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Study on Physical (PHY) layer

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Digital Enhanced Cordless Telecommunications (DECT).

The present document presents a study of a new radio interface named DECT-2020. DECT-2020 is a state of the art radio interface based on OFDM with options for MIMO and is intended as long-term evolution of DECT technology.

The present document is focused on the Physical layer.

Modal verbs terminology

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Introduction

The current DECT radio interface was designed in the early 1990's and is based on TDMA/TDD with Gaussian Frequency Shift Keying (GFSK) modulation. Although this interface is able to provide a cost-effective solution for cordless telephony applications with an appropriate reuse of the spectrum, it cannot provide the high data rates and bandwidth efficiency required by most modern evolution scenarios. In addition, promising applications such as Audio-Streaming and Wireless Industrial Automation in Internet of Things (IoT) domain introduces Ultra Reliability and Low Latency requirements that have to be taken into account in any technology evolution.

IMT-2000 is the term used by the International Telecommunications Union (ITU) for a set of globally harmonised standards for third generation (3G) mobile telecoms services and equipment. 3G services are designed to offer broadband cellular access at speeds of 2Mbps, which will allow mobile multimedia services to become possible.

DECT is, and will continue to be, one of the IMT-2000 technologies. However, the ITU work continued, first with IMT-Advanced, and it is now going further with IMT-2020. The term IMT-2020 was coined in 2012 by the ITU and means International Mobile Telecommunication system with a target date set for 2020, with the intention of addressing fifth generation (5G) mobile telecoms services and equipment.

The ETSI DECT Technical Committee and the industry body DECT Forum are currently supporting activities to develop DECT to meet the IMT-2020 requirements. This will require major changes to the existing DECT standards, and specifically to the MAC and PHL layers.

For the purpose of the present document the terms "DECT-2020", "DECT-2020 New Radio", "DECT-2020 NR" or "PHL-2020" have all the same meaning and all of them refer to the new radio interface based on OFDM outlined in the present document. This new radio interface is targeted to meet the IMT-2020 requirements.

The terms FP-2020 or PP-2020 refer to FP and PP (respectively) devices supporting DECT-2020.

The present document is motivated by recent efforts to identify new ways of utilizing efficiently DECT frequency bands and potentially additional bands. New modes of operation are defined to target a more diverse set of use cases, while addressing 5G requirements for low latency, high spectral efficiency and large numbers of client nodes.

1 Scope

The present document aims on studying "DECT-2020: New Radio", a new radio interface based on state of the art paradigms able to offer the required data rates, propagation characteristics and spectrum efficiency, while maintaining compatibility with the carrier and time structure of the DECT band.

The present document is focused on the Physical layer.

DECT-2020, as defined by the present document, will be based on OFDM and may support space multiplexing (MIMO).

The study focuses on:

1) Review of use cases and key application areas for DECT-2020.
2) Identification of methodology, initial sources, simulation tools and models.
3) Initial definition of "DECT-2020: New Radio" PHY layer, providing guidance for a following technical specification.
4) Preliminary simulation results and preliminary study on spatial multiplexing (MIMO).

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 300 175-1: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 1: Overview".

[i.2] ETSI EN 300 175-2: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 2: Physical Layer (PHL)".

[i.3] ETSI EN 300 175-3: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 3: Medium Access Control (MAC) layer".

[i.4] ETSI EN 300 175-4: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 4: Data Link Control (DLC) layer".

[i.5] ETSI EN 300 175-5: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 5: Network (NWK) layer".

[i.6] ETSI EN 300 175-6: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 6: Identities and addressing".

[i.7] ETSI EN 300 175-7: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 7: Security features".

[i.8] ETSI EN 300 175-8: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 8: Speech and audio coding and transmission".

[i.9] ETSI TS 102 939-1: "Digital Enhanced Cordless Telecommunications (DECT); Ultra Low Energy (ULE); Machine to Machine Communications; Part 1: Home Automation Network (phase 1)".

[i.10] ETSI TS 102 939-2: "Digital Enhanced Cordless Telecommunications (DECT); Ultra Low Energy (ULE); Machine to Machine Communications; Part 2: Home Automation Network (phase 2)".

[i.11] Draft new Report ITU-R M.[IMT-2020.TECH PERF REQ].

[i.12] ETSI TR 103 515: "Digital Enhanced Cordless Telecommunications (DECT); Study on URLLC use cases of vertical industries for DECT evolution and DECT-2020".

[i.13] 3GPP TR 22.804 (V1.0.0) (2017-12): "Study on Communication for Automation in Vertical Domains (Release 15)".

[i.14] ITU Radiocommunication Study Groups; Working Party 5D; draft new Report ITU-R M.[IMT-2020.EVAL]: "Guidelines for evaluation of radio interface technologies for IMT-2020".

[i.15] ITU Radiocommunication Study Groups; Working Party 5D; Attachment 7.4 to Document 5D/758; Liaison Statement to External Organizations; Further information related to draft new Report for IMT-2020 evaluation.

[i.16] Guidelines for evaluation of radio interface technologies for IMT-2020, ITU, Revision 2 to Document 5D/TEMP/347-E, 20 June 2017.

[i.17] IEEE Transactions on Communications: "Robust Frequency and Timing Synchronization for OFDM"; Timothy M. Schmidl and Donald C. Cox,, Vol. 45, No. 12, December 1997, pp 1613-1621.

[i.18] ETSI TS 136 211 (V10.7.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 10.7.0 Release 10)".

[i.19] 3GPP TS 38.211 (V1.0.0) (2017-09): "NR; Physical channels and modulation".

[i.20] IEEE P802.11ah™/D10.0, Part 11: "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 2: Sub 1 GHz License Exempt Operation", September 2016.

[i.21] IEEE Std 802.11ac™-2013, Part 11: "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz".

[i.22] IEEE P802.11ax™/D1.4, Part 11: "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 6: Enhancements for High Efficiency WLAN", August 2017.

[i.23] IEEE 802.11-03™/940r4: "TGn Channel Models", May 2004.

[i.24] ETSI TS 136 212 (V10.9.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding (3GPP TS 36.212 version 10.9.0 Release 10)".

[i.25] 3GPP TS 38.212 (V1.0.0) (2017-09): "NR; Multiplexing and channel coding".

[i.26] IEEE 802.15-04-0585-00-004b: "Multipath Simulation Models for Sub-GHz PHY Evaluation", October 2004.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in ETSI EN 300 175-1 [i.1] and the following apply:

beacon bearer packet types: packet formats intended for use in beacon bearers and C/L downlink bearers

NOTE: They include synchronization fields and do not need to support MIMO.

DFT bandwidth (MHz): maximum theoretical bandwidth that can be handled by the DFT in a given configuration

"HE" packet types: packet formats intended for continuous data transmission over several frames

NOTE: They may support circuit-mode traffic, URLLC traffic as well as packet mode traffic, and may implement MIMO.

"Legacy" DECT: current DECT technology as defined by ETSI EN 300 175 parts 1 [i.1] to 8 [i.8]

occupied bandwidth (MHz): bandwidth really occupied by a given configuration

NOTE: It is typically less than the DFT bandwidth due to the insertion of null sub-carriers at bandwidth edges.

RAC packet types: packet types formats intended for use in Random Access Channels (RAC)

NOTE: They may be used for initially accessing a channel, carry only C-plane traffic, and do not need to support MIMO.

"Standard" packet types: packets intended for IP data packet-mode transmissions

NOTE: They are self-detectable packets usable in either synchronous or asynchronous way and may implement MIMO. The design of these packets is closer to the designs used in other WLAN technologies.

ULE packet types: packet formats intended for use in ULE (Ultra Low Energy) packet data transmissions

NOTE: They may be used for initially accessing a channel, are able to carry both U-plane and C-plane traffic, and do not need to support MIMO.

Ultra-Low Energy (ULE): ultra-low power consumption packet data technology based on DECT intended for M2M communications and defined by ETSI TS 102 939 parts 1 [i.9] and 2 [i.10]

3.2 Symbols

For the purposes of the present document, the following symbols apply:

N_{BPSC}	Number of Bits Per SubCarrier
N_{CBPS}	Number of Coded Bits Per Symbol
N_{CTF}	Number of channel training symbols
N_{DBPS}	Number of data bits per symbol
N_{DC}	Number of null subcarriers at or surrounding DC
N_{DFT}	Discrete Fourier transform size
N_{SD}	Number of data subcarriers per OFDM symbol
$N_{SERVICE}$	Number of bits in the SERVICE subfield of the Data field
N_{SN}	Number of null subcarriers
N_{SP}	Number of pilot subcarriers per OFDM symbol
N_{SR}	Highest data subcarrier index per OFDM symbol
N_{SS}	Number of Spatial Streams
N_{ST}	Total number of used subcarriers per OFDM symbol,
N_{SYM}	Number of data SYMbols
N_{TAIL}	Number of TAIL bits for BCC encoder
RX	Receiver
T_{CTF}	Channel Training Field Time

T_{DFT}	DFT period
T_{FRAME}	Frame Time
T_{GT}	Guard field Time
T_{HF}	Header Field Time
T_{HFS}	Short Header Field Time
T_{SLOT}	Slot Time
T_{STF}	Synchronization Training Field Time
T_{STFS}	Short Synchronization Training Field Time
T_{SYM}	Symbol Time
TX	Transmitter
W_{BC}	Basic Channel Bandwidth / Spacing

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AGC	Automatic Gain Control
ARQ	Automatic Retransmission Query
ARQ	Automatic Repeat-reQuest
AWGN	Additive White Gaussian Noise
BCC	Binary Convolutional Codes
BCN	BeaCoN bearer
BPSK	Binary Phase Shift Keying
BS	Base Station (a.k.a FP, AP)
BW	BandWidth
BW_{DFT}	BandWidth DFT
BWO	BandWidth Occupied
CFO	Carrier Frequency Offset
CP	Cyclic Prefix
CTF	Channel Training Field
D	Downlink
DC	Direct Current
DECT	Digital Enhanced Cordless Telecommunications
DECT-2020	Physical Layer for DECT-2020
DECT-2020 NR	Physical Layer for DECT-2020
DF	Data Field
DFT	Discrete Fourier Transform
eMBB	enhanced Mobile BroadBand
EVM	Error Vector Magnitude
EXPP	EXponential Power Profile channel
FC	Full Carrier
FCS	Frame CheckSum
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFS	For Further Study
FP	Fixed Part (a.k.a BS, AP)
FP-2020	PP implementing DECT-2020
FS	Full Slot
GF	inter-slot Guard Field
GFSK	Gaussian Frequency Shift Keying
HARQ	Hybrid Automatic Repeat-reQuest
HC	Half Carrier
HE	High Efficiency
HF	Header Field
HS	Half Slot
iDFT	inverse Discrete Fourier Transform
IP	Internet Protocol
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union, Radiocommunication sector
LL-ULE	Low Latency-ULE
LP	Long Preamble
MAC	Medium Access Control

MCS	Modulation and Coding Scheme
MIMO	Multiple Input/Multiple Output
mMTC	massive Machine Type Communications
MRC	Maximal Ratio Combining
MU	Multi-User
NR	New Radio

NOTE: Refers to DECT-2020 radio interface as described in the present document.

OFDM	Orthogonal Frequency-Division Multiplexing
PAPR	Peak to Average Power Ratio
PDF	Probability Density Function
PER	Packet Error Rate
PHL	PHysical Layer
PHL-2020	PHysical Layer for DECT-2020
PHY	PHYsical
PMSE	Programme-Making and Special Events
PP	Portable Part (a.k.a UE)
PP-2020	PP implementing DECT-2020
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
R	code Rate
RAC	Random Access Channel
RIT	Radio Interface Technology
RMS	Root Mean Square
RPF	Reference Pilot Field
RRM	Radio Resource Management
SFM	Shadow Fading Margin
SISO	Single Input / Single Output
SNR	Signal to Noise Ratio
STF	Synchronization Training Field
SU	Single User
TCP	Cyclic Prefix Time
TDMA	Time Division Multiple Access
TFM	Time/Frequency Map
U	Uplink
UE	User Equipment (a.k.a PP)
ULE	Ultra-Low Energy
UR	Ultra-Reliable
URLLC	Ultra-Reliable and Low Latency Communications
WLAN	Wireless LAN

4 Introduction to DECT-2020 Use Cases and their Requirements

4.1 Introduction

A separate study on DECT evolution and DECT-2020 use cases and requirements has been conducted and published as ETSI TR 103 515 [i.12]. According to ETSI TR 103 515 [i.12], the following three major application areas have been identified as target for DECT-2020 radio technologies. These are:

- Home and Building Automation, including Smart Living.
- Industry automation - Factories of the Future, Industry 4.0.
- Media and entertainment industry - Programme Making and Special Events (PMSE).

Nevertheless, DECT-2020 application areas will not be restricted to these three major domains and additional applications and use cases may be supported. In particular, any Machine Type Communication, including massive M2M are considered candidate areas for the technology.

4.2 Summary of Use Cases and Requirements

ETSI TR 103 515 [i.12] has identified a set of Use Cases candidate for implementation using DECT-2020. Most of the identified use cases have Low Latency or Ultra Reliability requirements and therefore are part of the URLLC definition as given by ITU-R [i.14], [i.15] and [i.16]. ETSI TR 103 515 [i.12] is consistent with and reuses material from a contemporary TR published by 3GPP as TR 22.804 (V1.0.0) [i.13].

Table 1 summarizes the work done by ETSI TR 103 515 [i.12].

Table 1: Classification of the use cases regarding Reliability and Latency and feasibility for DECT implementation

Clause (s) of ETSI TR 103 515 [i.12]	**Use Case**	**DECT feasibility**		**Possible Implementation path**		**URLLC classification**			
		By range	*By license regimen*	*DECT-2020*	*DECT evolution*	*UR*	*LL*	*Synchronicity*	*Other requirements*
				Home and building automation					
5.2.2	Environmental monitoring	Y	Y	Y	Y	Y	N	N	
5.2.3	Fire detection	Y	Y	Y	Y	Y	< 10 ms	N	
5.2.4	Feedback control	Y	Y	Y	Y	Y	< 10 ms	maybe (1 ms jitter)	
				Industry Automation - Factories of the Future					
5.3.2	Motion control	Y	Y	Y	w/ restrictions	Y + ($1 - 10^{-8}$)	Y + (0,5 ms)	Y (1 µs)	
5.3.3	Motion control - transmission of non-real-time data	Y	Y	Y	Y	N	N	N	
5.3.4	Motion control - seamless integration with Industrial Ethernet	Y	Y	Requires further study	Requires further study				
5.3.5	Control-to-control communication (motion subsystems)	Y	Y	Y	w/ Restrictions	Y + ($1 - 10^{-8}$)	Y (4 ms cyclic)	Y (1 µs)	
5.3.6	Mobile control panels with safety functions	Y	Y	Requires further study	Requires further study				
5.3.7	Mobile robots	Y	Y	Probably, but requires further study	N	Y	Y	probably	
5.3.8	Massive wireless sensor networks	Y	Y	Probably, but requires further study	Requires further study	Y + ($1 - 10^{-8}$)	10 ms	N	High bit rate Low power operation required (see clause 5.3.8 for details)

Clause (s) of ETSI TR 103 515 [i.12]	Use Case	DECT feasibility		Possible Implementation path		URLLC classification			
		By range	*By license regimen*	*DECT-2020*	*DECT evolution*	*UR*	*LL*	*Synchronicity*	*Other requirements*
5.3.9	Remote access and maintenance	Y	Y	Y	Y	N/A	N/A	N/A	backward compatibility for > 25 years (see clause 5.3.9 for details)
5.3.10	Augmented reality	Y	Y	Y	N	N	10 ms	N	High bit rate required (see clause 5.3.10 for details)
5.3.11	Process automation - closed-loop control	Y	Y	Y	w/ restrictions	Y + (1 - 10^{-8})	10 ms cyclic	Y	
5.3.12	Process automation - process monitoring	Y	Y	Y	Y	N	N	N	High user equipment density (see clause 5.3.12 for details)
5.3.13	Process automation - plant asset management	Y	Y	Y	Y	N	N	N	High user equipment density (see clause 5.3.13 for details)
5.3.14	Connectivity for the factory floor	Y	Y	Y	Y	N/A	N/A	N/A	
5.3.15	Inbound logistics for manufacturing	Y	Y	Y	Y	N/A	N/A	N/A	
5.3.16	Variable message reliability	Y	Y	Y	Y	N/A	N/A	N/A	
5.3.17	Flexible, modular assembly area	Y	Y	Requires further study	Requires further study				
5.3.18	Plug and produce for field devices	Y	Y	Requires further study	Requires further study				
5.3.19	Private-public interaction	Y	Y	Y	Y	N/A	N/A	N/A	
Use cases for Smart Living - Health Care									
5.4.2	Telecare data traffic between home and remote monitoring centre	Indoor only	Indoor only	Y	Y	N	N	N	
Use cases for Programme Making and Special Events (PMSE)									
5.5.2	Low-latency audio streaming for live performance	Y	Y	Y	w/ restrictions	Y	Y	Y	
5.5.3	Low-latency audio streaming for local conference systems	Y	Y	Y	Y	Y	< 4 ms	Y	
5.5.4	High data rate video streaming / professional video production	Y	Y	Y	N	Y	< 4 ms	Y	Very high data rates (see clause 5.5.4 for details)
Y YES Y+ YES and goes beyond ITU-R requirement									

Clause (s) of ETSI TR 103 515 [i.12]	**Use Case**	**DECT feasibility**		**Possible Implementation path**		**URLLC classification**			
		By range	*By license regimen*	*DECT-2020*	*DECT evolution*	*UR*	*LL*	*Synchronicity*	*Other requirements*
NOTE All clause numbers in this table refer to corresponding clauses in ETSI TR 103 515 [i.12].									

4.3 Other Design Targets for DECT-2020

In addition to the use cases related to URLLC identified by ETSI TR 103 515 [i.12], the support of efficient transmission of IP data and the support of voice communications are also considered basic requirements.

Regarding bandwidth efficiency, the technology should be efficient as any other state of the art (5G) radio technology.

Regarding radio propagation characteristics, the new technology should provide an advantage over existing DECT that may be used to either, extend the cell range or decrease the power.

It should be assumed that the maximum transmission power will be the same as DECT (250 mW). In case of using space multiplexing, this power will be split between the different antennas.

5 Methodology, initial sources, simulation tools and models

5.1 Initial sources

Different OFDM 5G or pre-5G technologies have been studied and have had an influence in the design of DECT-2020. In particular, the following technologies should be noted:

- IEEE 802.11ah [i.20].
- LTE (4G) [i.18] and [i.24].
- LTE NR (new radio) [i.19] and [i.25].

Other technologies leveraged in DECT-2020 development have been the following:

- IEEE 802.11ac [i.21].
- IEEE 802.11ax [i.22].

Nevertheless, DECT-2020 is an original technology with its own design choices, OFDM parameters, overall concepts and PHY layer architecture.

5.2 Simulation tools

A simulation environment combining MATLAB and C++ code has been developed and has been used for assessing important performance metrics concerning detection, synchronization, channel estimation and forward error correction. This is done under various types of channel impairments.

5.3 Channel Models

The radio channel has been modelled primarily by Additive White Gaussian Noise (AWGN) model and Exponential Power Profile model, for both SISO and MIMO configurations. These models are very commonly used in the literature.

The current simulation environment contains an implementation of IEEE 802.11-03 [i.23]. These models include support for channel variation over time caused by motion and fluorescent lighting, and will be used in the future for simulations of complex in-door scenarios.

Suitable out-door models are still being studied.

5.4 Channel measurements

No specific channel measurements have been done by this STF. However, information from external sources has been used where applicable. The following sources have been used:

- IEEE 802.11-03 "TGn" channel models [i.23].
- IEEE 802.15-04 "Multipath Simulation Models for Sub-GHz PHY Evaluation" [i.26].
- Guidelines for evaluation of radio interface technologies for IMT-2020, ITU, Revision 2 [i.16].

6 Initial definition of DECT-2020: New Radio (NR)

6.1 Introduction

The new radio interface based on state of the art paradigms able to offer the required data rates, propagation characteristics and spectrum efficiency, necessary for the IMT-2020 use-cases and DECT-2020 use-cases, while maintaining compatibility with the carrier and time structure of the DECT band.

IMT-2020 defines 3 usage scenarios:

- Enhanced Mobile Broadband (eMBB).
- Massive Machine-Type Communications (mMTC).
- Ultra-Reliable Low Latency Communications (URLLC).

IMT-2020 defines 13 technical performance requirements for these usage scenarios (see [i.11]):

- Peak data rate.
- Peak spectral efficiency.
- User experienced data rate.
- 5th percentile user spectral efficiency.
- Average spectral efficiency.
- Area traffic capacity.
- Latency:
  - User plane latency.
  - Control plane latency.
- Connection density.
- Energy efficiency.
- Reliability.
- Mobility.
- Mobility interruption time.
- Bandwidth.

In addition to the IMT-2020 requirements, the following general requirements are also design goals:

- Improved range compared to legacy DECT.

