Coexistence

The WLAN system shall be able to share one antenna out of two with BT.

The diversity switch as depicted in **Figure 1** shall be controlled appropriately. The antenna switch for the Bluetooth device shall not be controlled by the WLAN Radio but by the Bluetooth device.

Clone MAC Address

It shall be supported to manually clone mode.

1.1.2 Security Requirements

This chapter lists the security related software requirements.

Encryption

The WLAN software shall support the following encryption modes:

WPA

WPA is a partial implementation of the 802.11i with TKIP based encryption. The implementation shall support at least following features:

- Extensible Authentication Protocol (EAP)
- Use of a less secure "pre-shared key" mode, where every user is given the same pass-phrase (WPA-PSK)

WPA2

WPA2 is a full implementation of the 802.11i standard with CCMP based encryption. The software implementation shall support at least following features:

- Extensible Authentication Protocol (EAP)
- Use of a less secure "pre-shared key" mode, where every user is given the same pass-phrase (WPA-PSK)

WEP

Wired Equivalent Privacy (WEP) is the original encryption scheme of WLAN networks. The software implementation shall support at least following features:

- Extensible Authentication Protocol (EAP)
- Configurable key (64/128 bit)

- Static (no authentication) and dynamic keys.

Station Related Encryption

Following security modes shall be supported per station:

- WEP
- WPA
- WPA2
- None
- Hidden SSID

Authentication

Independent of the used encryption following authentication modes shall be supported:

- Radius client
- 802.1X (authenticator and supplicant)
- EAP Protocols: EAP-TLS, EAP-TTLS/MSCHAPv2, PEAPv0/EAP-MSCHAPv2, PEAPv1/EAP-GTC, EAP-SIM
- EAP Protocols (Software Package 2): LEAP, EAP-PSK, EAP-FAST, EAP-AKA, EAP-MD5

1.1.3 QoS Requirements

This chapter lists the QoS related software requirements.

Wi-Fi Multimedia (WMM)

Wi-Fi Multimedia (WMM) is an interoperability certification based on the IEEE 802.11e standard that provides basic QoS functionality. WMM prioritizes traffic according to 4 access categories (voice, video, best effort, and background) but it does not provide guaranteed throughput. Four access categories (AC) with individually programmable access parameters according to 802.11e are supported.

Wi-Fi Multimedia PS Certifiable Support

Wi-Fi Multimedia PS provide additional handling of power save conditions by using mechanisms from 802.11e and legacy 802.11 to save power and fine-tune power consumption. The certification provides an indication that the certified product is targeted for power critical applications.

Traffic Category Classification

The following functionality is implemented:

- Mapping between User Priorities (UP) and AC according to 802.11e
- Determination of UP from DSCP or VLAN priorities according to WiFi Alliance WMM System Interoperability Test Plan
- Software Package 2: Determination of UP from either DSCP/TOS field, VLAN priorities (with differentiation of SP using VLAN tags) or UDP/TCP port combined with IP address
- Software Package 2: Frame classification according to 802.11e Classifier types 0, 1 and 2
- Forwarding and queuing enhancements according to IEEE P802.1Qav. Software to be implemented only **upon request** (HW has to be able to support this functionality.)

On the basis of the classification the queue mapping with access through different DMA (dependent on system configurations) should take place.

1.1.4 Management and Configuration

Configuration

The software responsible for management and configuration shall allow configuring the following:

802.11 interoperability

All parameters according to 802.11 (2007) specification shall be controllable via software API.

Throughput Enhancement

- Antenna diversity (configure hardware features, enable/disable)

Radio

- Overtime radio calibration per radio type: DCR
- Dynamic configuration of radio transmission power levels per station
- 802.11d multiple regulatory domains
- Access Point radio enable/disable
- Rate management (rate adaptation and rate fallback)

Gateway

- Access list
- 32 MAC address entries per black/white list for each BSSID (queue entries)
- Flexible configuration of queue numbers and depth. It shall be possible to choose between number of MAC addresses per BSSID and number of BSSID (e.g. 1 BSSID with support of 128 MAC addresses or 4 BSSID with support of 32 MAC addresses per BSSID or any other combination)
- WLAN station isolation mode (disabling local frame switching in BSS)
- WDS Manager (repeater support)
- 32 entries of associated station per BSSID
- Multiple BSSID (at least four Virtual AP)
- VLAN tagging (support on Virtual AP)
- AUTO Channel Selection

Utilities

- Radio measurement
- Rate control
- Link adaptation
- Manufacturing fine tune tool
- Power management (support of country specific power levels)

Debug

- Monitor the link status
- Source code level profiling (symbol levels).

Firmware upgrade

Firmware upgrade over HTTP and TFTP shall be available. In addition it shall be possible to upgrade the firmware without rebooting the whole system.

Backup and Restore

It shall be possible to backup the whole WLAN configuration in one location (e.g. configuration file). Restoring of the WLAN configuration from this location shall be possible.

1.2 WPAN-UWB

WP2 will investigate WPAN-UWB and develop enhanced methods and mechanisms. However, prototyping of WiMedia devices is not in the focus of WP2. We will show convergence by means of a standard development kit (SDK) with a state of the art feature set. The expected features and requirements are described in the following subsections.

1.2.1 Features

- Single chip solution for Ultra Wide Band connectivity (from RF to application)
- Supports Wireless-USB host and device functionality as well as IP over UWB.
- Complies with WiMedia Phy 1.2, WiMedia MAC 1.0 and Certified Wireless USB 1.0 standard specifications
- Optimized for mobile applications: low BoM and "mobile-friendly" DC concept
- Data rates: 53.3, 80, 106.7, 160, 200, 320, 400 and 480Mbit/s
- Band groups 1 (3.168GHz – 4.752GHz), 3 (6.336GHz - 7.92GHz) and 6 (7.392GHz – 8.976GHz)
- On-chip memory supports all operational modes
- External reference clocks: 38.4MHz or 26MHz
- External sleep clock: 32.768kHz
- Includes the following host interfaces:
  - 4bit SDIO slave (at clock speeds of up to 50MHz)
  - SPI slave
  - Data/Address bus

1.2.2 Power Management

1.2.2.1 Average Power Consumption

Table 9 Power Consumption

Throughput 25/480	25Mbit/s throughput is flowing through the chip using 480Mbit/s data rate in the air.	175mW
Throughput 100/480	100Mbit/s throughput is flowing through the chip using 480Mbit/s data rate in the air.	650mW
Throughput 200/480	200Mbit/s throughput is flowing through the chip using 480Mbit/s data rate in the air.	1300mW

Throughput 25/100	25Mbit/s throughput is flowing through the chip using 100Mbit/s data rate in the air.	350mW

1.2.3 RF Ports

1.2.3.1 Sensitivity

The following table specifies the sensitivity levels, at the RF ports, for different bit rates. The specified values are typical (in terms voltage, process and temperature variations).

Table 10 Sensitivity Levels

Bit Rate [Mbit/s]	Sensitivity Level [dBm]
53.3	-79.3
106.7	-76.0
200	-70.9
320	-68.7
480	-62.8

The specified sensitivity values are referring to the following conditions:

- Packet error rate (PER) of less than 8% with PSDU of 1024 octets.
- Mix of channels from channel models 2 and 3 as defined by the IEEE.
- Without any margins included.

1.2.4 TX Power Level

The maximum RMS Tx power at the chip ports is +3dBm (during dwelling time on OFDM symbol). This Tx power level supports a transmitted PSD of -41.3dBm/MHz with passive attenuation of 11.5dB from chip ports to EIRP, according to the following budget:

Table 11 Power Levels

-41.3 dBm/MHz	Transmitted EIRP PSD
+27dB	Corresponding to 500MHz band
+5.87dB	For transmission duty cycle (4.77dB for TFI and 1.1 dB for zero padding)
+11.5dB	Passive losses (filter insertion loss and antenna gain)
+3 dBm	**Maximum output power at chip output during TX symbol**

The minimum RMS Tx power at the chip ports is -19dBm during dwelling time. This yields dynamic power range of 22dB (13dB of which support WiMedia TPC requirements, and 9dB can be used for production alignment).