- Improved voice quality compared to legacy DECT.
- Improved data rates compared to legacy DECT.
- Improved number of simultaneous connections compared to legacy DECT.
- DECT-2020 should be able to coexist in the same area with legacy DECT systems operating over the same spectrum and should implement the proper channel selection rules to mitigate any interference to/from legacy DECT systems.
- It should be possible the implementation of compatible devices, either FP or PP, implementing both, DECT-2020 and legacy DECT, radio interfaces.

DECT-2020 devices need to coexist with legacy devices. Specifically, the operation of a DECT-2020 device should not interfere with, or significantly degrade the performance of nearby legacy DECT systems. Likewise, the design of DECT-2020 should ensure that legacy DECT systems will not interfere with nearby DECT-2020 systems, or reduce its performance beyond the unavoidable limitation by the available spectrum.

6.2 Design Choices

A primary assumption from earlier work and a review of other technologies (WiFi, LTE, etc.), is that the PHL should be based on OFDM. However, there are a number of other assumptions and design choices to be considered:

- Basic radio technology is OFDM and channel access is TDMA/FDMA based.
- DECT basic frame time of 10 ms:
    - This is the same as legacy DECT.
    - Basic frame split into 24 time-slots (i.e. same number of slots as legacy DECT).
    - Time-slots can be aggregated (e.g. double slots, quadruple slots, etc.).
    - Half-slots for some packet types are also supported.
- DECT basic channel width of 1,728 MHz:
    - This is the same as legacy DECT.
    - Multiple contiguous channels can be aggregated (i.e. bonded).
- Data rates require higher order modulation (up to 1024-QAM).
- Improved reliability requires protection by FEC and CRCs, with ARQ mechanism (i.e. HARQ).
- Use of MIMO for better data rates, increased reliability and efficiency.
- State of the art security (encryption).

6.3 Technical Proposal for DECT-2020 NR Physical (PHY) layer

6.3.1 Back-compatibility considerations

For the purpose of the present document, it will be assumed that the new DECT-2020 radio interface will be able to operate:

- Over the existing DECT 1 880 MHz to 1 900 MHz spectrum.
- Over other bands, adjacent or non-adjacent with the DECT band.
- Over a combination of both.

When operating over the DECT band, the design of the new technology should take into account the operation of existing DECT devices, and should be able to implement a fair an efficient sharing of the spectrum using adaptive radio, spectrum sensing paradigms.

Due to the requirement of efficient sharing of the spectrum with legacy DECT, DECT-2020 will use the same basic carrier and spectrum structure. The elementary carrier is defined as 1,728 MHz and the elementary slot is defined as 1/24 of a 10 ms frame. However, DECT-2020 foresees the use of both half-carriers (0,864 MHz) and half-slots (1/48 of a 10 ms frame).

Supported data rates range from 120 kbps to 187,2 Mbps with single input, single output (SISO) transmission, and up to 1,1232 Gbps with multiple input, multiple output (MIMO) configuration.

The chosen value of the sub-carrier spacing is Δ_F = 27 kHz. Frame time is T_{FRAME} = 10 ms.

When co-existing with legacy DECT and/or with other nearby DECT-2020 systems, the coexistence rules cannot require that the different systems be synchronized to the same time reference. Therefore, the rules should be able to handle properly unsynchronized systems. However, as the co-existence of unsynchronized systems is believed to be less efficient than synchronized systems, MAC layer design may implement mechanisms to favour synchronization to a common clock.

In a mixed network comprising both legacy DECT and PP-2020 devices, it is foreseen that dual-mode FP devices may simultaneously maintain both legacy DECT and DECT-2020 compliant links. When both radio interfaces are implemented in the same FP device, it is assumed that both will be synchronized, including frame and slot boundaries.

High average spectral efficiency is achieved by using a combination of MIMO, beamforming and multiuser (MU) techniques. Half channel transmission (0,864 MHz) combined with strong FEC and multi-antenna FP/PP can support highly reliable connectivity at lower cost and lower power consumption on PP side.

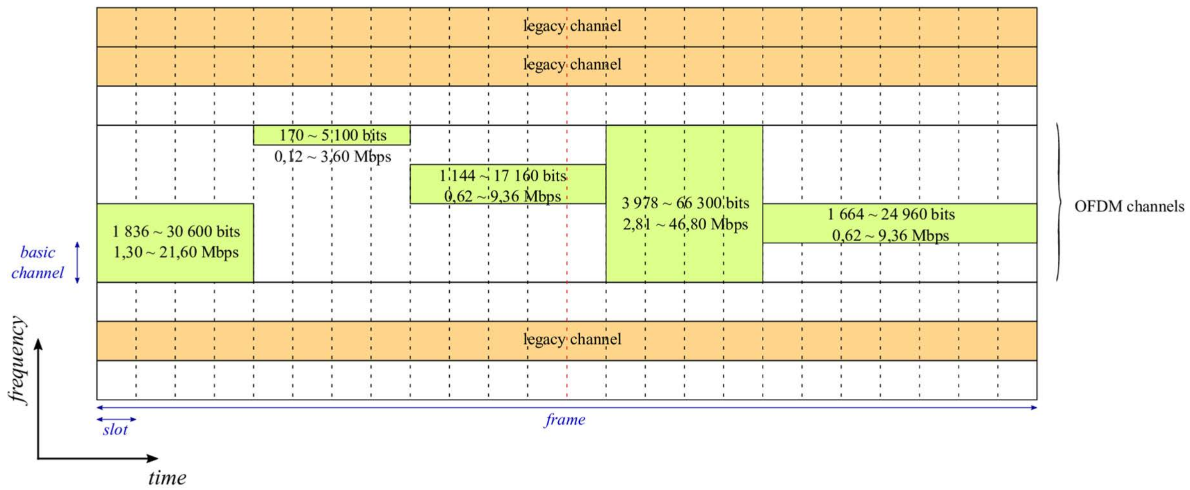

Figure 1: Example of mixed OFDM and legacy DECT coexistence

6.3.2 DECT-2020 NR Physical (PHY) layer overview

6.3.2.1 Frame Structure and Time / Frequency Allocation

DECT-2020 frame duration is T_{FRAME} = 10 ms, divided into 24 slots of fixed duration, $T_{SLOT} = T_{FRAME}/24$ = 416,7 µs. In order to support low-latency scenarios, DECT-2020 can also operate with 30 slots/frame (T_{SLOT} = 333,3 µs) or 40 slots/frame (T_{SLOT} = 250 µs) or in a frameless mode.

The FP maintains a Time/Frequency Map (TFM) for communication with PP clients. This TFM can change dynamically, based on MAC layer commands.

DECT-2020 FP and PP devices communicate using packets consisting of multiple OFDM symbols. Nominal OFDM symbol duration is $T_{SYM} = T_{SLOT}/10$ = 41,67µs. Packet duration is variable; however, packet transmissions always start on a slot boundary. All FP ↔ PP communication should follow the current TFM, except for certain slots specifically allocated for contention-based access.

A DECT-2020 FP device can initiate packet transmission on a half or single channel, or a combination of channels, to a single PP or to multiple PP devices. Independent transmission to multiple PP devices is optional, but encouraged. Support for FP→PP broadcast transmissions on contiguous channels is mandatory.

DECT-2020 FPs can receive packets on a half or single channel or a combination of channels, from a single PP or from multiple PP devices. Independent reception from multiple PP devices is optional, but encouraged.

Transitions from transmit mode to receive mode and from receive mode to transmit mode are separated by a nominal guard time interval $T_{GT} = T_{SYM}$ from the end of a packet to the beginning of the subsequent slot.

A DECT-2020 PP device can initiate packet transmission on a half or single channel or a number of contiguous channels. DECT-2020 PPs can receive packets on a half or single channel or a number of contiguous channels. DECT-2020 PPs support for transitions between transmit and receive modes within T_{SLOT} is mandatory. DECT-2020 PPs targeting low-latency applications should support transitions between transmit and receive modes within T_{SYM}.

Simultaneous transmit and receive operation over the same time interval is not supported in DECT-2020 due to the practical impossibility of implementing the required diplexer filter.

Figure 2 shows a basic communication link, limited to a single transaction at any given time.

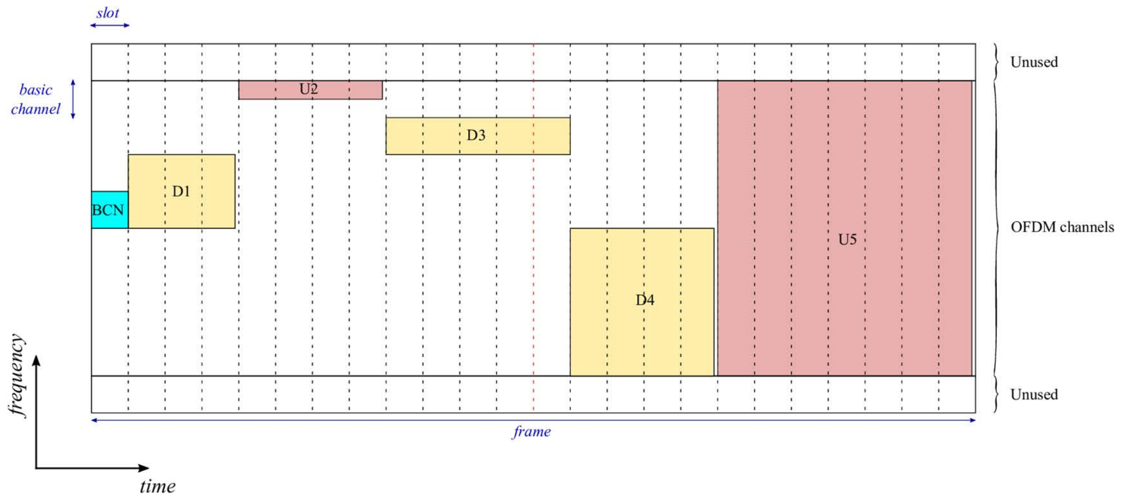

Figure 2: TFM with single communication link

An example of a FP supporting up to two simultaneous transactions is shown in Figure 3. This example also shows broadcast transmission and beacon transmission, repeated over multiple channels, and half channels.

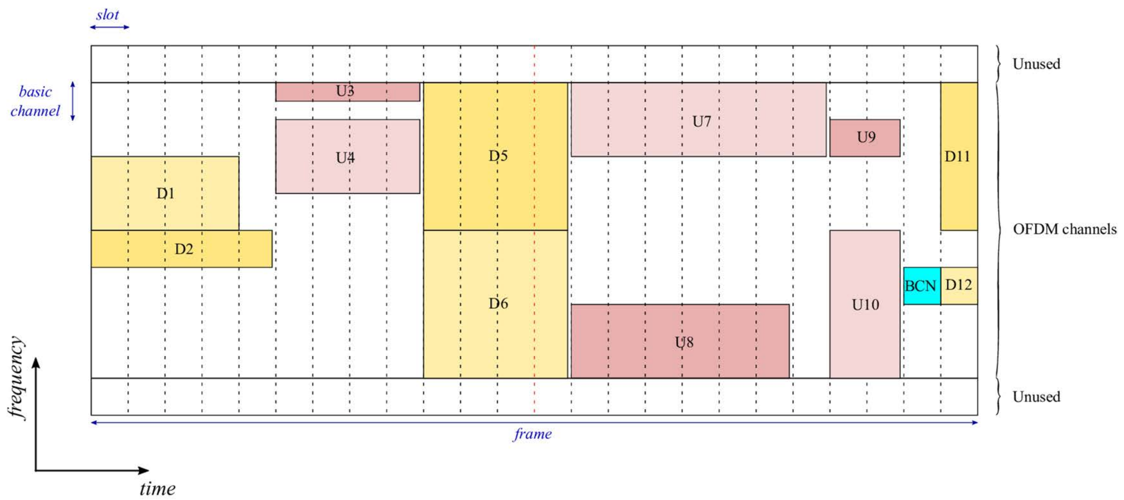

Figure 3: TFM with multiple communication links

The next example on Figure 4 illustrates a more complex TFM, where the FP device is capable of supporting up to five simultaneous links. This configuration includes four symmetric low-latency links, three of which of up to 12,94 Mbps each, and one of up to 6,22 Mbps. In addition, there are five low-speed links (up to 155 kbps each).

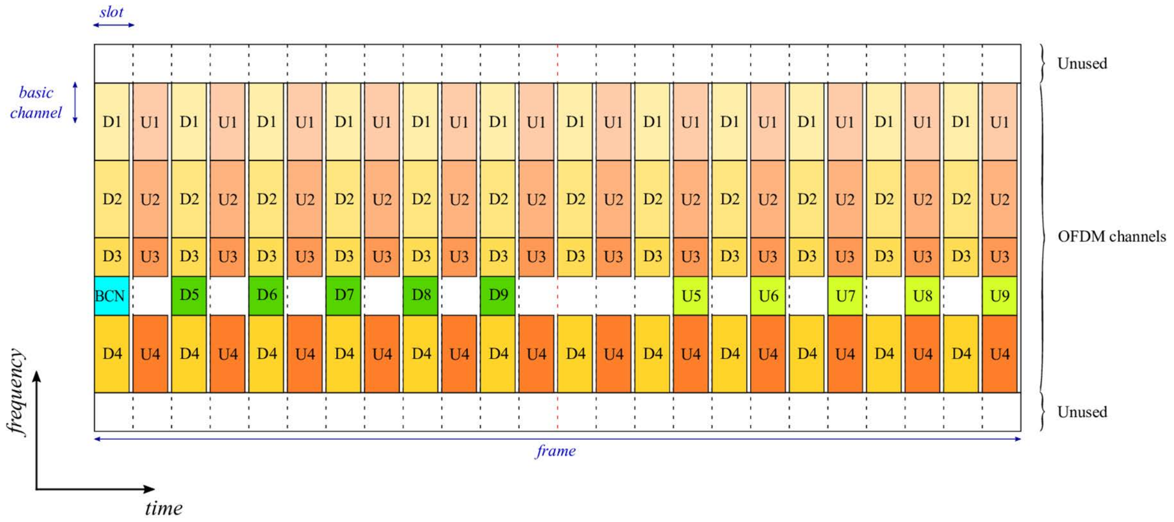

Figure 4: TFM with multiple low-latency communication links

Figure 5 illustrates the mixing of standard packet types and high-efficiency packet types.

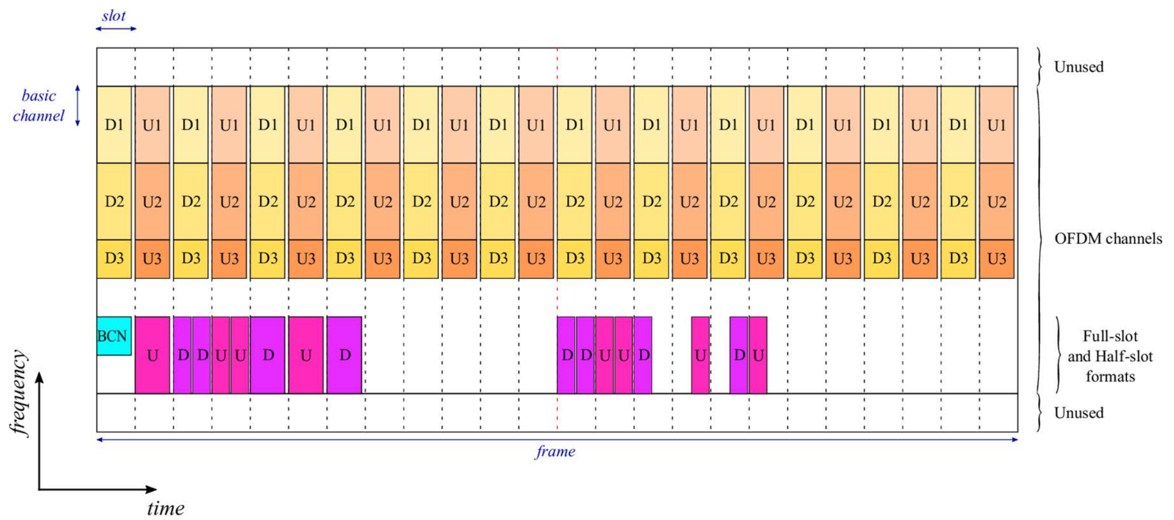

Figure 5: TFM mixing standard and HE packet types

6.3.2.2 PHL Packet Formats

6.3.2.2.1 Standard Packet Types

Two standard packet types are defined for both downlink and uplink SU transmissions. Figure 6 shows the long preamble packet type, which is used to initiate a downlink/uplink transmission. A packet with long preamble may be followed by one or more packets with short preamble (Figure 7). Packet fields are defined in table 2.

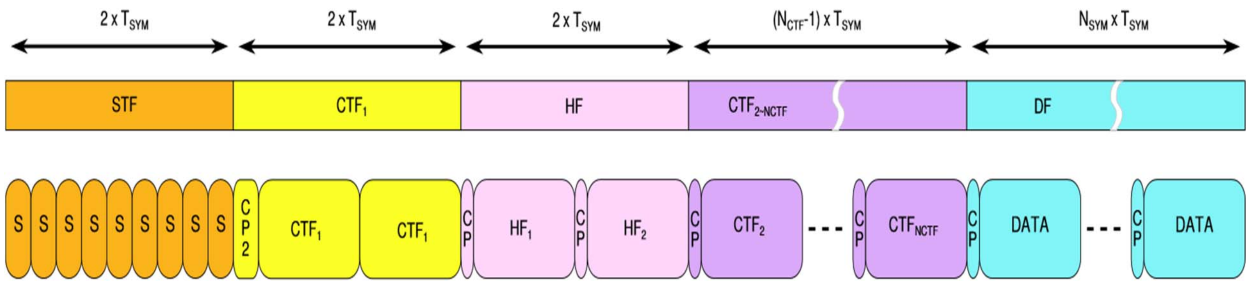

Figure 6: Long preamble packet type

Table 2: Packet fields.

Field	Description
STF	Synchronization training field. Used to perform detection, AGC, coarse CFO estimation and frame synchronization.
CTF_1	First channel training field. Used to perform fine CFO estimation, frame synchronization and initial channel estimation. In long format packets, CTF1 is assumed to be transmitted duplicated in two symbols to allow fast synchronization (see [i.17]). This is believed not to be necessary in short packet format.
HF/HFS	Header field. Contains parameters used in packet construction. It may also carry some MAC control information. This field is transmitted with a very robust MCS. In long format it is tentatively assumed to need two symbols. In short format HFS means that it is assumed to fit into a single symbol
$CTF_{2, \ldots, N_{CTF}}$	Second channel training field. Present only if: $N_{CTF} > 1$. Used to complete MIMO channel estimation.
DF	Data field. Contains the service payload.

Short preamble packet types are used in discontinuous transmission, a mode employed when a sufficiently long sequence of contiguous slots is not available. A sequence of short preamble packets should not cross frame boundaries. Note that the synchronization training field of a short preamble packet has duration that is slightly longer than T_{SYM}. This is compensated by reducing guard time to $(8/9 \times T_{SYM})$ for short preamble packets.

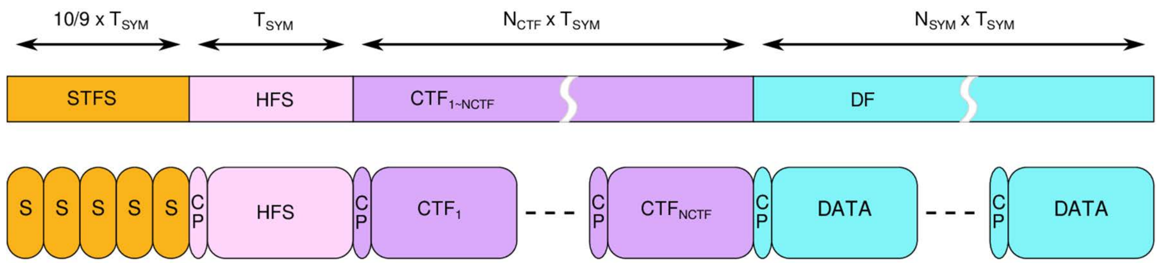

Figure 7: Short preamble packet type

Short preamble packet types can also be used under favourable channel conditions, where short preamble is sufficient for tracking slow channel and phase variations.

6.3.2.2.2 High-Efficiency (HE) Packet Types

6.3.2.2.2.1 General

These packet types enable more efficient communication for certain scenarios where continuous operation over several frames using the same slot (or slots) and carrier(s) happens. This applies to most cases of circuit mode communications, including Low Latency Communications.

Packet formats for Full (FS) and Half slots (HS) have been created, all of them have the basic structure shown in figures 8 and 9, HE packets comprise a single reference symbol followed by either 9 or 4 max data symbols. Finally, a guard field (GF) follows the last data symbol. In case of small payloads, the number of data symbols may be reduced accordingly.