The SDK also contains inter-band and intra-band Tx pre-equalizer. This equalizer can be used to compensate non flat frequency response of the passive RF front-end.

1.2.5 Robustness to interferes

When other narrow band wireless systems are working in the vicinity of the SDK, interfer ence can occur. The effect of the interference depends on the frequency and strength of the interfering signal as appears in the RF ports of the SDK. It also depends on the Band Group used by the SDK.

The following table specifies the robustness of the SDK to interferers. For each band group and frequency, the table lists three levels of interference strengths:

- Strength of interfering signal, at the SDK RF ports, that will cause sensitivity degradation of 2dB.
- Strength of interfering signal, at the SDK RF ports, that will cause sensitivity degradation of 2-5dB.
- Strength of interfering signal, at the SDK RF ports, that will cause sensitivity degradation of 2-5dB, while working in "Extra Interference-Robustness" mode. In this mode the noise figure increases by ~2dB, even when interference is not present, which result in degradation of 2dB in sensitivity level. On the other hand the allowed interferer signal strength is increased.

Table 12 Interference frequency

Interference frequency	**GSM 900 MHz [dBm]**		**GSM 1900 MHz [dBm]**		**ISM 2400 MHz [dBm]**		**UNII 5150 MHz [dBm]**		**UNII 5400 MHz [dBm]**		**UNII 5800 MHz [dBm]**	
UWB Band Grouping	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
Allowed interference level for sensitivity degradation of less than 2dB	-30	-30	-34	-30	-38	-30	-45	-34	-38	-36	-36	-45
Allowed interference level for sensitivity degradation of 2-5dB	-27	-27	-30	-27	-36	-27	-38	-30	-36	-34	-34	-38
Allowed interference level for sensitivity degradation of 2-5dB in extra Interference Robustness mode	-27	-27	-27	-27	-30	-27	-38	-27	-30	-31	-31	-38

1.3 WPAN 60-GHz

1.3.1 System requirements

The 60-GHz radio mainly consists of 60-GHz analog front-end (AFE), digital baseband processor and MAC processor. The 60-GHz AFEs are based on super-heterodyne conversion, particularly, sliding IF architecture which potentially eliminates the use of additional PLL for IF generation. These chipsets are fabricated with IHP 0.13um or 0.25um SiGe:C BiCMOS technologies. Digital baseband processor is composed of DAC/ADC and baseband part realized by high-speed FPGA. MAC processor has the sublocks of MAC FPGA board, MAC processor and memory which can be integrated into baseband FPGA board for small form factor.

It shall be possible to derive a 60-GHz AFE device from the complete hardware by a simple bond-out option. This 60-GHz AFE shall meet the RF requirements in IEEE 802.15.3c standard draft.

<u>**Coexistence**</u>

Coexistence with legacy 60-GHz devices should be supported.

- IEEE devices (802.15.3c and 802.11ad)
- ECMA and WirelessHD

- ITS or car-radar

Ambient Temperature range

The ambient temperature of the 60-GHz devices must be in the range of 0 to 75 deg.

Frequency channels in 60-GHz-band

It shall support two channels which have the center frequencies of 60.48 GHz and 62.64 GHz, and the maximum channel bandwidth of 2.16 GHz, specified in IEEE 802.15.3c standard.

Channel boding between two frequency channels shall not be considered. It allows allocating five narrow-band channels in each frequency channel and center frequencies of the narrow-band channels shall be generated in the same PLL supporting the channel plan of IEEE 802.15.3c Within the boundary of unlicensed 60-GHz frequency band allocated by a government, a 60-GHz radio device can select a channel as long as it keeps the defined maximum channel bandwidth and center frequencies.