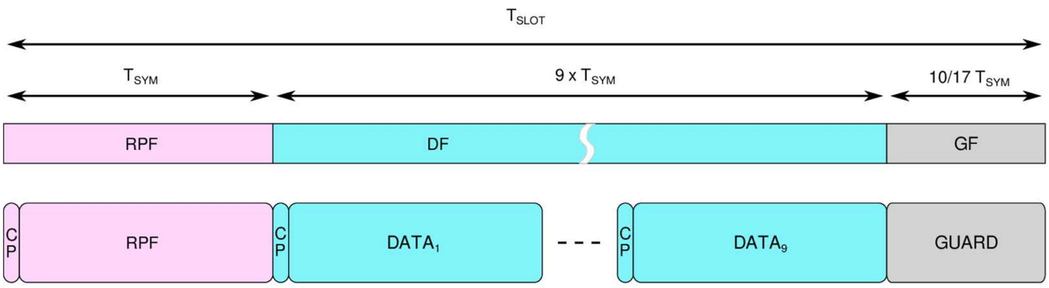

Figure 8: Full-slot HE packet type

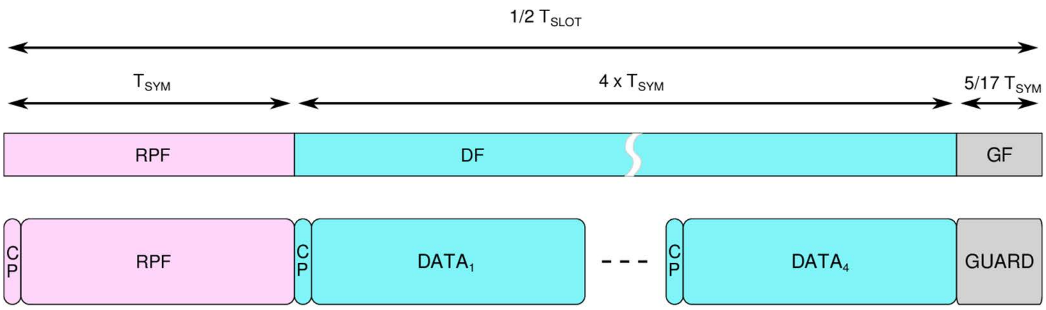

Figure 9: Half-slot HE packet type

Table 3: Packet fields

Field	Description
RPF	Reference Pilot Field. Used for channel training, fine CFO estimation, frame synchronization and initial channel estimation.
DF	Data field. Contains U-plane data and may contain several MAC control channels multiplexed at MAC layer.
GF	Inter-slot guard interval.

6.3.2.2.2.2 HE full slot packet types

Several variants of full slot HE packets have been proposed and analysed. They are listed in the table 4.

Not all variants are expected to be implemented. A choice of final types has to be done in later stages.

Table 4: Full-slot HE packet variants

Variant	Total symbols	Data symbols	Min BW	Pilot CP		Data CP		Inter-slot guard time (GF)		Notes
			(MHz)	(μs)	units	(μs)	units	(μs)	units	
1	10	9	3,456	2,3	4	2,3	4	23,1	40	1, 6
2	10	9	3,456	9,3	16	2,3	4	16,2	28	6
3	9	8	1,728	18,5	32	4,6	8	27,8	48	6
4	10	9	1,728	4,6	8	4,6	8	0	0	2, 3, 6
5	8	7	1,728	37,0	64	9,3	16	18,5	32	6
6	9	8	1,728	9,3	16	9,3	16	0	0	2, 3, 6
A1	10	9	1,728	4,6	8	3,5	6	10,4	18	6
A2	9	8	1,728	18,5	32	4,6	8	27,8	48	6
A2a	10	9	1,728	4,6	8	4,6	8	0	0	2, 3, 5, 6
A3	9	7	1,728	6,9	12	6,9	12	20,8	36	4, 6, 7

NOTE 1: This type is listed since it was the first HE type proposed. Based on later studies, it may probably be removed and replaced by types 2 or A1 in all cases.
NOTE 2: These types are designed for multi-slot transmissions using a burst of consecutive slots over the same carrier.
NOTE 3: When transmitting over multiple consecutive slots, it is assumed that a Reference Symbol (RPF) has to be inserted in each slot, however this is subject to further investigation and optimization in later stages.
NOTE 4: This type shares the data symbol CP with types B A1, B A2 and BA3 proposed for beacon and Random Access Channel (RAC) bearers. See clause 6.3.2.2.4.
NOTE 5: This type will start and will end 27,8 µs before the time reference This ensures continuation with a previous type 2 or 2A slot and also a Guard interval of 27,8 µs at the end.
NOTE 6: Times are also given in "units". Each unit equals to 0,5787037 µs, which corresponds to 1 sample at 1,728 MHz or two samples at 3,456 MHz. Durations in "units" are exact values while the figures in µs have been rounded to the closest decimal.
NOTE 7: In this configuration the reference symbol (RPF) is duplicated over the two first symbol intervals. Therefore 7 data symbols can be transmitted.

6.3.2.2.2.3 HE half-slot packet types

For half-slots, only one variant has been proposed with the parameters shown in table 5.

Table 5: Half-slot HE packet variants

Variant	Total symbols	Data symbols	Min BW	Pilot CP		Data CP		Inter-slot guard time (GF)		Notes
			(MHz)	(μs)	units	(μs)	units	(μs)	units	
HS1	5	4	3,456	2,3	4	2,3	4	11,6	20	See note

NOTE: Times are also given in "units". Each unit equals to 0,5787037 µs, which corresponds to 1 sample at 1,728 MHz or two samples at 3,456 MHz. Durations in "units" are exact values while the figures in µs have been rounded to the closest decimal.

6.3.2.2.2.4 Single carrier operation of packet types with CP = 2,3 μs

During investigation and simulation of the packet types with 2,3 µs CP (types 1, 2 and HE1) a potential issue has been identified concerning the implementation of such packet types over single carrier channels (BW = 1,728 MHz): due to the reduced number of samples of the CP at nominal sampling rates, the correct pulse shaping and filtering may be difficult. This is an implementation issue and ideas to overcome it have been suggested (oversampling the signal before filtering). Nevertheless, as no final conclusion has been made, this study will list 3,456 MHz (two carriers) as the minimum bandwidth for HE types 1, 2 and HS1 packets.

6.3.2.2.3 Packet Types for beacon and C/L downlink bearers

The need and use of a beacon C/L downlink bearer is a working assumption based on legacy DECT design and compatibility. This would need to be confirmed in the MAC design phase. Several structures and variants have been proposed and analysed for these packets. The format named B 1 shown in Figure 10 has been selected as primary option. No MIMO is assumed to be usable on these bearers.

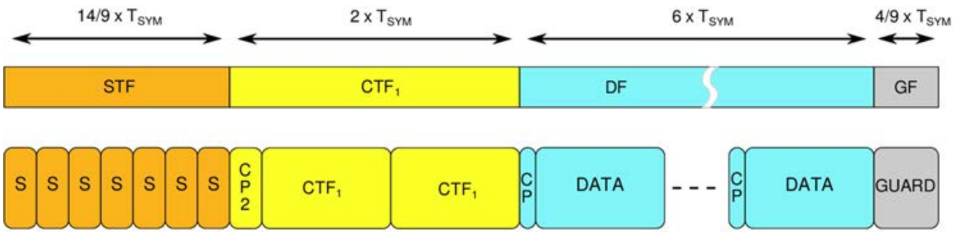

Figure 10: Beacon C/L downlink packet type

Table 6: Packet fields

Field	Description
STF	Synchronization training field. Same as in long packet format. Used to perform detection, AGC, coarse CFO estimation and frame synchronization.
CTF_1	First channel training field. Same as in long packet format Used to perform fine CFO estimation, frame synchronization and initial channel estimation. CTF is assumed to be transmitted duplicated in two symbols to allow fast synchronization (see [i.17]).
DF	Data field. Contains typically several MAC control channels. Transmitted with a very robust MCS. In ULE transmissions, at least the first data symbols are assumed to be transmitted with a very robust MCS, while a more efficient MCS may be used in the remaining symbols.
GF	Inter-slot guard interval.

To allow reception by all UEs in a cell, including those far from the base, beacon bearers are assumed to be transmitted with very robust MCS. MCS = 1 (QPSK, codec ratio ½) is proposed as working assumption.

Additional formats named B L1, B A1, B A2 and B A3 have been proposed and discussed. B L1 is directly based on the long packet format. Formats B A1, B A2 and B A3 increase the CP to 6,9 µs to allow better reception in problematic radio conditions. The increased CP may be at the expense of a reduced inter-slot guard time and/or slightly reduced STF. Format B A2 with reduced inter-slot guard is intended exclusively for beacon bearers, while format B A3 is mostly intended for RAC channels. These formats are documented in the table 7 for further consideration, if needed, however format B 1 is the primary working assumption at this stage of the work.

Table 7: Beacon bearer packet variants

Variant	Min BW	Synch. Field (STF) duration		Number of symbols		Symbol duration		Symbol Cyclic Prefix (CP) duration		Inter-slot guard time (GF)		Notes
	(MHz)	(µs)	units	Pilot (CTF)	Data	(µs)	units	(µs)	units	(µs)	units	
Primary working assumption												
B 1	1,728	64,9	112	2	6	41,7	72	4,6	8	18,5	32	1, 4
Other possible variants considered												
B L1	1,728	83,4	144	2	5	41,7	72	4,6	8	41,7	72	1, 2, 4
B A1	1,728	87,8	152	2	5	43,9	76	6,9	12	20,8	36	1, 3, 4
B A2	1,728	55,6	96	2	6	43,9	76	6,9	12	9,26	16	1, 3, 4, 6
B A3	1,728	46,3	80	2	6	43,9	76	6,9	12	18,5	32	1, 3, 4, 7
NOTE 1: In all cases, HF is embedded into the data symbols (MAC format not yet designed). NOTE 2: This format is similar to the long packet format. NOTE 3: These formats increase the CP to 6,9 µs to allow better reception in problematic radio conditions. The increased CP may be at the expense of a reduced inter-slot guard time and/or slightly reduced STF. NOTE 4: Times are also given in "units". Each unit equals to 0,5787037 µs, which corresponds to 1 sample at 1,728 MHz or two samples at 3,456 MHz. Durations in "units" are exact values while the figures in µs have been rounded to the closest decimal. NOTE 5: These formats (except type B A2) are also reused for RAC and ULE bearers (see clause 6.3.2.2.4). NOTE 6: This format is only intended for beacon bearers, due to the reduced inter-slot space. NOTE 7: This format is mostly intended for RAC and ULE bearers.												

6.3.2.2.4 Packet Types for Random Access Channels (RAC) and ULE bearers

6.3.2.2.4.1 General

The use of separate Random Access Channels (RAC) to better protect critical traffic (e.g. URLLC) has been proposed as a working idea that would need to be confirmed in the MAC design phase. The PHY layer study provides packet formats for these bearers.

The need to support ULE (Ultra Low Energy) low data rate packet format and also LL-ULE (Low latency ULE) makes necessary the creation of a packet format for ULE. After analysis, it seems that these packets share most of the issues and requirements of the RAC packets, since they are also "random access" packets. Therefore, a single format for RAC/ULE is proposed.

6.3.2.2.4.2 Common format for (RAC) and ULE bearers

The same packet types proposed for the beacon bearer are proposed to be used as RAC/ULE bearer. Typically, only one of the sub-variants listed in table 7 will be chosen.

Packet format B 1 is the primary candidate for beacon bearers. If this is finally the choice, reusing it as RAC/ULE format seems adequate.

If packet formats for beacon bearers with extended CP (6,9 µs) are finally selected (e.g. format B A2), then using the same CP in RAC/ULE channels seems a convenient option. Type B A3 may be used in this case. The reduced synchronization field is justified on the UE is already synchronized to the base when sending a RAC/ULE packet.

The long packet format without any change is one of the options (B L1), however it is questionable if the very long inter-slot space (41,7 µs) is really needed and provides any benefit. From this perspective any off the types B A1-BA3 (with increased CP) would be more effective.

The exact position of the HF field has to be decided during MAC phase design. For the time being, it is considered embedded into the data symbols. It may be assumed that it would be probably in data symbol 1.

RAC packets should be transmitted with a very conservative MCS. MCS = 1 (QPSK, codec ratio ½) has been proposed as working assumption.

A difference is proposed for the data symbols of the ULE variant (as described in clause 6.3.2.2.4.3).

6.3.2.2.4.2 RAC / long format detection problem

If any of the formats other than the B L1 (see table 7) is used and standard long packet format is also used as direct (random) access then the following problem may arise: a receiver would need to discriminate if the packet is using standard long format or the different RAC/ULE format. Several strategies have been proposed:

- Avoiding the problem by using long format as RAC /ULE format.
- Avoiding the problem by modifying the long packet format in the first frames to match identically the RAC/ULE format.
- Discrimination by means of a slightly different STF.
- Discrimination by using reception with dual expectation and the proper algorithms or clarification in the HF field.

6.3.2.2.4.3 Specific for ULE format

ULE formats are Random Access Packets that also transport U-plane data. For these packets the following strategy is proposed.

Modulation and coding of the data symbols (5 or 6) will be different:

- The first symbol or the first 2 symbols will be transmitted with a very conservative MCS (such as MCS = 1 - QPSK, codec ratio ½). These symbols will carry the MAC control information (MAC control messages plus quality reporting).
- The remaining two or three symbols that will contain U-plane ULE data, may be transmitted with a more efficient MCS, based on previous ULE transmission history.
- The design requires a proper mapping of MAC control and U-plane part to different symbols, as well as separate CRCs.
- In case of error in reception of the U-plane part, the more robustly transmitted MAC control part may be used to request retransmission and adaptation (reduction) in the MCS to be used for U-plane.

6.3.2.3 Transmitter Flow Diagram

The process of packet construction comprises a combination of steps from the list below:

1) Bit scrambling.
2) FEC encoding.
3) Interleaving.
4) Constellation mapping.
5) Pilot insertion.
6) Replication over multiple channels or half channels.
7) Space-time block encoding.
8) Spatial mapping.
9) Inverse discrete Fourier transform.
10) Cyclic prefix insertion.
11) Windowing.

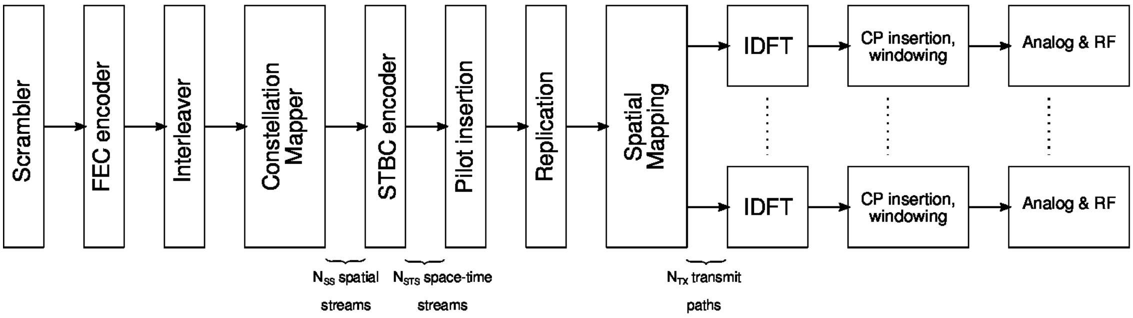

Figure 11: Conceptual transmit flow

6.3.2.4 Encoding Process

6.3.2.4.1 Modulation and Coding Scheme (MCS)

MCS is a parameter that determines the modulation and coding rate used in the construction of the DF field of the packet. This parameter is included in the long preamble packet HF field.

Rate-dependent values for full channel transmission derived from MCS, transmission bandwidth and the number of spatial streams can be found in table 22 to table 43.

Rate-dependent values for half channel transmission derived from MCS and the number of spatial streams can be found in table 16 to table 20. Note that MCS 12 is only valid for half channel transmission, $N_{SS} = 1$.

MCS index applies to all streams for a particular user. In case of MU transmission, each user can have a different MCS.

6.3.2.5 Ultra-Reliable and Low-Latency Communications

6.3.2.5.1 General

This clause discusses URLLC support. The following assumes a receiver processing delay of $2 \times T_{SYM}$.

6.3.2.5.2 Low-Latency Channel Access

6.3.2.5.2.1 General

Low-latency communication requirement stipulates Layer 1 delay of 1 ms with packet service payload of 32 bytes. Assuming single-slot long preamble packet, starting from idle state and no other traffic and assuming a processing delay on the receive side of $2 \times T_{SYM}$, a service payload delivered to Layer 1 of the transmit side can start coming out from Layer 1 of the receive side within approximately $(6 + 2)/10 \times T_{SLOT} \approx 0{,}333$ ms. Assuming $N_{SYM} = 4$ data symbols, data can be ready for layers above Layer 1 at the receiver within approximately $(6 + 4 + 2) / 10 \times T_{SLOT} = 0{,}500$ ms.

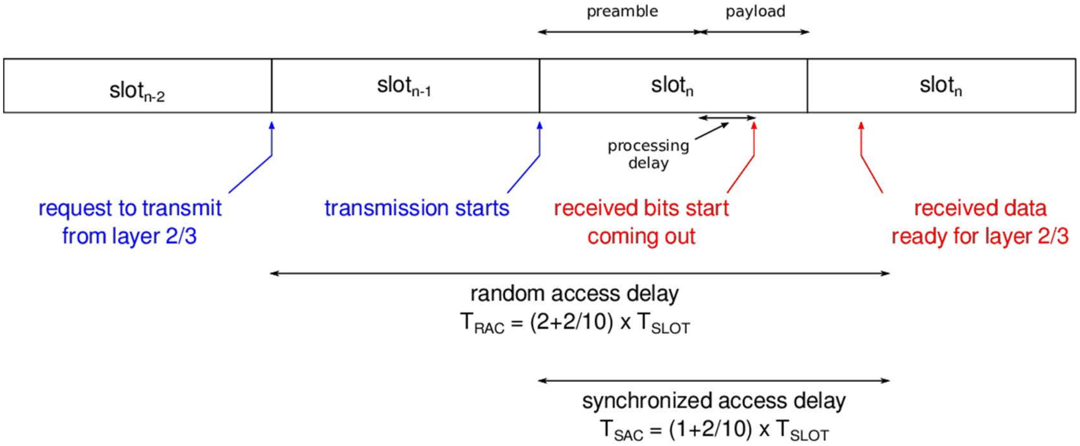

Figure 12: URLLC timing

6.3.2.5.2.2 Steady-State Low-Latency

In a steady-state regime, where upper layers are in sync with Layer 1, and alternating downlink/uplink packets are single-slot long preamble packets (see Figure 4), a delay of $(1 + (6+4+2)/10) \times T_{SLOT} \approx 0{,}917$ ms is achievable. Furthermore, by using short preamble packets or HE packets, more trade-off options are available for data rate vs. reliability.

6.3.2.5.2.3 Random Access

In order to support low-latency random access the system may be configured as follows:

- Set the number of slots / frame to 30, in which case $T_{SLOT} = 8 \times T_{SYM} = 333{,}3$ µs.
- Use short-preamble packet format.
- Select higher data rate to decrease the number of required data symbols.

Assuming the number of required data symbols to transmit a 32-byte payload is $N_{SYM} = 2$, the worst-case Layer 1 latency is $(2 + (3 + 2 + 2) / 8) \times T_{SLOT} \approx 0{,}958$ ms. $N_{SYM} = 2$ is possible with one of the following single-stream (SISO) transmission modes:

- 1,728 MHz, MCS4.
- 3,456 MHz, MCS2.
- 6,912 MHz, MCS1.
- 13,824 MHz, MCS0.

Employing MIMO transmission can further increase reliability, lower MCS requirement and decrease the number of required data field symbols. Furthermore, by using HE packets, more data rate vs. reliability trade-off choices are available.

It should be noted that the selection of higher MCS data rates is only a valid strategy if the radio conditions are known to be good. Otherwise it may cause the opposite result (due to transmission errors and/or retransmissions).

The change in the number of slots to 30 per frame has impact in back compatibility.

Other strategies that can be used for low-latency random access are the following:

- Allow the transmission of initial access packets (either RAC/ULE or standard packet formats) starting at half-slot boundaries.
- Use RAC/ULE packet types.
- Reduce the STF overhead in RAC and/or standard packet formats.

6.3.2.5.3 High-Reliability Link

Assuming downlink/uplink single-stream configuration and BCC coding, the most reliable single-slot, 32 byte payload, long preamble packet corresponds to $W = W_{BC} = 1{,}728$ MHz with MCS2 (raw data rate: 1,872 Mbps). Such packet can carry up to 37 bytes over 4 available data field symbols.

From simulation results the required SNR for 10^{-5} PER is approximately 8,6 dB (see Figure 13).

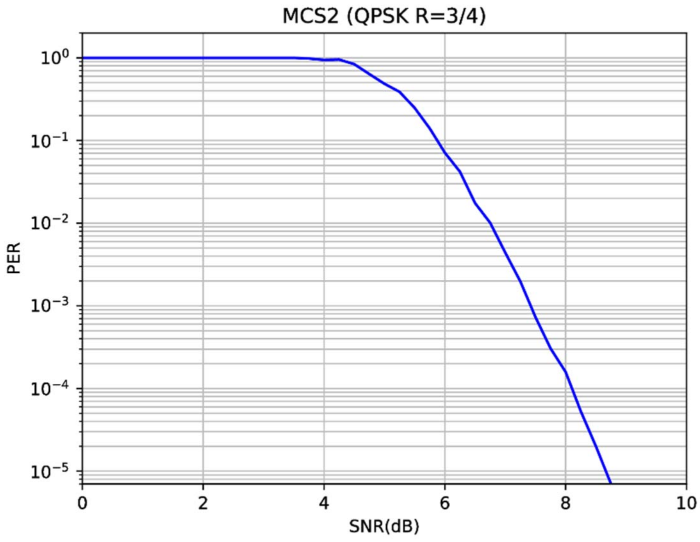

Figure 13: URLLC simulation

6.3.2.6 Basic DECT Voice Service (32 kbps) over DECT-2020

Basic DECT 32 kbps voice service requires a single full-slot packet carrying 360 bits of information over a 1,728 MHz channel. The associated A-field provides 40 additional bits for signalling (tail) logical channels.

That can be accomplished by long-preamble single-stream packets with 4 data field symbols (no guard symbol), modulated according to MCS3 (see table 22), such that each data field symbol can carry 104 bits, i.e. 416 bits would be available per slot. However, the use of the format without guard symbol is questionable since it may block the use of the next slot.

If the guard symbol is used, only 3 data symbols would be available and the system would require MCS 4 to implement the service. MCS 4 would provide 156 bits per symbol, i.e. 468 per slot.

Another possibility is to employ short-preamble single-stream packets with 6 data field symbols and one guard symbol, modulated according to MCS2 (see table 22), such that each data field symbol can carry 78 bits, i.e. 468 bits would be available per slot.

Using HE packets, the basic voice service can be implemented in a further efficient way, or with a more robust MCS. For example:

- A HE type 1, 2 of A1 packet (9 data symbols) may provide the service with MCS 1, i.e. 468 bits would be available per slot.
- A HE type 3, A2 or A3 packet (8 data symbols) may also provide the service with MCS 1, i.e. 416 bits would be available per slot.
- Potentially a HE type 3, A2 or A3 packet (8 data symbols) operating over Half Carrier channels (BW = 0,864 MHz, see table 16) may provide the service with MCS 4, i.e. 60 bits per symbol and 480 per slot would be available.
- An HE type HS1 (Half Slot) packet (4 data symbols) may, in theory, provide the service with MCS 3, i.e. 104 bits per symbol and 416 per slot would be available. However, note the possible difficulty to implement such Half Slots over single carriers (see clause 6.3.2.2.3).

Referring to Figure 14, for 1 % PER a performance gain of 1,7 dB can be expected compared to legacy DECT systems, if MCS3 is used. If MCS2 is used instead, the expected performance gain climbs to 4,7 dB.

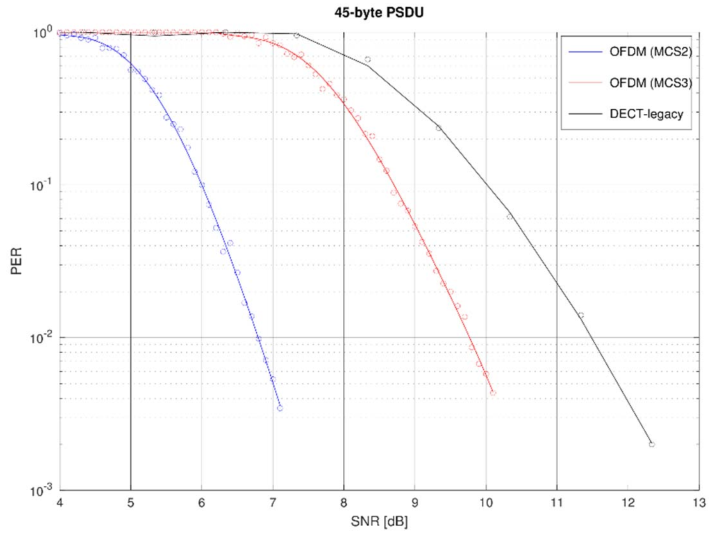

Figure 14: DECT legacy vs. OFDM

6.3.3 DECT-2020 NR Detailed Description

6.3.3.1 Packet formats

6.3.3.1.1 Overview

Several packet formats have been studied as candidate for DECT-2020. They can be split into three groups, each of them with several sub-variants:

- "Standard" packet types.
- "HE" packet types.
- Beacon, RAC and ULE packet types.

"Standard" packet types are packets intended for IP data packet-mode transmissions. They are self-detectable packets usable in either synchronous or asynchronous way and may implement MIMO. The design of these packets is closer to the designs used in other WLAN technologies. The parameters for these packets are given in clause 6.3.3.1.2.

"HE" packet types (HE stands for "High Efficiency) are packets intended for continuous data transmission over several frames. They may support circuit-mode traffic, URLLC traffic as well as packet mode traffic in some systems. They do not carry synchronization fields, so they require a previous synchronization by means of beacon bearers or other mechanisms. They are not intended for initial channel access and are assumed to be used only after an allocation action by a central entity. These packets may also implement MIMO, however with different mechanisms compared to standard packets. The design of these packets is very different to the packets used in other WLAN technologies and is closer to technologies such as LTE [i.18] or LTE NR [i.19]. The parameters for these packets are given in clause 6.3.3.1.3.

Beacon, RAC and ULE packet types are packets intended for beacon bearers, Random Access Channels (RAC) and ULE traffic. They include synchronization fields (important in beacons) and may be used for initially accessing a channel. These packets do not need to support MIMO. The parameters for these packets are given in clause 6.3.3.1.4.

6.3.3.1.2 Standard Packet parameters

The PHY layer parameters for standard packet formats are shown in table 8. There are two variants of the standard packets named long preamble and short preamble.

Table 8: Standard packet parameters

	½x	1×	2×	4×	8×	12× (note 1)	16×	Description
BW_{DFT}	0,864	1,728	3,456	6,912	13,824	20,736	27,648	DFT bandwidth (MHz)
BWO	0,648	1,512	3,132	6,588	13,500	17,928	27,000	Occupied bandwidth (MHz)
N_{DFT}	32	64	128	256	512	768	1024	Discrete Fourier transform size
N_{SD}	20	52	108	234	468	636	936	Number of data subcarriers per OFDM symbol
N_{SP}	4	4	6	8	16	22	32	Number of pilot subcarriers per OFDM symbol
N_{ST}	24	56	114	242	484	658	968	Total number of used subcarriers per OFDM symbol, $N_{ST} = N_{SD} + N_{SP}$
N_{SN}	8	8	14	14	28	110	56	Number of null subcarriers, $N_{SN} = N_{DFT} - N_{ST}$
N_{DC}	1	1	3	3	5	7	5	Number of null subcarriers at or surrounding DC
N_{SR}	12	28	58	122	250	332	500	Highest data subcarrier index per OFDM symbol
Δ_F	27 kHz							Subcarrier frequency spacing
T_{DFT}	37,037 µs = 1 / Δ_F (64 units)							DFT period
T_{CP}	4,63 µs = T_{DFT} / 8 (8 units)							Cyclic prefix duration
T_{CP2}	9,259 µs = T_{DFT} / 4 (16 units)							Double cyclic prefix duration
T_{SYM}	41,67 µs = T_{CP} + T_{DFT} (72 units)							OFDM symbol duration
T_{STF}	FFS	83,33 µs = 2 × T_{SYM} (144 units)						STF duration
T_{STFS}	FFS	46,3 µs = 10/9 × T_{SYM} (80 units)						STF duration for short preamble packets
T_{CTF1}	FFS	83,33 µs = 2 × T_{SYM} (144 units)						First CTF duration
T_{CTF}	FFS	41,67 µs = T_{SYM} (72 units)						Second and subsequent CTF duration
T_{HF}	FFS	83,33 µs = 2 × T_{SYM} (144 units)						HF field duration
T_{HFS}	FFS	41,67 µs = T_{SYM} (72 units)						HF field duration for short preamble packets
$N_{SERVICE}$	8							Number of bits in the SERVICE subfield of the Data field
N_{TAIL}	6							Number of tail bits for BCC encoder
N_{CTF}	≤ 6							Number of channel training symbols
N_{SS}	≤ 6							Number of spatial streams
N_{BPSC}	1,2, 4, 6, 8 or 10							Number of bits per subcarrier
R	1/4, 1/2, 2/3, 3/4, 5/6							Code rate
N_{CBPS}	$N_{SS} \times N_{SD} \times N_{BPSC}$							Number of coded bits per symbol
N_{DBPS}	$N_{CBPS} \times R$							Number of data bits per symbol

NOTE 1: The Occupied bandwidth (MHz) of this configuration has been designed so it will fit into the bandwidth allocated to 10 DECT carriers.

NOTE 2: Times are also given in "units". Each unit equals to 0,5787037 µs, which corresponds to 1 sample at 1,728 MHz or two samples at 3,456 MHz. Durations in "units" are exact values while the figures in µs have been rounded to the closest decimal.

6.3.3.1.3 HE Packet parameters

The PHY layer parameters for HE packet formats are shown in tables 9 and 10. Table 9 shows the common parameters and table 10 shows the list of analysed variants and the parameters that are variant dependent.

As noted before it is not the intention implementing all listed proposed types. A short list of types would need to be made in further design stages.

Table 9: High-Efficiency packet parameters - common to all types

	1× (note 1)	2×	4×	8×	12× (note 2)	16×	Description
BW_{DFT}	1,728	3,456	6,912	13,824	20,736	27,648	DFT bandwidth (MHz)
BWO	1,512	3,132	6,588	13,500	17,928	27,000	Occupied bandwidth (MHz)
N_{DFT}	64	128	256	512	768	1024	Discrete Fourier transform size
N_{SD}	52	108	234	468	636	936	Number of data subcarriers per OFDM symbol
N_{SP}	4	6	8	16	22	32	Number of pilot subcarriers per OFDM symbol
N_{ST}	56	114	242	484	658	968	Total number of used subcarriers per OFDM symbol, $N_{ST} = N_{SD} + N_{SP}$
N_{SN}	8	14	14	28	110	56	Number of null subcarriers, $N_{SN} = N_{DFT} - N_{ST}$
N_{DC}	1	3	3	5	7	5	Number of null subcarriers at or surrounding DC
N_{SR}	28	58	122	250	332	500	Highest data subcarrier index per OFDM symbol
Δ_F	27 kHz						Subcarrier frequency spacing
T_{DFT}	37,037 µs = 1 / Δ_F (64 units)						DFT period
N_{SS}	≤ 6						Number of spatial streams
N_{BPSC}	1, 2, 4, 6, 8 or 10						Number of bits per subcarrier
R	1/4, 1/2, 2/3, 3/4, 5/6						Code rate
N_{CBPS}	$N_{SS} \times N_{SD} \times N_{BPSC}$						Number of coded bits per symbol
N_{DBPS}	$N_{CBPS} \times R$						Number of data bits per symbol

NOTE 1: The feasibility of using packet types 1, 2, A1 and HS1 over 1x (1,728 MHz) channels requires further study.

NOTE 2: The Occupied bandwidth (MHz) of this configuration has been designed so it will fit into the bandwidth allocated to 10 DECT carriers.

NOTE 3: Times are also given in "units". Each unit equals to 0,5787037 µs, which corresponds to 1 sample at 1,728 MHz or two samples at 3,456 MHz. Durations in "units" are exact values while the figures in µs have been rounded to the closest decimal.

The number of symbols, CP duration and inter-slot guard space depend on the packet format. They are given in table 10.

The total symbol duration is the sum of the T_{DFT} (37,037 µs = 1 / Δ_F) plus the indicated CP duration.

Table 10: High Efficiency packets - parameters per type

Variant	Total symbols	Data symbols	Min BW	Pilot CP		Data CP		Inter-slot guard time (GF)		Notes
			(MHz)	(µs)	units	(µs)	units	(µs)	units	
1	10	9	3,456	2,3	4	2,3	4	23,1	40	1, 6
2	10	9	3,456	9,3	16	2,3	4	16,2	28	6
3	9	8	1,728	18,5	32	4,6	8	27,8	48	6
4	10	9	1,728	4,6	8	4,6	8	0,0	0	2, 3, 6
5	8	7	1,728	37,0	64	9,3	16	18,5	32	6
6	9	8	1,728	9,3	16	9,3	16	0,0	0	2, 3, 6
A1	10	9	1,728	4,6	8	3,5	6	10,4	18	6
A2	9	8	1,728	18,5	32	4,6	8	27,8	48	6
A2a	10	9	1,728	4,6	8	4,6	8	0	0	2, 3, 5, 6
A3	9	7	1,728	6,9	12	6,9	12	20,8	36	4, 6, 7
HS1	5	4	3,456	2,3	4	2,3	4	11,6	20	6

NOTE 1: This type is listed since it was the first HE type proposed. Based on later studies, it may probably be removed and replaced by types 2 or A1 in all cases.

NOTE 2: These types are designed for multi-slot transmissions using a burst of consecutive slots over the same carrier.

NOTE 3: When transmitting over multiple consecutive slots, it is assumed that a Reference Symbol (RPF) has to be inserted in each slot, however this is subject to further investigation and optimization in later stages.

NOTE 4: This type shares the data symbol CP with types B A1, B A2 and B A3 proposed for beacon and Random Access Channel (RAC) bearers. See clause 6.3.2.2.4.

NOTE 5: This type will start and will end 27,8 µs before the time reference This ensures continuation with a previous type 2 or 2A slot and also a Guard interval of 27,8 µs at the end.

NOTE 6: Times are also given in "units". Each unit equals to 0,5787037 µs, which corresponds to 1 sample at 1,728 MHz or two samples at 3,456 MHz. Durations in "units" are exact values while the figures in µs have been rounded to the closest decimal.

NOTE 7: In this configuration the reference symbol (RPF) is duplicated over the two first symbol intervals. Therefore 7 data symbols can be transmitted.

6.3.3.1.4 Beacon, RAC and ULE Packet Parameters

The PHY layer parameters for Beacon, RAC and ULE packet formats are shown in tables 11 and 12. Table 12 shows the common parameters and table 12 shows the list of analysed variants and the parameters that are variant dependent.

As noted before it is not the intention implementing necessarily several variants. Current assumption is that variant B 1 may be usable for both, beacons and RAC/ULE bearers, and is the primary choice at this stage. If variants with CP = 6,9 µs (types B A1 - B A3), a possible option may be using B A2 for beacon bearers and B A3 for RAC/ULE channels. This will be decided in further design stages when more simulation data is available.

Table 11: Beacon, RAC and ULE packet parameters - common to all types

Parameter	Value	Description
BW_{DFT}	1,728 MHz	DFT bandwidth (MHz)
BWO	1,515 MHz	Occupied bandwidth (MHz)
N_{DFT}	64	Discrete Fourier transform size
N_{SD}	52	Number of data subcarriers per OFDM symbol
N_{SP}	4	Number of pilot subcarriers per OFDM symbol
N_{ST}	56	Total number of used subcarriers per OFDM symbol, $N_{ST} = N_{SD} + N_{SP}$
N_{SN}	8	Number of null subcarriers, $N_{SN} = N_{DFT} - N_{ST}$
N_{DC}	1	Number of null subcarriers at or surrounding DC
N_{SR}	28	Highest data subcarrier index per OFDM symbol
Δ_F	27 kHz	Subcarrier frequency spacing
T_{DFT}	37,037 µs = 1 / Δ_F (64 units)	DFT period
N_{SS}	1	Number of spatial streams
N_{BPSC}	1, 2, 4, 6, 8 or 10	Number of bits per subcarrier
R	1/4, 1/2, 2/3, 3/4, 5/6	Code rate
N_{CBPS}	$N_{SS} \times N_{SD} \times N_{BPSC}$	Number of coded bits per symbol
N_{DBPS}	$N_{CBPS} \times R$	Number of data bits per symbol

Table 12: Beacon, RAC and ULE packet parameters per type

Variant	Min BW	Synch. Field (STF) duration		Number of symbols		Symbol duration		Symbol Cyclic Prefix (CP) duration		Inter-slot guard time (GF)		Notes
	(MHz)	(µs)	units	Pilot (CTF)	Data	(µs)	units	(µs)	units	(µs)	units	
Primary working assumption												
B 1	1,728	64,9	112	2	6	41,7	72	4,6	8	18,5	32	1, 4
Other possible variants considered												
B L1	1,728	83,4	144	2	5	41,7	72	4,6	8	41,7	72	1, 2, 4
B A1	1,728	87,8	152	2	5	43,9	76	6,9	12	20,8	36	1, 3, 4
B A2	1,728	55,6	96	2	6	43,9	76	6,9	12	9,26	16	1, 3, 4, 6
B A3	1,728	46,3	80	2	6	43,9	76	6,9	12	18,5	32	1, 3, 4, 7

NOTE 1: In all cases, HF is embedded into the data symbols (MAC format not yet designed).
NOTE 2: This format is similar to the long packet format.
NOTE 3: These formats increase the CP to 6,9 µs to allow better reception in problematic radio conditions. The increased CP may be at the expense of a reduced inter-slot guard time and/or slightly reduced STF.
NOTE 4: Times are also given in "units". Each unit equals to 0,5787037 µs, which corresponds to 1 sample at 1,728 MHz or two samples at 3,456 MHz. Durations in "units" are exact values while the figures in µs have been rounded to the closest decimal.
NOTE 5: These formats (except type B A2) are also reused for RAC and ULE bearers (see clause 6.3.2.2.4).
NOTE 6: This format is only intended for beacon bearers, due to the reduced inter-slot space.
NOTE 7: This format is mostly intended for RAC and ULE bearers.

6.3.3.2 Channel Bandwidth

6.3.3.2.1 General

Different options of channel bandwidth have been considered. They have already been taken into account in the channel parameters given in clause 6.3.3.1 and in the MCS configurations described in clause 6.3.4.

6.3.3.2.2 Full-carrier Transmission

In this mode the transmission bandwidth will be a basic DECT channel with 1,728 MHz bandwidth. To guarantee compatibility with other DECT-2020 and DECT transmitters the Occupied bandwidth has been set to 1,512 MHz. This is achieved by inserting a proper number of zero (null) sub-carriers close to the channel edges. The number of zero subcarriers can be seen in the tables shown in clause 6.3.3.1.

6.3.3.2.3 Multiple-carrier Transmission

In this mode the transmission bandwidth can be 2x, 4x, 8x, 12x or 16x the basic channel bandwidth (1,728, 3,456, 6,912, 13,824, 20,736 or 27,648 MHz). The proper number of zero (null) sub-carriers are inserted to produce the occupied bandwidth. They can be seen in tables 8 and 9 (clause 6.3.3.1).

Due to the different number of null sub-carriers and to the fact that they are calculated by spectrum mask considerations, the available data rates of each mode is not exactly proportional to the mode multiplier. For instance, mode 2x provides more than two times the bitrate of mode 1x, and so on.

The case of 12x should be especially noted, since the number of subcarriers have been calculated to produce an occupied bandwidth of 17,928 MHz, compatible with the full DECT spectrum (1 880 MHz to 1 900 MHz).

6.3.3.2.4 Half-carrier Transmission

In this mode the transmission bandwidth is 1/2 of the basic channel (0,864 MHz). The Occupied bandwidth is 0,648 MHz. The number of zero subcarriers can be seen in the tables 8 and 9 of clause 6.3.3.1.

6.3.3.3 Transmitter Specification

6.3.3.3.1 Spectrum Mask

Figure 15 shows the spectral density vs. normalized frequency. Equal power neighbouring channel densities are also shown for reference.

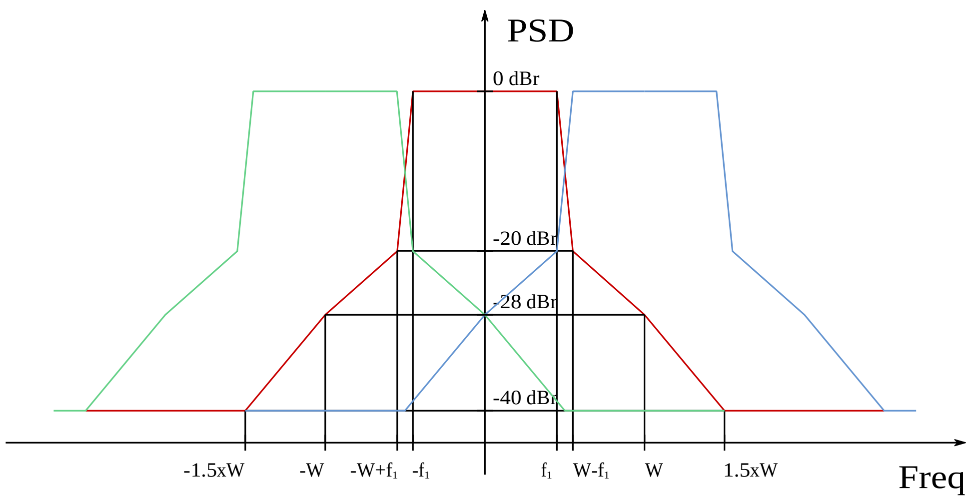

Figure 15: Transmit spectral mask

In Figure 15, W is the transmission bandwidth, 0,5×, 1×, 2×, 4×, 8×, 12×, or 16 × W_{BC}. The values for the used bandwidth f_1, are given in table 13.