Channel switching time

Channel switching time shall be less than 200 us

- The channel switch time is defined as the time from the last valid bit is received at the antenna on one channel until the device (DEV) is ready to transmit or receive on a new channel.

Center frequency tolerance

The transmit center frequency tolerance shall be ± 25 ppm maximum

Transmit power

The maximum allowable transmit output power, as measured in accordance with practices specified by the appropriate regulatory bodies, is shown in the following figure.

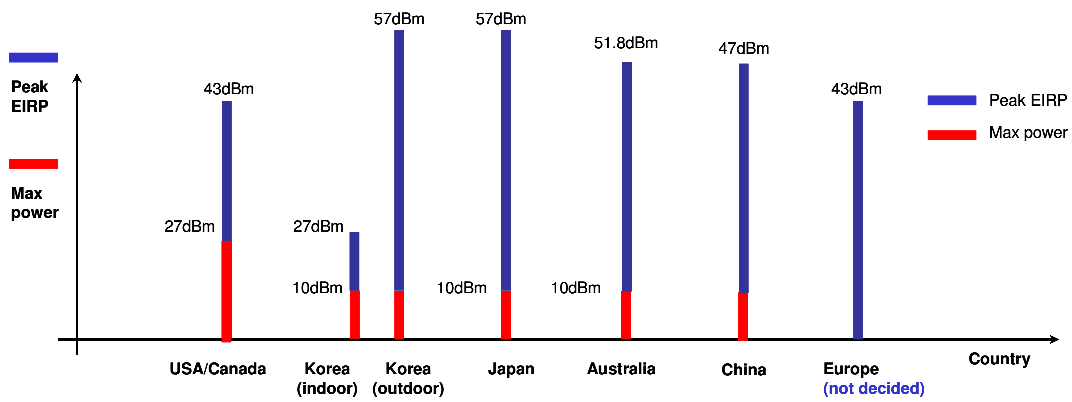

Figure 3 Output Power

Power consumption

The power consumption for complete 60-GHz analog front-ends including high power amplifier shall not exceed 10 W.

Crystal oscillator for PLL

The crystal oscillator used for reference clock of PLL shall support either 19.2 MHz or 38.4 MHz.

Ethernet frame length

The minimum frame length of 2K bytes and the maximum frame length of 100K byte shall be supported. (512 bytes and 8388608 octets in 802.15.3c, respectively)

- This total includes the MAC subheader, frame payload, and FCS, but not the PHY preamble, base header (PHY header, MAC header and HCS). The maximum frame length also does not include the tail bits, nor the stuff bits.

PHY-SAP rate

The maximum PHY-SAP rate of 1 Gbps at 10 m shall be supported.

Baseband and 60-GHz RF AFE interface

Data interface between baseband and the 60-GHz RF shall be differential.

- Maximum 6 bit ENOB analog-to-digital converter (ADC) shall be used.
- One ADC for I-channel and One ADC for Q-channel

The external interfaces

The interface shall be either Gbit Ethernet or PCI-express to have common interface.

1.3.2 60-GHz RF transceiver

The 60-GHz transceiver for the OMEGA project is based on a superheterodyne architecture. In particular, it adapts sliding IF architecture which uses RF PLL for IF generation with frequency divider. Figure 4 shows the schematic diagram of sliding IF receiver. A single 48-GHz-band PLL extended with a static ¼ frequency divider generated 12-GHz-band IF which is used for IF conversion. This high IF is expected to mitigate image rejection problem of conventional super-heterodyne architecture.

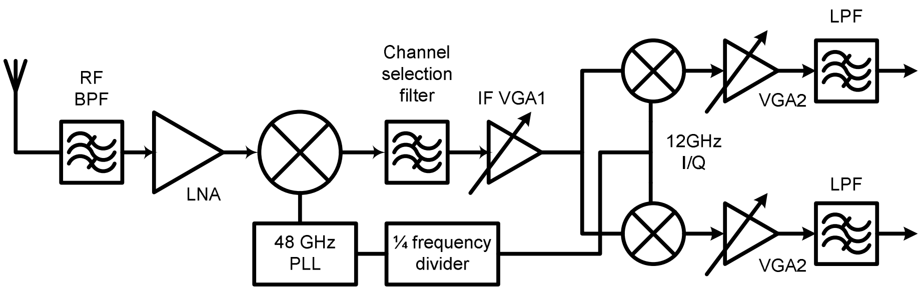

Figure 4 Sliding If architecture for 60-GHz analog front-ends

60-GHz RF and antenna interface

60-GHz interface between RF components and antenna shall be differential.

Receiver noise figure

Noise figure of complete receiver chain shall be less than 12 dB.

IF channel selection filter and variable gain amplifier

IF channel selection filter should be used in receiver blocks to have better channel selectivity. Dynamic gain range of IF variable gain amplifier shall be larger than 25 dB.

Tx and Rx filter.

Tx and Rx filters at 60-GHz band may be removed if the connected amplifiers have the capability to reject out-of-band emissions and receptions. This provides better integration as well as lower noise figure of receiver.

Power consumption of 60-GHz AFE

The estimated power consumptions for 60-GHz AFE are following.

Table 13 Estimated Power Consumptions

Transmitter	I [mA]	V_{DD} [V]	**Receiver**	I [mA]	V_{DD} [V]
HPA	165 mA	3.7 V	VCO	65 mA	2.6 V
HPA control	6 mA	3.7 V	Divider	80 mA	3.0 V
VCO	65 mA	2.6 V	PLL (PFD and charge pump)	1 mA	2.7 V
Divider	80 mA	3.0 V	LNA	44 mA	2.0 V
PLL (PFD and charge pump)	1 mA	2.7 V	Mixer	29 mA	3.5 V
Preamp	80 mA	2.6 V			
Mixer	10 mA	3.5 V			

48-GHz Phase-locked loops

PLL shall support to have not only the two center frequencies of 60-GHz channels (60.48-GHz and 62.64-GHz) but also center frequencies of 10 narrowband channels (59.616, 60.048, 60.480, 60.912, 61.344, 61.776, 62.208, 62.640, 63.072, 63.504-GHz), The sampling frequencies applied to DAC and ADC shall be also generated from the same PLL in order to provide simple transceiver architecture.

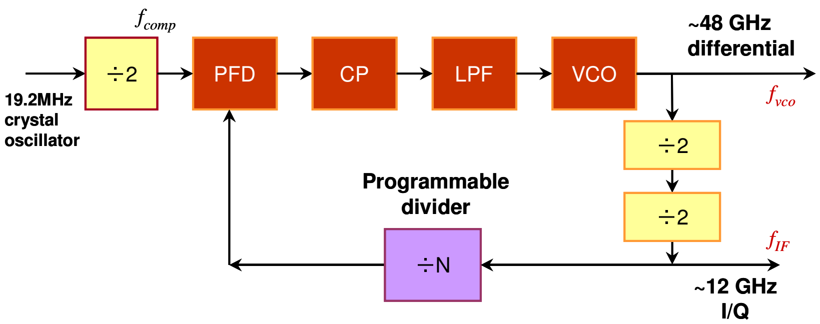

Figure 5 A 48-GHz PLL architecture supporting the proposed channel plan and IEEE 802.15.3c channels.

For OFDM transmission, the RMS phase-error generated from 48-GHz PLL shall be guaranteed to be less than 3 degree.

1.3.3 Gbps OFDM baseband

OFDM PHY layers

Gbps OFDM PHY shall support both wideband and narrowband schemes which are based on FFT bandwidths of 2016-MHz and 504-MHz, respectively.