Table 13: Transmit spectral mask bandwidth parameters

W (MHz)	f_1 (MHz)
0,864	0,324
1,728	0,756
3,456	1,566
6,912	3,294
13,824	6,750
20,736	8,964
27,648	13,500

6.3.3.3.2 Spectral Flatness

This parameter requires further study.

6.3.3.3.3 Carrier Frequency and Symbol Clock Frequency Tolerance

This parameter requires further study.

6.3.3.3.4 Modulation Accuracy

6.3.3.3.4.1 Transmitter Constellation Accuracy

Table 14: Constellation error allowed vs. modulation and code rate

Modulation	R	EVM (dB)
BPSK	1/4	-4
BPSK	1/2	-5
QPSK	1/2	-10
QPSK	3/4	-13
16-QAM	1/2	-16
16-QAM	3/4	-19
64-QAM	2/3	-22
64-QAM	3/4	-25
64-QAM	5/6	-27
256-QAM	3/4	-30
256-QAM	5/6	-32
1024-QAM	3/4	-35
1024-QAM	5/6	-37

6.3.3.3.5 Time of Departure Accuracy

This parameter requires further study.

6.3.3.3.6 PP Time Synchronization

A PP approaching the time for transmission should be synchronized to FP time to within T_{SYNC} = ±5,2 µs of the relevant slot start time. In case of PP (uplink) transmission, this tolerance ensures enough time for other transmitters to back-off before the end of the previous slot. In case of FP (downlink) transmission, this tolerance ensures enough time for the PP to initiate detection procedure for an expected packet.

6.3.3.4 Receiver Specification

6.3.3.4.1 Receiver Sensitivity

Table 15 contains rate and bandwidth dependent minimum input levels for which the packet error rate (PER) will be less than 10 % for packets of length 256 bytes.

Table 15: Receiver minimum input sensitivity [dBm]

Modulation	R	0,864 MHz	1,728 MHz	3,456 MHz	6,912 MHz	13,824 MHz	20,736 MHz	27,648 MHz
BPSK	1/4	-99	-	-	-	-	-	-
BPSK	1/2	-96	-93	-90	-87	-84	-82	-81
QPSK	1/2	-93	-90	-87	-84	-81	-79	-78
QPSK	3/4	-91	-88	-85	-82	-79	-77	-76
16-QAM	1/2	-88	-85	-82	-79	-76	-74	-73
16-QAM	3/4	-84	-81	-78	-75	-72	-70	-69
64-QAM	2/3	-80	-77	-74	-71	-68	-66	-65
64-QAM	3/4	-79	-76	-73	-70	-67	-65	-64
64-QAM	5/6	-78	-75	-72	-69	-66	-64	-63
256-QAM	3/4	-73	-70	-67	-64	-61	-59	-58
256-QAM	5/6	-	-	-65	-62	-59	-57	-56
1024-QAM	3/4	-66	-63	-60	-57	-54	-52	-51
1024-QAM	5/6	-	-	-57	-54	-51	-49	-48

6.3.3.4.2 Adjacent channel rejection

This parameter requires further study.

6.3.3.4.3 Non-Adjacent Channel Rejection

This parameter requires further study.

6.3.3.4.4 Receiver Maximum Input Level

This parameter requires further study.

6.3.4 MCS Parameters

6.3.4.1 General

Table 16 to table 57 contain rate-dependent parameters for supported bandwidths and number of spatial streams (N_{SS}). See table 5 for definitions of parameters appearing in tables 16 to 57. Data rates figures represent rates within the Data Field of the packet in kbps.

6.3.4.2 MCS parameters for 0,864 MHz

Table 16: MCSs for 0,864 MHz, N_{SS} = 1

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	20	4	20	10	240
1	QPSK	1/2	2	20	4	40	20	480
2	QPSK	3/4	2	20	4	40	30	720
3	16-QAM	1/2	4	20	4	80	40	960
4	16-QAM	3/4	4	20	4	80	60	1 440
5	64-QAM	2/3	6	20	4	120	80	1 920
6	64-QAM	3/4	6	20	4	120	90	2 160
7	64-QAM	5/6	6	20	4	120	100	2 400
8	256-QAM	3/4	8	20	4	160	120	2 880
9	256-QAM	5/6	8	20	4	160	-	-
10	1024-QAM	3/4	10	20	4	200	150	3 600
11	1024-QAM	5/6	10	20	4	200	-	-
12	BPSK	1/4	1	20	4	20	5	120

Table 17: MCSs for 0,864 MHz, N_{SS} = 2

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	20	4	40	20	480
1	QPSK	1/2	2	20	4	80	40	960
2	QPSK	3/4	2	20	4	80	60	1 440
3	16-QAM	1/2	4	20	4	160	80	1 920
4	16-QAM	3/4	4	20	4	160	120	2 880
5	64-QAM	2/3	6	20	4	240	160	3 840
6	64-QAM	3/4	6	20	4	240	180	4 320
7	64-QAM	5/6	6	20	4	240	200	4 800
8	256-QAM	3/4	8	20	4	320	240	5 760
9	256-QAM	5/6	8	20	4	320	-	-
10	1024-QAM	3/4	10	20	4	400	300	7 200
11	1024-QAM	5/6	10	20	4	400	-	-

Table 18: MCSs for 0,864 MHz, N_{SS} = 3

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	20	4	60	30	720
1	QPSK	1/2	2	20	4	120	60	1 440
2	QPSK	3/4	2	20	4	120	90	2 160
3	16-QAM	1/2	4	20	4	240	120	2 880
4	16-QAM	3/4	4	20	4	240	180	4 320
5	64-QAM	2/3	6	20	4	360	240	5 760
6	64-QAM	3/4	6	20	4	360	270	6 480
7	64-QAM	5/6	6	20	4	360	300	7 200
8	256-QAM	3/4	8	20	4	480	360	8 640
9	256-QAM	5/6	8	20	4	480	400	9 600
10	1024-QAM	3/4	10	20	4	600	450	10 800
11	1024-QAM	5/6	10	20	4	600	500	12 000

Table 19: MCSs for 0,864 MHz, N_{SS} = 4

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	20	4	80	40	960
1	QPSK	1/2	2	20	4	160	80	1 920
2	QPSK	3/4	2	20	4	160	120	2 880
3	16-QAM	1/2	4	20	4	320	160	3 840
4	16-QAM	3/4	4	20	4	320	240	5 760
5	64-QAM	2/3	6	20	4	480	320	7 680
6	64-QAM	3/4	6	20	4	480	360	8 640
7	64-QAM	5/6	6	20	4	480	400	9 600
8	256-QAM	3/4	8	20	4	640	480	11 520
9	256-QAM	5/6	8	20	4	640	-	-
10	1024-QAM	3/4	10	20	4	800	600	14 400
11	1024-QAM	5/6	10	20	4	800	-	-

Table 20: MCSs for 0,864 MHz, N_{SS} = 5

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	20	4	100	50	1 200
1	QPSK	1/2	2	20	4	200	100	2 400
2	QPSK	3/4	2	20	4	200	150	3 600
3	16-QAM	1/2	4	20	4	400	200	4 800
4	16-QAM	3/4	4	20	4	400	300	7 200
5	64-QAM	2/3	6	20	4	600	400	9 600
6	64-QAM	3/4	6	20	4	600	450	10 800
7	64-QAM	5/6	6	20	4	600	500	12 000
8	256-QAM	3/4	8	20	4	800	600	14 400
9	256-QAM	5/6	8	20	4	800	-	-
10	1024-QAM	3/4	10	20	4	1 000	750	18 000
11	1024-QAM	5/6	10	20	4	1 000	-	-

Table 21: MCSs for 0,864 MHz, N_{SS} = 6

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	20	4	120	60	1 440
1	QPSK	1/2	2	20	4	240	120	2 880
2	QPSK	3/4	2	20	4	240	180	4 320
3	16-QAM	1/2	4	20	4	480	240	5 760
4	16-QAM	3/4	4	20	4	480	360	8 640
5	64-QAM	2/3	6	20	4	720	480	11 520
6	64-QAM	3/4	6	20	4	720	540	12 960
7	64-QAM	5/6	6	20	4	720	600	14 400
8	256-QAM	3/4	8	20	4	960	720	17 280
9	256-QAM	5/6	8	20	4	960	800	19 200
10	1024-QAM	3/4	10	20	4	1 200	900	21 600
11	1024-QAM	5/6	10	20	4	1 200	1 000	24 000

6.3.4.3 MCS parameters for 1,728 MHz

Table 22: MCSs for 1,728 MHz, N_{SS} = 1

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	52	4	52	26	624
1	QPSK	1/2	2	52	4	104	52	1 248
2	QPSK	3/4	2	52	4	104	78	1 872
3	16-QAM	1/2	4	52	4	208	104	2 496
4	16-QAM	3/4	4	52	4	208	156	3 744
5	64-QAM	2/3	6	52	4	312	208	4 992
6	64-QAM	3/4	6	52	4	312	234	5 616
7	64-QAM	5/6	6	52	4	312	260	6 240
8	256-QAM	3/4	8	52	4	416	312	7 488
9	256-QAM	5/6	8	52	4	416	-	-
10	1024-QAM	3/4	10	52	4	520	390	9 360
11	1024-QAM	5/6	10	52	4	520	-	-

Table 23: MCSs for 1,728 MHz, N_{SS} = 2

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	52	4	104	52	1 248
1	QPSK	1/2	2	52	4	208	104	2 496
2	QPSK	3/4	2	52	4	208	156	3 744
3	16-QAM	1/2	4	52	4	416	208	4 992
4	16-QAM	3/4	4	52	4	416	312	7 488
5	64-QAM	2/3	6	52	4	624	416	9 984
6	64-QAM	3/4	6	52	4	624	468	11 232
7	64-QAM	5/6	6	52	4	624	520	12 480
8	256-QAM	3/4	8	52	4	832	624	14 976
9	256-QAM	5/6	8	52	4	832	-	-
10	1024-QAM	3/4	10	52	4	1 040	780	18 720
11	1024-QAM	5/6	10	52	4	1 040	-	-

Table 24: MCSs for 1,728 MHz, N_{SS} = 3

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	52	4	156	78	1 872
1	QPSK	1/2	2	52	4	312	156	3 744
2	QPSK	3/4	2	52	4	312	234	5 616
3	16-QAM	1/2	4	52	4	624	312	7 488
4	16-QAM	3/4	4	52	4	624	468	11 232
5	64-QAM	2/3	6	52	4	936	624	14 976
6	64-QAM	3/4	6	52	4	936	702	16 848
7	64-QAM	5/6	6	52	4	936	780	18 720
8	256-QAM	3/4	8	52	4	1 248	936	22 464
9	256-QAM	5/6	8	52	4	1 248	1 040	24 960
10	1024-QAM	3/4	10	52	4	1 560	1 170	28 080
11	1024-QAM	5/6	10	52	4	1 560	1 300	31 200

Table 25: MCSs for 1,728 MHz, N_{SS} = 4

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	52	4	208	104	2 496
1	QPSK	1/2	2	52	4	416	208	4 992
2	QPSK	3/4	2	52	4	416	312	7 488
3	16-QAM	1/2	4	52	4	832	416	9 984
4	16-QAM	3/4	4	52	4	832	624	14 976
5	64-QAM	2/3	6	52	4	1 248	832	19 968
6	64-QAM	3/4	6	52	4	1 248	936	22 464
7	64-QAM	5/6	6	52	4	1 248	1 040	24 960
8	256-QAM	3/4	8	52	4	1 664	1 248	29 952
9	256-QAM	5/6	8	52	4	1 664	-	-
10	1024-QAM	3/4	10	52	4	2 080	1 560	37 440
11	1024-QAM	5/6	10	52	4	2 080	-	-

Table 26: MCSs for 1,728 MHz, N_{SS} = 5

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	52	4	260	130	3 120
1	QPSK	1/2	2	52	4	520	260	6 240
2	QPSK	3/4	2	52	4	520	390	9 360
3	16-QAM	1/2	4	52	4	1 040	520	12 480
4	16-QAM	3/4	4	52	4	1 040	780	18 720
5	64-QAM	2/3	6	52	4	1 560	1 040	24 960
6	64-QAM	3/4	6	52	4	1 560	1 170	28 080
7	64-QAM	5/6	6	52	4	1 560	1 300	31 200
8	256-QAM	3/4	8	52	4	2 080	1 560	37 440
9	256-QAM	5/6	8	52	4	2 080	-	-
10	1024-QAM	3/4	10	52	4	2 600	1 950	46 800
11	1024-QAM	5/6	10	52	4	2 600	-	-

Table 27: MCSs for 1,728 MHz, N_{SS} = 6

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	52	4	312	156	3 744
1	QPSK	1/2	2	52	4	624	312	7 488
2	QPSK	3/4	2	52	4	624	468	11 232
3	16-QAM	1/2	4	52	4	1 248	624	14 976
4	16-QAM	3/4	4	52	4	1 248	936	22 464
5	64-QAM	2/3	6	52	4	1 872	1 248	29 952
6	64-QAM	3/4	6	52	4	1 872	1 404	33 696
7	64-QAM	5/6	6	52	4	1 872	1 560	37 440
8	256-QAM	3/4	8	52	4	2 496	1 872	44 928
9	256-QAM	5/6	8	52	4	2 496	2 080	49 920
10	1024-QAM	3/4	10	52	4	3 120	2 340	56 160
11	1024-QAM	5/6	10	52	4	3 120	2 600	62 400

6.3.4.4 MCS parameters for 3,456 MHz

Table 28: MCSs for 3,456 MHz, N_{SS} = 1

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	108	6	108	54	1 296
1	QPSK	1/2	2	108	6	216	108	2 592
2	QPSK	3/4	2	108	6	216	162	3 888
3	16-QAM	1/2	4	108	6	432	216	5 184
4	16-QAM	3/4	4	108	6	432	324	7 776
5	64-QAM	2/3	6	108	6	648	432	10 368
6	64-QAM	3/4	6	108	6	648	486	11 664
7	64-QAM	5/6	6	108	6	648	540	12 960
8	256-QAM	3/4	8	108	6	864	648	15 552
9	256-QAM	5/6	8	108	6	864	720	17 280
10	1024-QAM	3/4	10	108	6	1 080	810	19 440
11	1024-QAM	5/6	10	108	6	1 080	900	21 600

Table 29: MCSs for 3,456 MHz, N_{SS} = 2

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	108	6	216	108	2 592
1	QPSK	1/2	2	108	6	432	216	5 184
2	QPSK	3/4	2	108	6	432	324	7 776
3	16-QAM	1/2	4	108	6	864	432	10 368
4	16-QAM	3/4	4	108	6	864	648	15 552
5	64-QAM	2/3	6	108	6	1 296	864	20 736
6	64-QAM	3/4	6	108	6	1 296	972	23 328
7	64-QAM	5/6	6	108	6	1 296	1 080	25 920
8	256-QAM	3/4	8	108	6	1 728	1 296	31 104
9	256-QAM	5/6	8	108	6	1 728	1 440	34 560
10	1024-QAM	3/4	10	108	6	2 160	1 620	38 880
11	1024-QAM	5/6	10	108	6	2 160	1 800	43 200

Table 30: MCSs for 3,456 MHz, N_{SS} = 3

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	108	6	324	162	3888
1	QPSK	1/2	2	108	6	648	324	7 776
2	QPSK	3/4	2	108	6	648	486	11 664
3	16-QAM	1/2	4	108	6	1 296	648	15 552
4	16-QAM	3/4	4	108	6	1 296	972	23 328
5	64-QAM	2/3	6	108	6	1 944	1 296	31 104
6	64-QAM	3/4	6	108	6	1 944	1 458	34 992
7	64-QAM	5/6	6	108	6	1 944	1 620	38 880
8	256-QAM	3/4	8	108	6	2 592	1 944	46 656
9	256-QAM	5/6	8	108	6	2 592	2 160	51 840
10	1024-QAM	3/4	10	108	6	3 240	2 430	58 320
11	1024-QAM	5/6	10	108	6	3 240	2 700	64 800

Table 31: MCSs for 3,456 MHz, N_{SS} = 4

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	108	6	432	216	5184
1	QPSK	1/2	2	108	6	864	432	10368
2	QPSK	3/4	2	108	6	864	648	15552
3	16-QAM	1/2	4	108	6	1 728	864	20 736
4	16-QAM	3/4	4	108	6	1 728	1 296	31 104
5	64-QAM	2/3	6	108	6	2 592	1 728	41 472
6	64-QAM	3/4	6	108	6	2 592	1 944	46 656
7	64-QAM	5/6	6	108	6	2 592	2 160	51 840
8	256-QAM	3/4	8	108	6	3 456	2 592	62 208
9	256-QAM	5/6	8	108	6	3 456	2 880	69 120
10	1024-QAM	3/4	10	108	6	4 320	3 240	77 760
11	1024-QAM	5/6	10	108	6	4 320	3 600	86 400

Table 32: MCSs for 3,456 MHz, N_{SS} = 5

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	108	6	540	270	6 480
1	QPSK	1/2	2	108	6	1 080	540	12 960
2	QPSK	3/4	2	108	6	1 080	810	19 440
3	16-QAM	1/2	4	108	6	2 160	1 080	25 920
4	16-QAM	3/4	4	108	6	2 160	1 620	38 880
5	64-QAM	2/3	6	108	6	3 240	2 160	51 840
6	64-QAM	3/4	6	108	6	3 240	2 430	58 320
7	64-QAM	5/6	6	108	6	3 240	2 700	64 800
8	256-QAM	3/4	8	108	6	4 320	3 240	77 760
9	256-QAM	5/6	8	108	6	4 320	3 600	86 400
10	1024-QAM	3/4	10	108	6	5 400	4 050	97 200
11	1024-QAM	5/6	10	108	6	5 400	4 500	108 000

Table 33: MCSs for 3,456 MHz, N_{SS} = 6

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	108	6	648	324	7 776
1	QPSK	1/2	2	108	6	1 296	648	15 552
2	QPSK	3/4	2	108	6	1 296	972	23 328
3	16-QAM	1/2	4	108	6	2 592	1 296	31 104
4	16-QAM	3/4	4	108	6	2 592	1 944	46 656
5	64-QAM	2/3	6	108	6	3 888	2 592	62 208
6	64-QAM	3/4	6	108	6	3 888	2 916	69 984
7	64-QAM	5/6	6	108	6	3 888	3 240	77 760
8	256-QAM	3/4	8	108	6	5 184	3 888	93 312
9	256-QAM	5/6	8	108	6	5 184	4 320	103 680
10	1024-QAM	3/4	10	108	6	6 480	4 860	116 640
11	1024-QAM	5/6	10	108	6	6 480	5 400	129 600

6.3.4.5 MCS parameters for 6,912 MHz

Table 34: MCSs for 6,912 MHz, N_{SS} = 1

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	234	8	234	117	2 808
1	QPSK	1/2	2	234	8	468	234	5 616
2	QPSK	3/4	2	234	8	468	351	8 424
3	16-QAM	1/2	4	234	8	936	468	11 232
4	16-QAM	3/4	4	234	8	936	702	16 848
5	64-QAM	2/3	6	234	8	1 404	936	22 464
6	64-QAM	3/4	6	234	8	1 404	1 053	25 272
7	64-QAM	5/6	6	234	8	1 404	1 170	28 080
8	256-QAM	3/4	8	234	8	1 872	1 404	33 696
9	256-QAM	5/6	8	234	8	1 872	1 560	37 440
10	1024-QAM	3/4	10	234	8	2 340	1 755	42 120
11	1024-QAM	5/6	10	234	8	2 340	1 950	46 800

Table 35: MCSs for 6,912 MHz, N_{SS} = 2

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	234	8	468	234	5 616
1	QPSK	1/2	2	234	8	936	468	11 232
2	QPSK	3/4	2	234	8	936	702	16 848
3	16-QAM	1/2	4	234	8	1 872	936	22 464
4	16-QAM	3/4	4	234	8	1 872	1 404	33 696
5	64-QAM	2/3	6	234	8	2 808	1 872	44 928
6	64-QAM	3/4	6	234	8	2 808	2 106	50 544
7	64-QAM	5/6	6	234	8	2 808	2 340	56 160
8	256-QAM	3/4	8	234	8	3 744	2 808	67 392
9	256-QAM	5/6	8	234	8	3 744	3 120	74 880
10	1024-QAM	3/4	10	234	8	4 680	3 510	84 240
11	1024-QAM	5/6	10	234	8	4 680	3 900	93 600

Table 36: MCSs for 6,912 MHz, N_{SS} = 3

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	234	8	702	351	8 424
1	QPSK	1/2	2	234	8	1 404	702	16 848
2	QPSK	3/4	2	234	8	1 404	1 053	25 272
3	16-QAM	1/2	4	234	8	2 808	1 404	33 696
4	16-QAM	3/4	4	234	8	2 808	2 106	50 544
5	64-QAM	2/3	6	234	8	4 212	2 808	67 392
6	64-QAM	3/4	6	234	8	4 212	3 159	75 816
7	64-QAM	5/6	6	234	8	4 212	3 510	84 240
8	256-QAM	3/4	8	234	8	5 616	4 212	101 088
9	256-QAM	5/6	8	234	8	5 616	4 680	112 320
10	1024-QAM	3/4	10	234	8	7 020	5 265	126 360
11	1024-QAM	5/6	10	234	8	7 020	5 850	140 400

Table 37: MCSs for 6,912 MHz, N_{SS} = 4

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	234	8	936	468	11 232
1	QPSK	1/2	2	234	8	1 872	936	22 464
2	QPSK	3/4	2	234	8	1 872	1 404	33 696
3	16-QAM	1/2	4	234	8	3 744	1 872	44 928
4	16-QAM	3/4	4	234	8	3 744	2 808	67 392
5	64-QAM	2/3	6	234	8	5 616	3 744	89 856
6	64-QAM	3/4	6	234	8	5 616	4 212	101 088
7	64-QAM	5/6	6	234	8	5 616	4 680	112 320
8	256-QAM	3/4	8	234	8	7 488	5 616	134 784
9	256-QAM	5/6	8	234	8	7 488	6 240	149 760
10	1024-QAM	3/4	10	234	8	9 360	7 020	168 480
11	1024-QAM	5/6	10	234	8	9 360	7 800	187 200

Table 38: MCSs for 6,912 MHz, N_{SS} = 5

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	234	8	1 170	585	14 040
1	QPSK	1/2	2	234	8	2 340	1 170	28 080
2	QPSK	3/4	2	234	8	2 340	1 755	42 120
3	16-QAM	1/2	4	234	8	4 680	2 340	56 160
4	16-QAM	3/4	4	234	8	4 680	3 510	84 240
5	64-QAM	2/3	6	234	8	7 020	4 680	112 320
6	64-QAM	3/4	6	234	8	7 020	5 265	126 360
7	64-QAM	5/6	6	234	8	7 020	5 850	140 400
8	256-QAM	3/4	8	234	8	9 360	7 020	168 480
9	256-QAM	5/6	8	234	8	9 360	7 800	187 200
10	1024-QAM	3/4	10	234	8	11 700	8 775	210 600
11	1024-QAM	5/6	10	234	8	11 700	9 750	234 000

Table 39: MCSs for 6,912 MHz, N_{SS} = 6

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	234	8	1 404	702	16 848
1	QPSK	1/2	2	234	8	2 808	1 404	33 696
2	QPSK	3/4	2	234	8	2 808	2 106	50 544
3	16-QAM	1/2	4	234	8	5 616	2 808	67 392
4	16-QAM	3/4	4	234	8	5 616	4 212	101 088
5	64-QAM	2/3	6	234	8	8 424	5 616	134 784
6	64-QAM	3/4	6	234	8	8 424	6 318	151 632
7	64-QAM	5/6	6	234	8	8 424	7 020	168 480
8	256-QAM	3/4	8	234	8	11 232	8 424	202 176
9	256-QAM	5/6	8	234	8	11 232	9 360	224 640
10	1024-QAM	3/4	10	234	8	14 040	10 530	252 720
11	1024-QAM	5/6	10	234	8	14 040	11 700	280 800

6.3.4.6 MCS parameters for 13,824 MHz

Table 40: MCSs for 13,824 MHz, N_{SS} = 1

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	468	16	468	234	5 616
1	QPSK	1/2	2	468	16	936	468	11 232
2	QPSK	3/4	2	468	16	936	702	16 848
3	16-QAM	1/2	4	468	16	1 872	936	22 464
4	16-QAM	3/4	4	468	16	1 872	1 404	33 696
5	64-QAM	2/3	6	468	16	2 808	1 872	44 928
6	64-QAM	3/4	6	468	16	2 808	2 106	50 544
7	64-QAM	5/6	6	468	16	2 808	2 340	56 160
8	256-QAM	3/4	8	468	16	3 744	2 808	67 392
9	256-QAM	5/6	8	468	16	3 744	3 120	74 880
10	1024-QAM	3/4	10	468	16	4 680	3 510	84 240
11	1024-QAM	5/6	10	468	16	4 680	3 900	93 600

Table 41: MCSs for 13,824 MHz, N_{SS} = 2

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	468	16	936	468	11 232
1	QPSK	1/2	2	468	16	1 872	936	22 464
2	QPSK	3/4	2	468	16	1 872	1 404	33 696
3	16-QAM	1/2	4	468	16	3 744	1 872	44 928
4	16-QAM	3/4	4	468	16	3 744	2 808	67 392
5	64-QAM	2/3	6	468	16	5 616	3 744	89 856
6	64-QAM	3/4	6	468	16	5 616	4 212	101 088
7	64-QAM	5/6	6	468	16	5 616	4 680	112 320
8	256-QAM	3/4	8	468	16	7 488	5 616	134 784
9	256-QAM	5/6	8	468	16	7 488	6 240	149 760
10	1024-QAM	3/4	10	468	16	9 360	7 020	168 480
11	1024-QAM	5/6	10	468	16	9 360	7 800	187 200

Table 42: MCSs for 13,824 MHz, N_{SS} = 3

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	468	16	1 404	702	16 848
1	QPSK	1/2	2	468	16	2 808	1 404	33 696
2	QPSK	3/4	2	468	16	2 808	2 106	50 544
3	16-QAM	1/2	4	468	16	5 616	2 808	67 392
4	16-QAM	3/4	4	468	16	5 616	4 212	101 088
5	64-QAM	2/3	6	468	16	8 424	5 616	134 784
6	64-QAM	3/4	6	468	16	8 424	6 318	151 632
7	64-QAM	5/6	6	468	16	8 424	7 020	168 480
8	256-QAM	3/4	8	468	16	11 232	8 424	202 176
9	256-QAM	5/6	8	468	16	11 232	9 360	224 640
10	1024-QAM	3/4	10	468	16	14 040	10 530	252 720
11	1024-QAM	5/6	10	468	16	14 040	11 700	280 800

Table 43: MCSs for 13,824 MHz, N_{SS} = 4

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	468	16	1 872	936	22 464
1	QPSK	1/2	2	468	16	3 744	1 872	44 928
2	QPSK	3/4	2	468	16	3 744	2 808	67 392
3	16-QAM	1/2	4	468	16	7 488	3 744	89 856
4	16-QAM	3/4	4	468	16	7 488	5 616	134 784
5	64-QAM	2/3	6	468	16	11 232	7 488	179 712
6	64-QAM	3/4	6	468	16	11 232	8 424	202 176
7	64-QAM	5/6	6	468	16	11 232	9 360	224 640
8	256-QAM	3/4	8	468	16	14 976	11 232	269 568
9	256-QAM	5/6	8	468	16	14 976	12 480	299 520
10	1024-QAM	3/4	10	468	16	18 720	14 040	336 960
11	1024-QAM	5/6	10	468	16	18 720	15 600	374 400

Table 44: MCSs for 13,824 MHz, N_{SS} = 5

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	468	16	2 340	1 170	28 080
1	QPSK	1/2	2	468	16	4 680	2 340	56 160
2	QPSK	3/4	2	468	16	4 680	3 510	84 240
3	16-QAM	1/2	4	468	16	9 360	4 680	112 320
4	16-QAM	3/4	4	468	16	9 360	7 020	168 480
5	64-QAM	2/3	6	468	16	14 040	9 360	224 640
6	64-QAM	3/4	6	468	16	14 040	10 530	252 720
7	64-QAM	5/6	6	468	16	14 040	11 700	280 800
8	256-QAM	3/4	8	468	16	18 720	14 040	336 960
9	256-QAM	5/6	8	468	16	18 720	15 600	374 400
10	1024-QAM	3/4	10	468	16	23 400	17 550	421 200
11	1024-QAM	5/6	10	468	16	23 400	19 500	468 000

Table 45: MCSs for 13,824 MHz, N_{SS} = 6

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	468	16	2 808	1 404	33 696
1	QPSK	1/2	2	468	16	5 616	2 808	67 392
2	QPSK	3/4	2	468	16	5 616	4 212	101 088
3	16-QAM	1/2	4	468	16	11 232	5 616	134 784
4	16-QAM	3/4	4	468	16	11 232	8 424	202 176
5	64-QAM	2/3	6	468	16	16 848	11 232	269 568
6	64-QAM	3/4	6	468	16	16 848	12 636	303 264
7	64-QAM	5/6	6	468	16	16 848	14 040	336 960
8	256-QAM	3/4	8	468	16	22 464	16 848	404 352
9	256-QAM	5/6	8	468	16	22 464	18 720	449 280
10	1024-QAM	3/4	10	468	16	28 080	21 060	505 440
11	1024-QAM	5/6	10	468	16	28 080	23 400	561 600

6.3.4.7 MCS parameters for 20,736 MHz

Table 46: MCSs for 20,736 MHz, N_{SS} = 1

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	636	22	636	318	7 632
1	QPSK	1/2	2	636	22	1 272	636	15 264
2	QPSK	3/4	2	636	22	1 272	954	22 896
3	16-QAM	1/2	4	636	22	2 544	1 272	30 528
4	16-QAM	3/4	4	636	22	2 544	1 908	45 792
5	64-QAM	2/3	6	636	22	3 816	2 544	61 056
6	64-QAM	3/4	6	636	22	3 816	2 862	68 688
7	64-QAM	5/6	6	636	22	3 816	3 180	76 320
8	256-QAM	3/4	8	636	22	5 088	3 816	91 584
9	256-QAM	5/6	8	636	22	5 088	4 240	101 760
10	1024-QAM	3/4	10	636	22	6 360	4 770	114 480
11	1024-QAM	5/6	10	636	22	6 360	5 300	127 200

Table 47: MCSs for 20,736 MHz, N_{SS} = 2

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	636	22	1 272	636	15 264
1	QPSK	1/2	2	636	22	2 544	1 272	30 528
2	QPSK	3/4	2	636	22	2 544	1 908	45 792
3	16-QAM	1/2	4	636	22	5 088	2 544	61 056
4	16-QAM	3/4	4	636	22	5 088	3 816	91 584
5	64-QAM	2/3	6	636	22	7 632	5 088	122 112
6	64-QAM	3/4	6	636	22	7 632	5 724	137 376
7	64-QAM	5/6	6	636	22	7 632	6 360	152 640
8	256-QAM	3/4	8	636	22	10 176	7 632	183 168
9	256-QAM	5/6	8	636	22	10 176	8 480	203 520
10	1024-QAM	3/4	10	636	22	12 720	9 540	228 960
11	1024-QAM	5/6	10	636	22	12 720	10 600	254 400

Table 48: MCSs for 20,736 MHz, N_{SS} = 3

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	636	22	1 908	954	22 896
1	QPSK	1/2	2	636	22	3 816	1 908	45 792
2	QPSK	3/4	2	636	22	3 816	2 862	68 688
3	16-QAM	1/2	4	636	22	7 632	3 816	91 584
4	16-QAM	3/4	4	636	22	7 632	5 724	137 376
5	64-QAM	2/3	6	636	22	11 448	7 632	183 168
6	64-QAM	3/4	6	636	22	11 448	8 586	206 064
7	64-QAM	5/6	6	636	22	11 448	9 540	228 960
8	256-QAM	3/4	8	636	22	15 264	11 448	274 752
9	256-QAM	5/6	8	636	22	15 264	12 720	305 280
10	1024-QAM	3/4	10	636	22	19 080	14 310	343 440
11	1024-QAM	5/6	10	636	22	19 080	15 900	381 600

Table 49: MCSs for 20,736 MHz, N_{SS} = 4

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	636	22	2 544	1 272	30 528
1	QPSK	1/2	2	636	22	5 088	2 544	61 056
2	QPSK	3/4	2	636	22	5 088	3 816	91 584
3	16-QAM	1/2	4	636	22	10 176	5 088	122 112
4	16-QAM	3/4	4	636	22	10 176	7 632	183 168
5	64-QAM	2/3	6	636	22	15 264	10 176	244 224
6	64-QAM	3/4	6	636	22	15 264	11 448	274 752
7	64-QAM	5/6	6	636	22	15 264	12 720	305 280
8	256-QAM	3/4	8	636	22	20 352	15 264	366 336
9	256-QAM	5/6	8	636	22	20 352	16 960	407 040
10	1024-QAM	3/4	10	636	22	25 440	19 080	457 920
11	1024-QAM	5/6	10	636	22	25 440	21 200	508 800

Table 50: MCSs for 20,736 MHz, N_{SS} = 5

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	636	22	3 180	1 590	38 160
1	QPSK	1/2	2	636	22	6 360	3 180	76 320
2	QPSK	3/4	2	636	22	6 360	4 770	114 480
3	16-QAM	1/2	4	636	22	12 720	6 360	152 640
4	16-QAM	3/4	4	636	22	12 720	9 540	228 960
5	64-QAM	2/3	6	636	22	19 080	12 720	305 280
6	64-QAM	3/4	6	636	22	19 080	14 310	343 440
7	64-QAM	5/6	6	636	22	19 080	15 900	381 600
8	256-QAM	3/4	8	636	22	25 440	19 080	457 920
9	256-QAM	5/6	8	636	22	25 440	21 200	508 800
10	1024-QAM	3/4	10	636	22	31 800	23 850	572 400
11	1024-QAM	5/6	10	636	22	31 800	26 500	636 000

Table 51: MCSs for 20,736 MHz, N_{SS} = 6

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	636	22	3 816	1 908	45 792
1	QPSK	1/2	2	636	22	7 632	3 816	91 584
2	QPSK	3/4	2	636	22	7 632	5 724	137 376
3	16-QAM	1/2	4	636	22	15 264	7 632	183 168
4	16-QAM	3/4	4	636	22	15 264	11 448	274 752
5	64-QAM	2/3	6	636	22	22 896	15 264	366 336
6	64-QAM	3/4	6	636	22	22 896	17 172	412 128
7	64-QAM	5/6	6	636	22	22 896	19 080	457 920
8	256-QAM	3/4	8	636	22	30 528	22 896	549 504
9	256-QAM	5/6	8	636	22	30 528	25 440	610 560
10	1024-QAM	3/4	10	636	22	38 160	28 620	686 880
11	1024-QAM	5/6	10	636	22	38 160	31 800	763 200

6.3.4.8 MCS parameters for 27,648 MHz

Table 52: MCSs for 27,648 MHz, N_{SS} = 1

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	936	32	936	468	11 232
1	QPSK	1/2	2	936	32	1 872	936	22 464
2	QPSK	3/4	2	936	32	1 872	1 404	33 696
3	16-QAM	1/2	4	936	32	3 744	1 872	44 928
4	16-QAM	3/4	4	936	32	3 744	2 808	67 392
5	64-QAM	2/3	6	936	32	5 616	3 744	89 856
6	64-QAM	3/4	6	936	32	5 616	4 212	101 088
7	64-QAM	5/6	6	936	32	5 616	4 680	112 320
8	256-QAM	3/4	8	936	32	7 488	5 616	134 784
9	256-QAM	5/6	8	936	32	7 488	6 240	149 760
10	1024-QAM	3/4	10	936	32	9 360	7 020	168 480
11	1024-QAM	5/6	10	936	32	9 360	7 800	187 200

Table 53: MCSs for 27,648 MHz, N_{SS} = 2

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	936	32	1 872	936	22 464
1	QPSK	1/2	2	936	32	3 744	1 872	44 928
2	QPSK	3/4	2	936	32	3 744	2 808	67 392
3	16-QAM	1/2	4	936	32	7 488	3 744	89 856
4	16-QAM	3/4	4	936	32	7 488	5 616	134 784
5	64-QAM	2/3	6	936	32	11 232	7 488	179 712
6	64-QAM	3/4	6	936	32	11 232	8 424	202 176
7	64-QAM	5/6	6	936	32	11 232	9 360	224 640
8	256-QAM	3/4	8	936	32	14 976	11 232	269 568
9	256-QAM	5/6	8	936	32	14 976	12 480	299 520
10	1024-QAM	3/4	10	936	32	18 720	14 040	336 960
11	1024-QAM	5/6	10	936	32	18 720	15 600	374 400

Table 54: MCSs for 27,648 MHz, N_{SS} = 3

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	936	32	2 808	1 404	33 696
1	QPSK	1/2	2	936	32	5 616	2 808	67 392
2	QPSK	3/4	2	936	32	5 616	4 212	101 088
3	16-QAM	1/2	4	936	32	11 232	5 616	134 784
4	16-QAM	3/4	4	936	32	11 232	8 424	202 176
5	64-QAM	2/3	6	936	32	16 848	11 232	269 568
6	64-QAM	3/4	6	936	32	16 848	12 636	303 264
7	64-QAM	5/6	6	936	32	16 848	14 040	336 960
8	256-QAM	3/4	8	936	32	22 464	16 848	404 352
9	256-QAM	5/6	8	936	32	22 464	18 720	449 280
10	1024-QAM	3/4	10	936	32	28 080	21 060	505 440
11	1024-QAM	5/6	10	936	32	28 080	23 400	561 600

Table 55: MCSs for 27,648 MHz, N_{SS} = 4

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	936	32	3 744	1 872	44 928
1	QPSK	1/2	2	936	32	7 488	3 744	89 856
2	QPSK	3/4	2	936	32	7 488	5 616	134 784
3	16-QAM	1/2	4	936	32	14 976	7 488	179 712
4	16-QAM	3/4	4	936	32	14 976	11 232	269 568
5	64-QAM	2/3	6	936	32	22 464	14 976	359 424
6	64-QAM	3/4	6	936	32	22 464	16 848	404 352
7	64-QAM	5/6	6	936	32	22 464	18 720	449 280
8	256-QAM	3/4	8	936	32	29 952	22 464	539 136
9	256-QAM	5/6	8	936	32	29 952	24 960	599 040
10	1024-QAM	3/4	10	936	32	37 440	28 080	673 920
11	1024-QAM	5/6	10	936	32	37 440	31 200	748 800

Table 56: MCSs for 27,648 MHz, N_{SS} = 5

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	936	32	4 680	2 340	56 160
1	QPSK	1/2	2	936	32	9 360	4 680	112 320
2	QPSK	3/4	2	936	32	9 360	7 020	168 480
3	16-QAM	1/2	4	936	32	18 720	9 360	224 640
4	16-QAM	3/4	4	936	32	18 720	14 040	336 960
5	64-QAM	2/3	6	936	32	28 080	18 720	449 280
6	64-QAM	3/4	6	936	32	28 080	21 060	505 440
7	64-QAM	5/6	6	936	32	28 080	23 400	561 600
8	256-QAM	3/4	8	936	32	37 440	28 080	673 920
9	256-QAM	5/6	8	936	32	37 440	31 200	748 800
10	1024-QAM	3/4	10	936	32	46 800	35 100	842 400
11	1024-QAM	5/6	10	936	32	46 800	39 000	936 000

Table 57: MCSs for 27,648 MHz, N_{SS} = 6

MCS	Modulation	R	N_{BPSC}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate
0	BPSK	1/2	1	936	32	5 616	2 808	67 392
1	QPSK	1/2	2	936	32	11 232	5 616	134 784
2	QPSK	3/4	2	936	32	11 232	8 424	202 176
3	16-QAM	1/2	4	936	32	22 464	11 232	269 568
4	16-QAM	3/4	4	936	32	22 464	16 848	404 352
5	64-QAM	2/3	6	936	32	33 696	22 464	539 136
6	64-QAM	3/4	6	936	32	33 696	25 272	606 528
7	64-QAM	5/6	6	936	32	33 696	28 080	673 920
8	256-QAM	3/4	8	936	32	44 928	33 696	808 704
9	256-QAM	5/6	8	936	32	44 928	37 440	898 560
10	1024-QAM	3/4	10	936	32	56 160	42 120	1 010 880
11	1024-QAM	5/6	10	936	32	56 160	46 800	1 123 200

7 Further technical work on selected topics

7.1 About this clause

This clause presents initial simulation results for some physical layer configurations. Some aspects of MIMO operation are also discussed.

7.2 Preliminary simulation results

7.2.1 General

Performance of two packet types are investigated, namely "High-efficiency Full-Slot" (HE-FS) packet type and "Standard Long Preamble" (ST-LP) packet type. Results are presented in two forms:

1) Packet Error Rate (PER) vs. Signal-to-Noise Ratio (SNR) at the receiver *digital* input(s); and

2) Data Rate vs. SNR.