These sampling frequencies should be generated from the PLL specified in the section 1.3. Table 12 summarizes key parameters for both wideband and narrowband OFDM modes. Each mode supports different transmission rates with the modulations from BPSK to 64-QAM. The subcarrier spacing, guard interval, FFT time and OFDM symbol time shall be the same in two different OFDM modes. Table 13 is the estimated transmission rate assuming that it adapts only convolutional coding with puncturing. Optional cyclic prefix length of 63.5 ns and 31.75 ns can be used for providing higher throughput.

Table 14 Wideband and narrowband OFDM parameters

Parameter	Wideband	Narrowband
Channel spacing	2160 MHz	432 MHz
FFT bandwidth	2016 MHz	504 MHz
FFT size	1024	256
Sub-carrier spacing	1,96875 MHz	1,96875 MHz
Guard interval	127 ns	127 ns
FFT period	508 ns	508 ns
OFDM symbol time	635 ns	635 ns
Data sub-carriers	840	192
Pilot sub-carriers	66	16
Zero sub-carriers	5	5
Used bandwidth	1793.531 MHz	419.344 MHz

Table 15 Estimated transmission rates

Parameter	Wideband	Narrowband
BPSK-1/2	661.5 Mbit/s	151.2 Mbit/s
BPSK-2/3	882 Mbit/s	201.6 Mbit/s
QPSK-1/2	1323 Mbit/s	302.4 Mbit/s
QPSK-2/3	1764 Mbit/s	403.2 Mbit/s
16-QAM-1/2	2646 Mbit/s	604.8 Mbit/s
16-QAM-2/3	3528 Mbit/s	806.4 Mbit/s
64-QAM-1/2	3969 Mbit/s	907.2 Mbit/s
64-QAM-2/3	5292 Mbit/s	1209.6 Mbit/s

Channel coding

Reed-Solomon coding (RS) as outer code. Convolutional coding or LDPC coding as inner code. Outer RS coding may not be used for simple hardware architecture.

Reed-Solomon (255, 239) channel coding shall be used as outer code. Either convolutional coding with code rate R = ½ and generator polynomials g0 = (133)8 and g1 = (171)8 or LDPC coding (672, 336) and (672, 504) shall be used as inner code. Bit interleaving or tone interleaving can be also used.

1.3.4 MAC

MAC features of 60-GHz demonstrators

- Standard IEEE 802.15.3 MAC adapted to 60-GHz PHY

- Centrally controlled TDMA scheme piconet controller + several terminal
- QoS (Quality of Service) support
- Authentication, privacy, dynamic channel selection, power management, etc
- Unit-case, multi-case and broadcast capabilities
- Point-to-point and point-to-multipoint connection support

2 Conclusion

Radio prototype specifications of 802.11n-based WLAN, UWB-based WPAN and 60-GHz systems are described in detail. RF blocks of these systems are integrated into a single chip using silicon-based semiconductor processes, which provides small form factor and low power consumption. Testing these radio prototypes includes not only low-level measurements, for example device characteristics, but also system demonstration in conjunction with baseband processors. Baseband and MAC parts of WLAN and UWB are also realized by ASIC chip, however those parts for 60-GHz systems will be implemented with FPGA for providing better flexibility and easier implementation of new approaches. This document lists up all necessary functions that OMEGA radio hardware demonstrators require, but not necessarily locked up. The contents can be added or changed as long as all WP2 partners agree.

3 References

[1] IEEE P802.3as™/D3.3, Amendment: Frame format extensions

[2] PCI Local Bus Specification Revision 3.0

[3] Mini PCI Specification Revision 1.0

[4] SDIO Specification Version 2.00

[5] PC CARD STANDARD

[6] PCI BUS POWER MANAGEMENT INTERFACE SPECIFICATION, REV. 1.2

[7] PC Card Standard -Electrical Specification, Volume 2

[8] PCI Mobile Design Guide

[9] SD Specifications, Physical Layer Specification

[10] SD Specifications, SDIO Simplified Specification