SNR is defined as the *total* signal power at all receiver inputs divided by the noise power at each individual receiver input. Noise bandwidth is determined by the baseband channel bandwidth. Data Rate is the max information rate of the packet data field, defined as the number of information bits carried by one OFDM symbol divided by the symbol duration.

7.2.2 Simulation conditions

Performance analysis is done for two channel models:

1) Gaussian channel (AWGN); and

2) Exponential Power Profile channel (EXPP). EXPP channel is characterized by its RMS time delay parameter, t_{RMS}.

Typical in-doors environments correspond to RMS delays in the range $50\ ns \leq t_{RMS} \leq 200\ ns$. Results presented in this clause reflect losses due to channel additive noise and channel response estimation errors. Results do not reflect losses due to carrier, sampling time and frame synchronization errors, which are assumed perfect. Furthermore, results do not reflect losses due to RF/analogue front-end and digital baseband quantization errors. In all cases binary convolutional coding FEC technique is used with coding rate corresponding to MCS definitions described in previous clauses. HE packet payloads vary according to MCS parameter to maintain total packet duration of one slot ($416{,}67\ \mu s$). LP packet payloads vary according to MCS parameter to match corresponding HE packets.

7.2.3 Simulation of HE-FS packets

Figure 16 depicts HE-FS performance in terms of PER vs. SNR for various MCS cases, in a Gaussian channel. Figure 17 compares data rates for various channel types: Gaussian channel, Gaussian channel assuming perfect channel knowledge (channel estimation disabled), Exponential multipath channel with $t_{RMS} = 100\ ns$, and Exponential multipath channel with $t_{RMS} = 150\ ns$.

Packet variant 1 from table 4 (clause 6.3.2.2.2.2) over a dual carrier channel (3,456 MHz) has been used in the simulations.

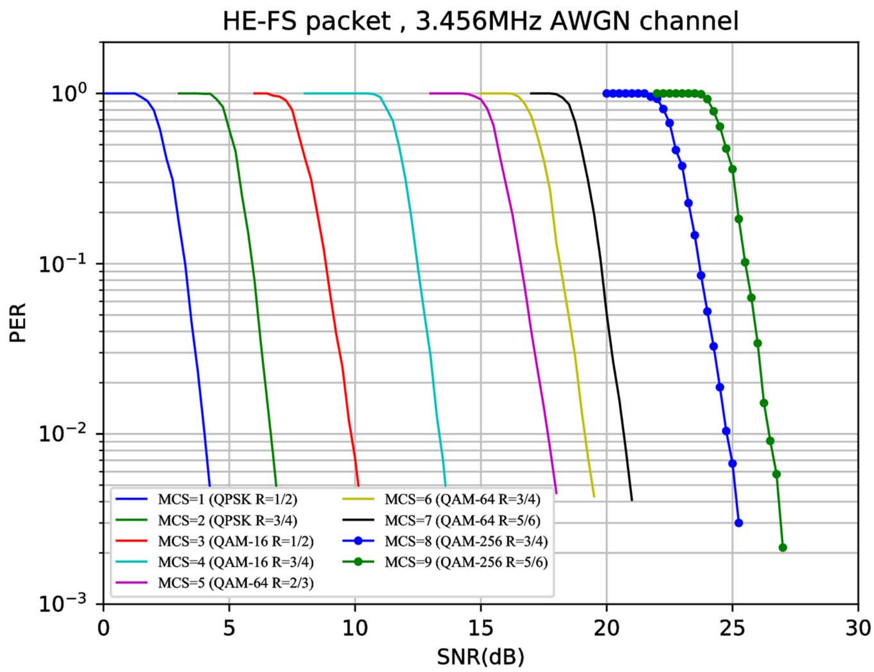

Figure 16: Performance of HE-FS packets, 3,456 MHz Gaussian channel, MCS1-9

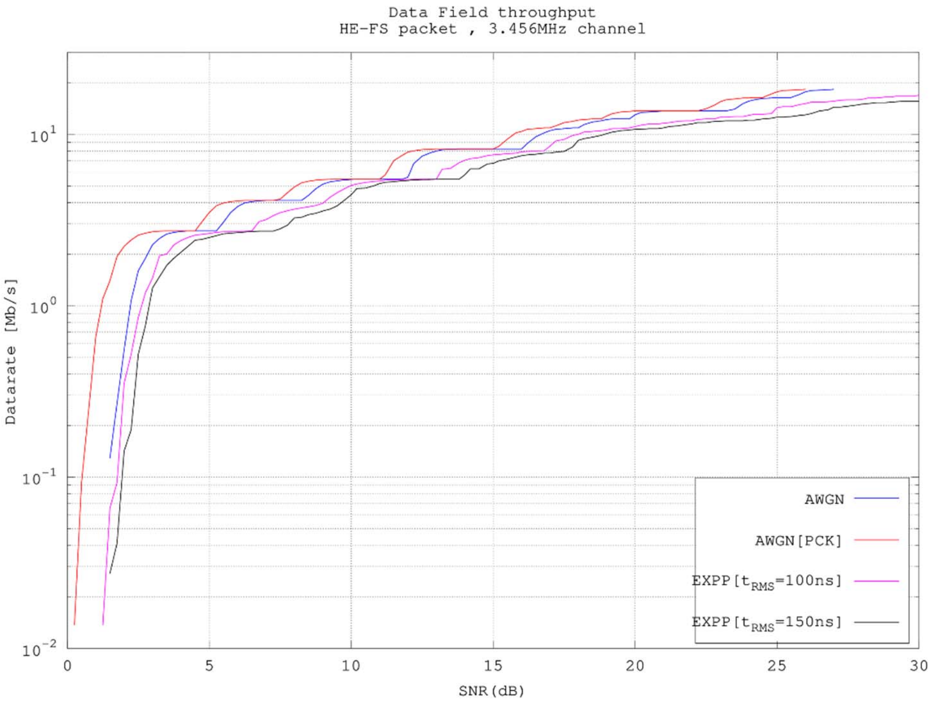

Figure 17: Performance of HE-FS packets, 3,456 MHz channels

7.2.4 Simulation of ST-LP packets

Figure 18 depicts ST-LP performance in terms of PER vs. SNR for various MCS cases, in a Gaussian channel. Figure 19 compares data rates for various channel types: Gaussian channel, Exponential multipath channel with $t_{RMS} = 150\ ns$ with single receiver antenna, and Exponential multipath channel with $t_{RMS} = 150\ ns$ with two receiver antennas. In the latter case the receiver uses maximum-ratio combining (MRC) on the pair of receive paths, to achieve diversity gain.

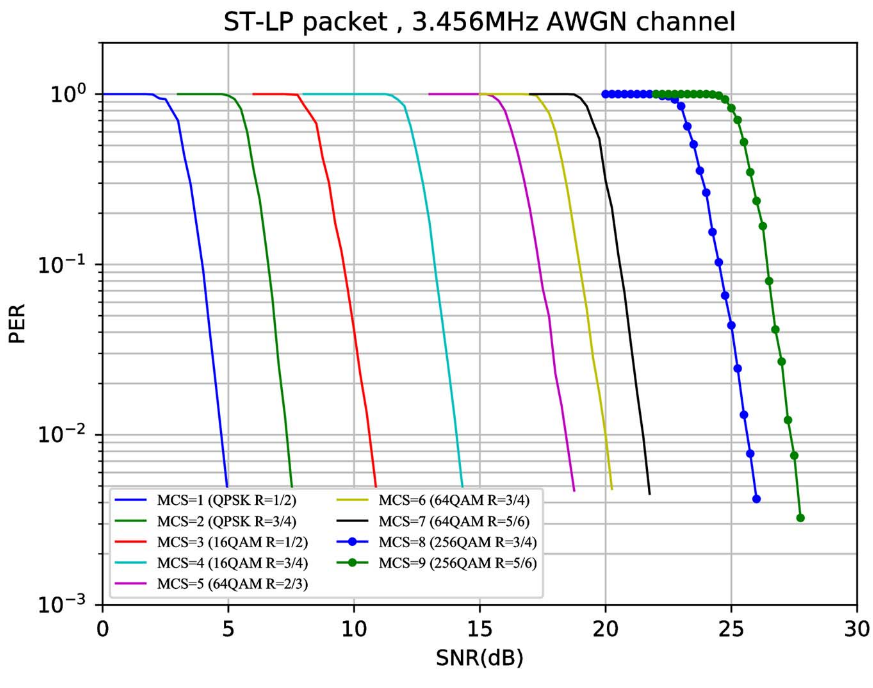

Figure 18: Performance of ST-LP packets, 3,456 MHz Gaussian channel, MCS1-9

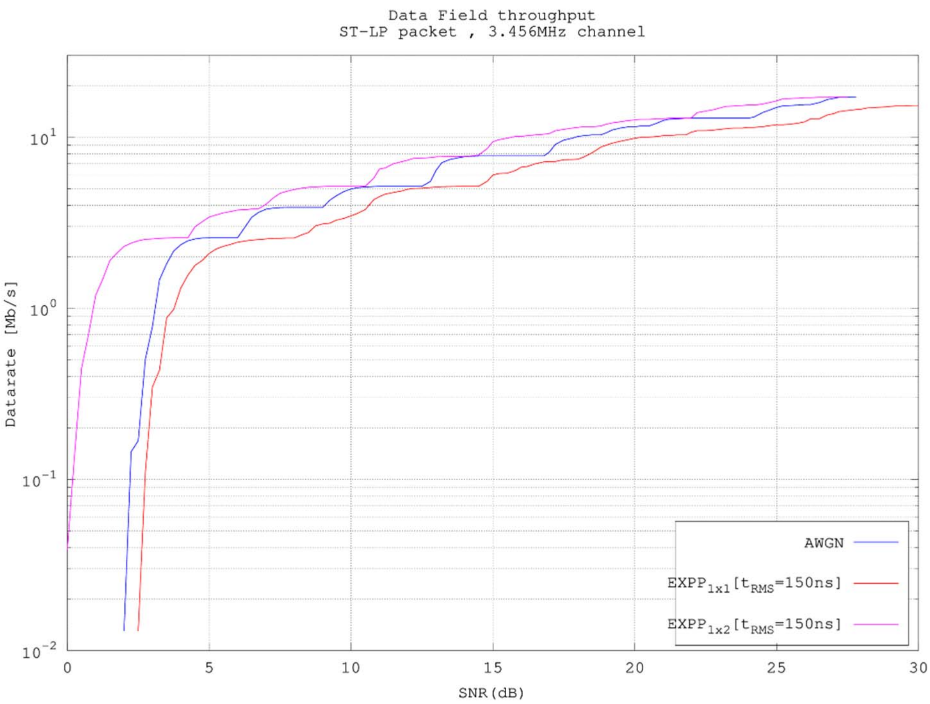

Figure 19: Performance of ST-LP packets, 3,456 MHz channels

7.2.5 Shadow fading margin simulation

Shadow fading margin (SFM) is a parameter affecting link budget calculations. Shadow fading attenuation A_{SF} is characterized as a Gaussian random variable with zero mean and a given standard deviation σ_{SF} , expressed in dB, that is, $A_{SF} \sim \mathcal{N}(0, \sigma_{SF}^2)$. In simulation, for each packet transmission a different realization of A_{SF} is used.

For the purpose of link budget calculations, an initial estimation of system performance can be obtained by first simulating the system with 0 dB shadow fading, and then using the results to simulate shadow fading effect. The goal is to calculate a suitable SFM value that ensures a desired system performance.

As an example, figure 20 shows the estimated PER vs. SNR function. For experiments involving shadow fading, the SNR is itself a random variable with PDF centered at some μ_{SNR}.

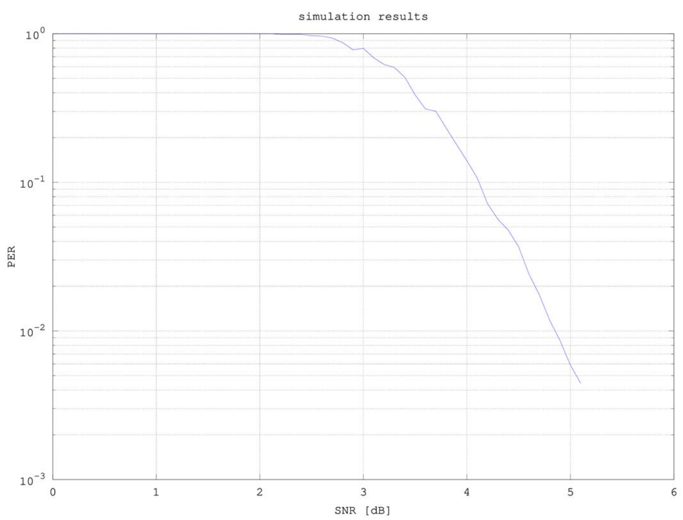

Figure 20: Actual simulation results PER vs. SNR

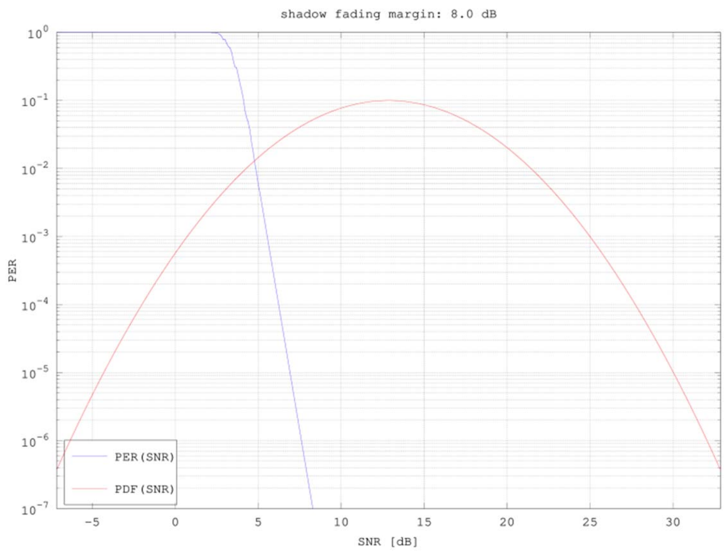

Figure 21: Extrapolated PER results and SNR PDF

Figure 22 shows the "optimal" SFM obtained by numerical integration for various μ_{SNR} values.

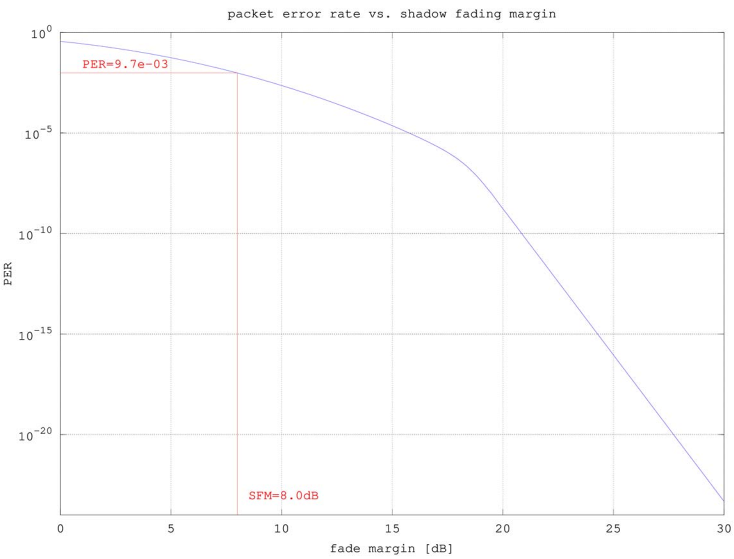

Figure 22: Optimal SFM

7.2.6 Transmit and receive example

This clause presents a preliminary example of FP signal construction and PP receiver processing. Figures 24 and 25 depict the transmitted signal, which is composed of four individual packets of different length, modulation and coding.

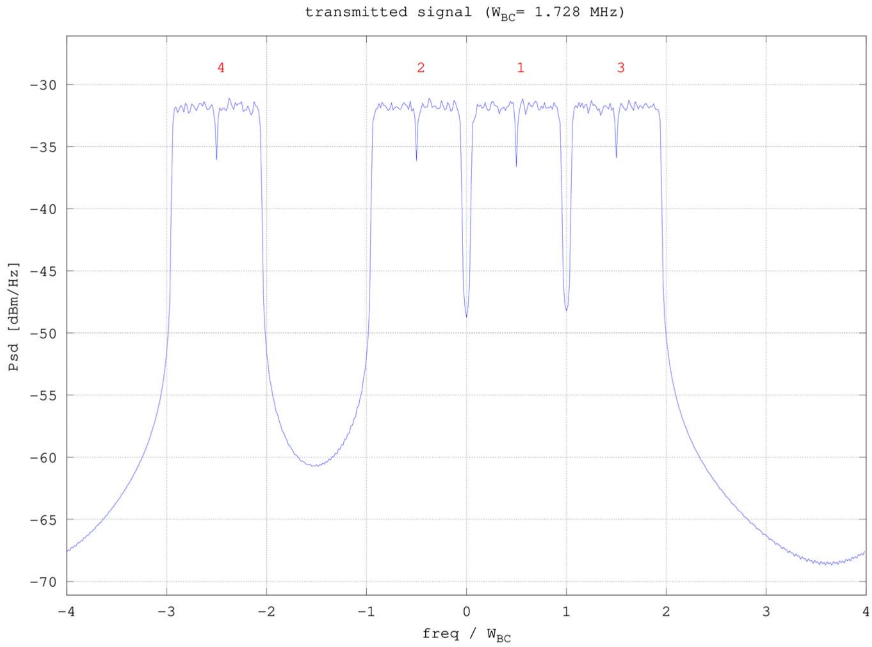

Figure 23: FP baseband signal: power spectral density

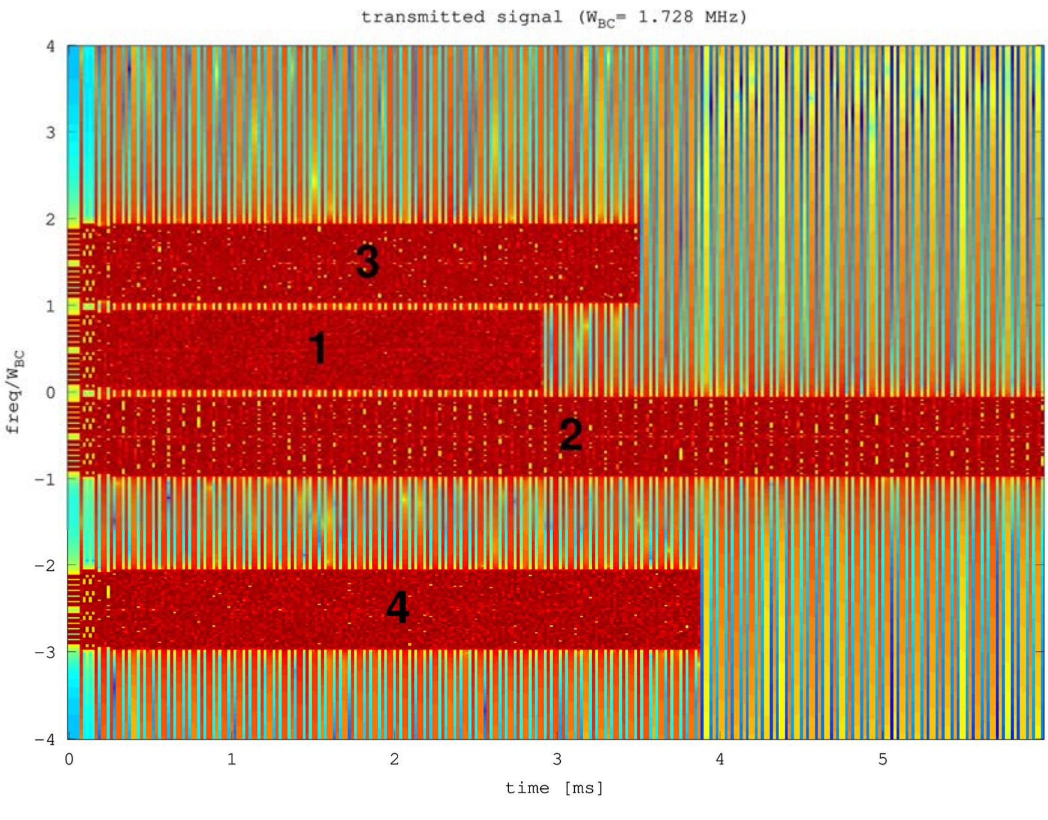

Figure 24: FP baseband signal: signal spectrogram

On the PP side the baseband digitized signal may be down-mixed according to the channel of interest (Figure 25), and subsequently filtered and down-sampled. Figures 26 to 29 depict a 3-stage down-sampling process.

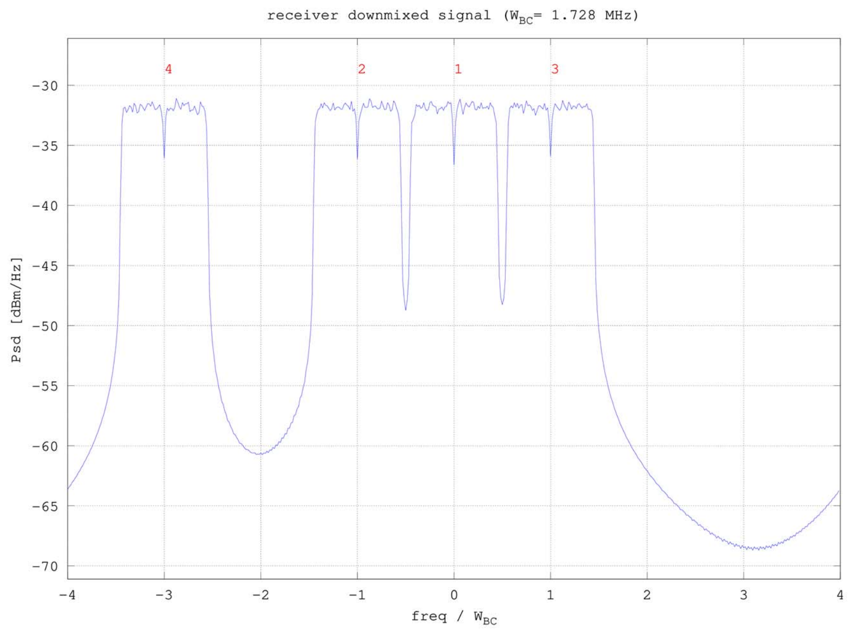

Figure 25: Baseband signal down-mixing

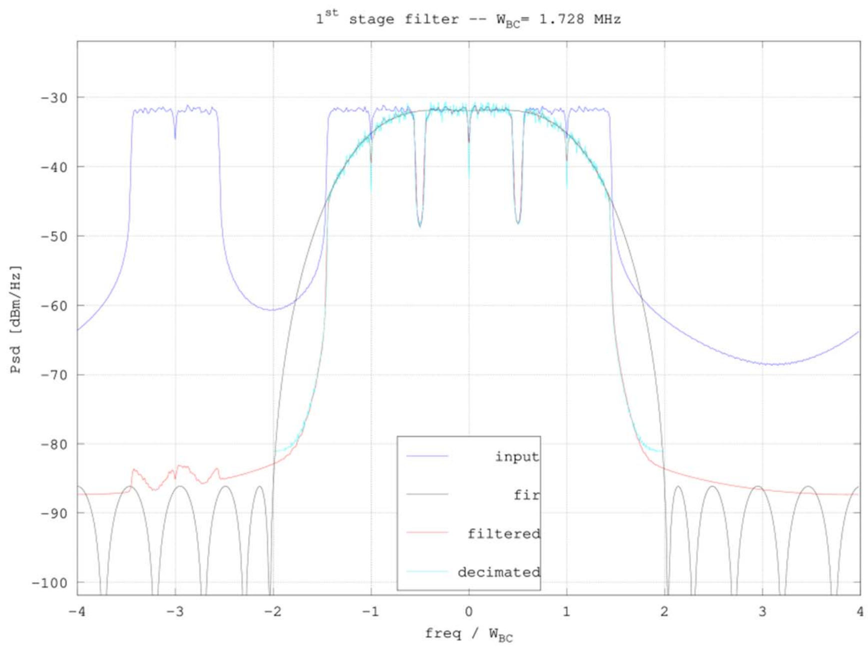

Figure 26: First stage down-sampling (13-tap type-I FIR)

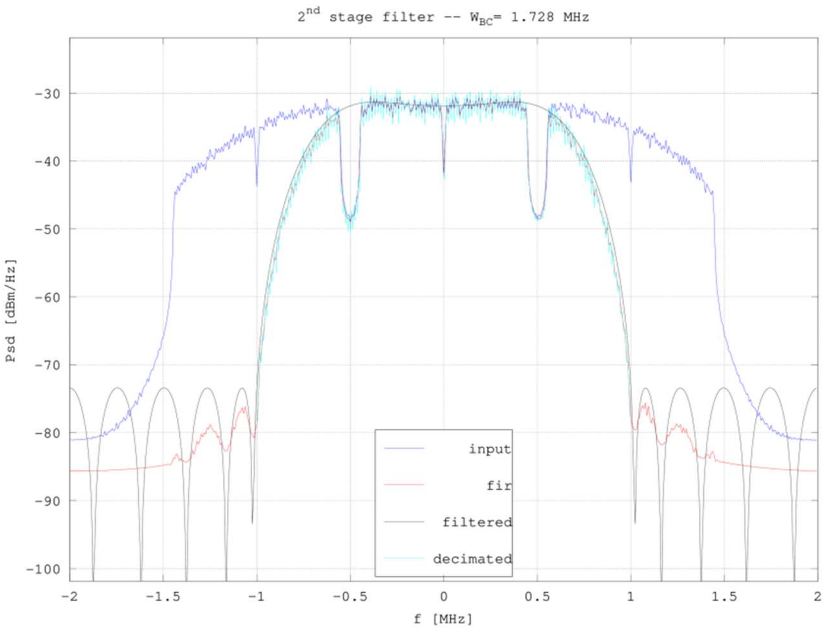

Figure 27: Second stage down-sampling (15-tap type-I FIR)

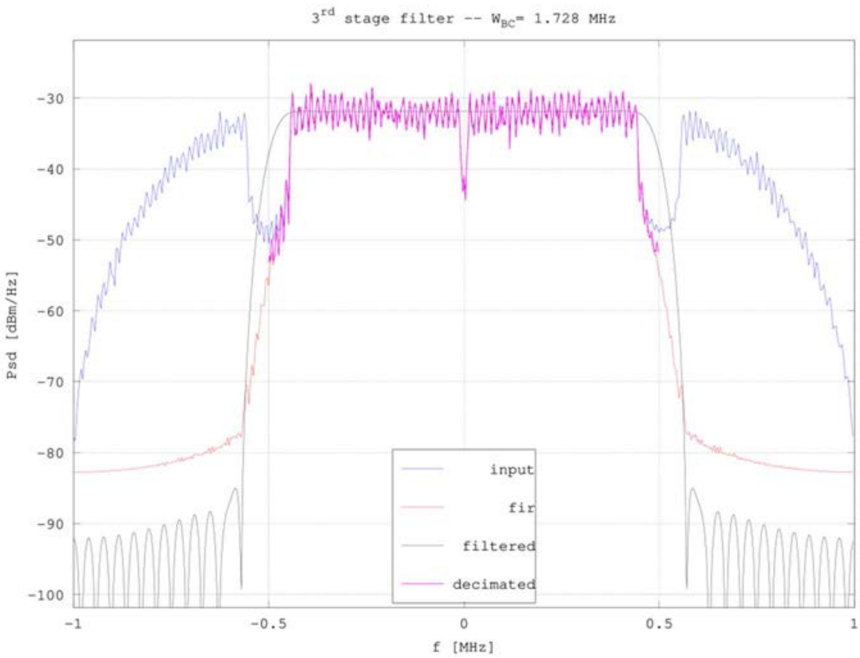

Figure 28: Last stage down-sampling (51-tap half-band FIR)

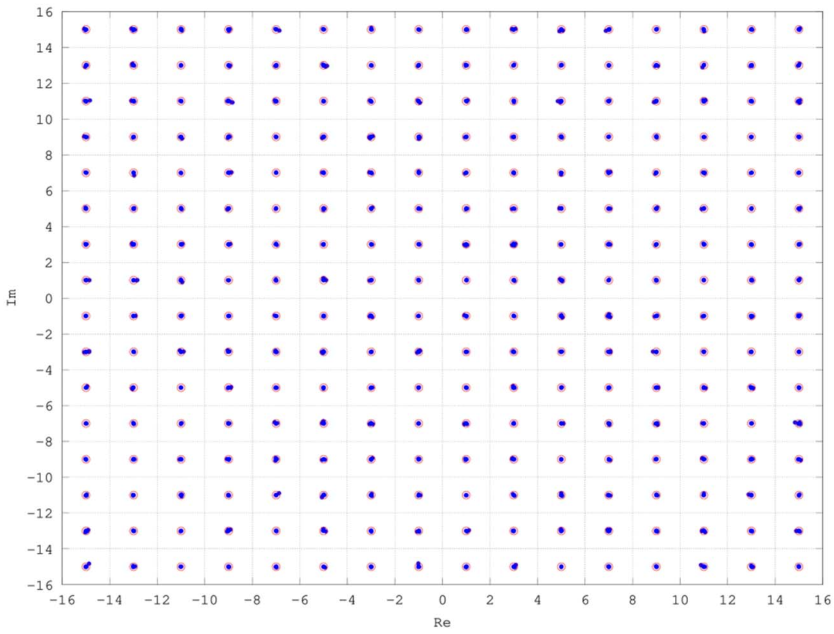

Figure 29: Transmitted (○) and received (●) constellation symbols

The down-sampled signal is input to the remaining receiver processing stages. Calculated EVM for HF and DF fields are -60 dB and -53 dB, respectively. A payload of 2 200 bytes is successfully decoded.

7.3 Preliminary study of MIMO

7.3.1 MIMO in transmissions using standard packet types

Standard packet types contain channel training fields based on the number of transmitted space-time layers, which enables channel estimation at the receiver free of inter-layer interference. Space-time layer separation, combined with suitable frequency domain filtering, enables robust MIMO link performance. These methods have been successfully implemented in connection to multiple communication standards, including IEEE 802.11ac [i.21].

7.3.2 MIMO in transmissions using HE packet types

Unlike standard packet types, HE packets employ channel training symbols co-located in time, as depicted in Figure 30. The gain in channel utilization comes at the expense of inherent inter-layer interference, which should be managed in order to achieve acceptable error levels. A trade-off is made between channel estimation errors and inter-layer interference by choosing appropriate pilot sequences for the desired operating point.

An example of *noiseless* ($SNR = \infty$) MIMO simulation 2 two spatial layers and 3 receiver antennas is shown in Figure 31 through Figure 35. Figure 31 depicts subcarrier values in the complex plane for each pilot. Figure 32 through Figure 34 compare estimated vs. actual channel frequency responses for each TX to RX path. Finally, Figure 35 displays equalized vs. actual data constellation points in the complex plane. The effects of inter-layer interference are noticeable in Figure 35. The resulting equalized data EVM is -33,5 dB. The same example with $SNR = 20\ dB$ results in equalized data EVM of -20,4 dB. See Figure 36. Proper choice of pilot sequences and channel estimation procedure results in relatively small inter-layer interference compared to channel noise.

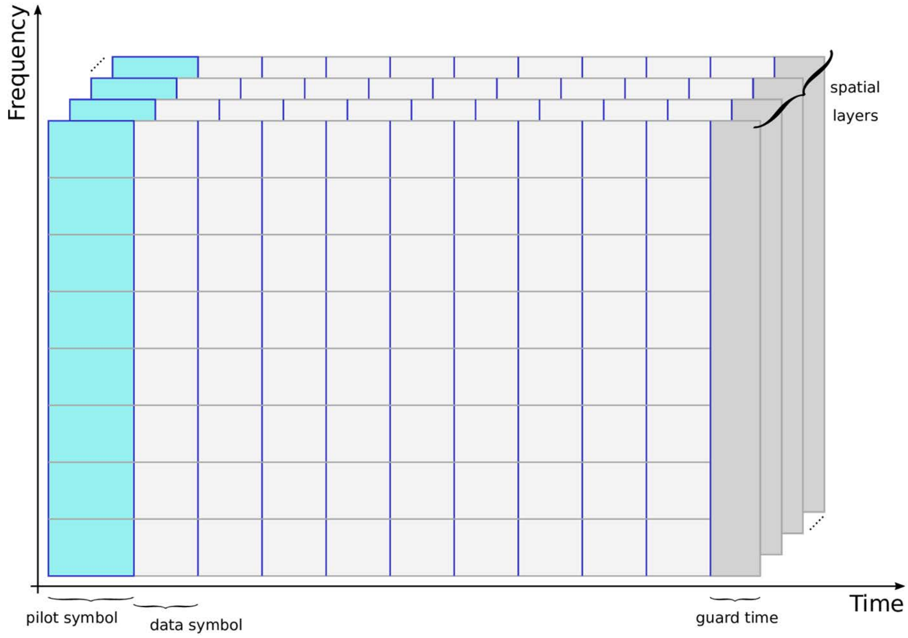

Figure 30: HE-FS MIMO transmission

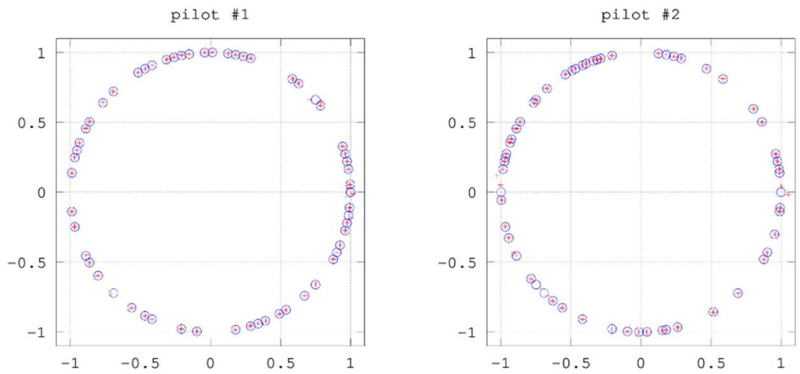

Figure 31: HE-FS pilot subcarrier symbols for 2-layer transmission

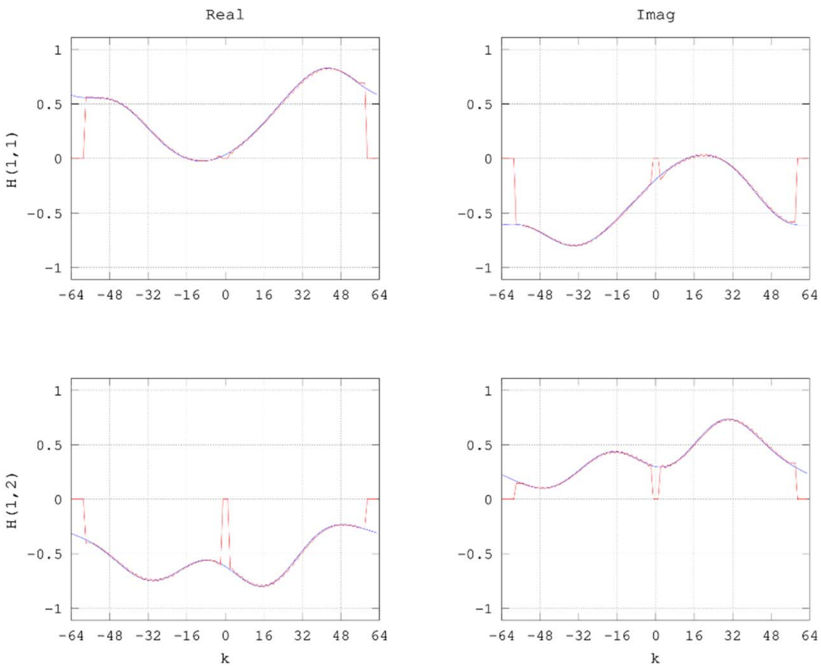

Figure 32: HE-FS 2x3 MIMO, channel estimation vs. actual (1/3)

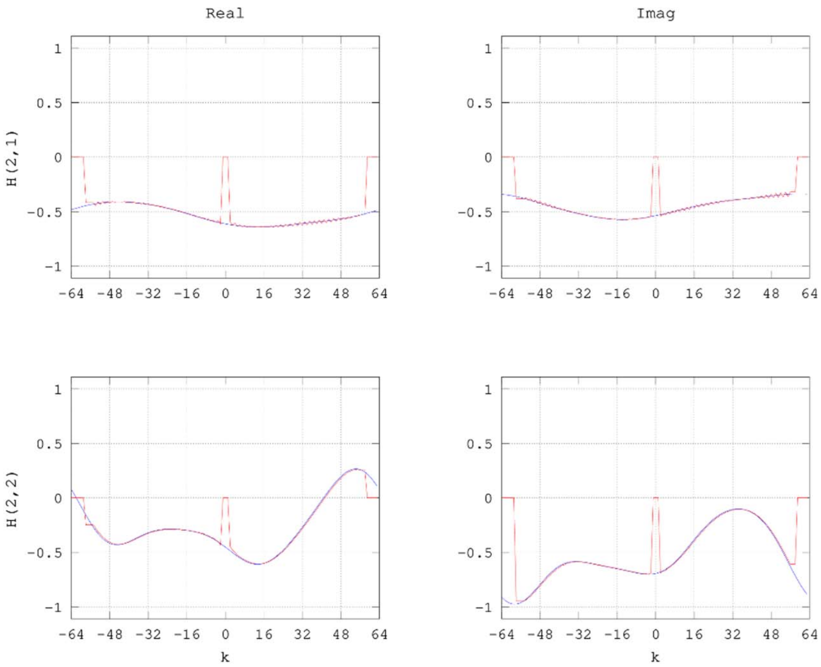

Figure 33: HE-FS 2x3 MIMO, channel estimation vs. actual (2/3)

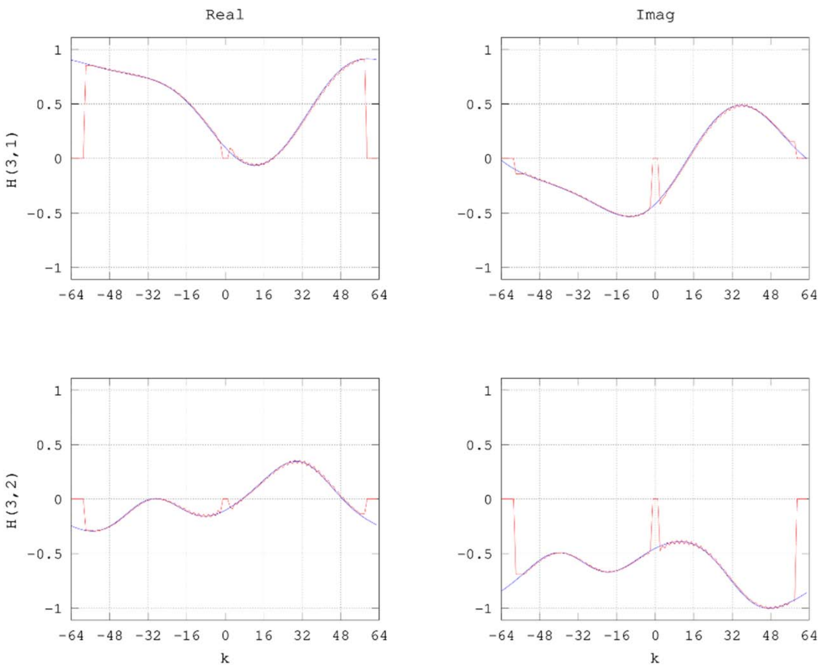

Figure 34: HE-FS 2x3 MIMO, channel estimation vs. actual (3/3)

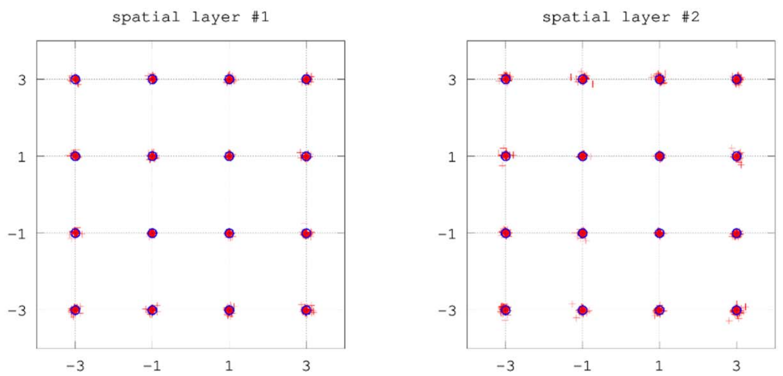

Figure 35: HE-FS 2x3 MIMO, equalized constellations

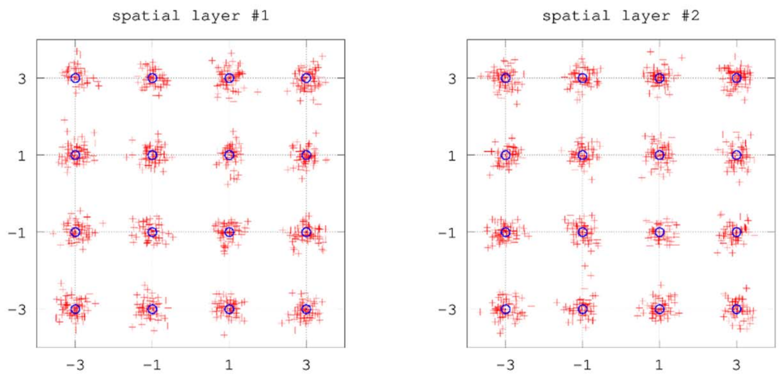

Figure 36: HE-FS 2x3 MIMO, equalized constellations (SNR = 20 dB)

History

Document history		
V1.1.1	July 2018	Publication