Techniques for pre and post Forward Error Correction and packet padding in radio transmission

TECHNICAL FIELD

The present disclosure relates to techniques for pre Forward Error Correction (FEC), post Forward Error Correction and packet padding in radio transmission. The disclosure particularly relates to WiFi radio transmission and packet extension (PE) and pre/post-FEC padding in WiFi radio transmission.

BACKGROUND

In radio transmission using OFDM (Orthogonal Frequency Division Multiplex), some padding at the end of the packet that does not contain any information is inserted to relax processing requirements. This padding artificially increases the packet, allowing the receiver to complete the decoding processing. In radio communication according to WiFi standard, for example according to IEEE 802.11ax, packet extension (PE) and pre&post FEC were introduced to relax the processing requirements. These two mechanisms were introduced based on specific requirements for number of spatial streams, resource unit (RU) size and QAM (Quadrature Amplitude Modulation) size. When a new version of the radio communication standard, e.g. a new version of WiFi according to IEEE 802.11be, is introduced, these original requirements for number of spatial streams, RU size and QAM size require an update by introducing additional values.

As the new standard, in particular IEEE 802.11be is going to support higher values for number of spatial streams, RU size and QAM size, the definitions, signalling and usage of PE & pre&post-FEC padding needs to be revised.

SUMMARY

It is the object of this disclosure to provide techniques for improving performance of radio transmission in advanced communication schemes such as EHT (Extreme High Throughput) WiFi, for example according to IEEE 802.11be.

In particular, it is an object of this disclosure to update the definitions, signalling and usage of PE & pre&post-FEC padding in new radio transmission standards such as EHT WiFi, for example according to IEEE 802.11be.

This object is achieved by the features of the independent claims. Further implementation forms are apparent from the dependent claims, the description and the figures.

A basic idea of this disclosure is to apply a new definition of packet extension and pre&post Forward Error Correction (FEC) padding that is compliant to the new radio transmission standard, for example EHT WiFi, e.g. according to IEEE 802.11be.

An appropriate pre&post-FEC and packet extension mechanism is designed particularly for IEEE 802.11be. This mechanism is based on the mechanism that was defined in the current standard IEEE 802.11ax (IEEE 802.11-15/0810, September 2015: HE PHY Padding and Packet Extension) which is not suitable to the new features that are added to the new standard.

IEEE 802.11be introduces three aspects which require adaptation of the pre&post-FEC parameters: bandwidth of 240MHz (achieved by puncturing 80MHz within a BW of 320MHz) and/or 320MHz; multi-RUs; and 4K-QAM. In order to evaluate these aspects, the disclosure illustrates potential values for N_{SD_Short} and their impact on N_{CBPS_Short}, N_{DBPS_Short} and N_{DBPS_Short}/N_{ES}, considering the requirement for maintaining integer values. It can be shown by validating link-level simulation, that there is no real impact by slightly modifying the value of N_{SD_Short}. In the disclosure, values are chosen that work with/without DCM, considering that BCC is limited to ≤242-tone RUs (and therefore requires an integer N_{DBPS_Short}/N_{ES}).

In order to describe the invention in detail, the following terms, abbreviations and notations will be used:

FEC	Forward Error Correction
Post-FEC	Post Forward Error Correction
Pre-FEC	Pre Forward Error Correction
PE	Packet Extension
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
QAM	Quadrature Amplitude Modulation
BW	bandwidth
N_{SD_Short}	number of subcarrier per symbol
N_{CBPS_Short}	number of coded bits per symbol
N_{DBPS_Short}	number of data bits per symbol
RU	resource unit
STA	Station according to WiFi notation
AP	Access point according to WiFi notation
EHT	Extreme High Throughput
SIFS	Short Interframe Space
PPDU	Physical Protocol Data Unit

Resource Unit (RU) is a unit in OFDMA terminology used in WiFi schemes to denote a group of subcarriers (tones) used in both Downlink (DL) and Uplink (UL) transmissions. With OFDMA, different transmit powers may be applied to different RUs. There are maximum of 9 RUs for 20 MHz bandwidth, 18 in case of 40 MHz and more in case of 80 or 160 MHz bandwidth. The RUs enable an Access Point to allow multi-users to access it simultaneously and efficiently.

Short Interframe Space (SIFS), is the amount of time in microseconds required for a wireless interface to process a received frame and to respond with a response frame. It is the difference in time between the first symbol of the response frame in the air and the last symbol of the received frame in the air.

In this disclosure pre and post Forward Error Correction (FEC) parameters are described, also abbreviated as pre&post-FEC parameters or pre/post FEC parameters. Pre-FEC parameters are related to pre-FEC padding and corresponding pre-FEC padding bits. Post-FEC parameters are related to post-FEC padding and corresponding post-FEC padding bits. Pre-FEC padding is performed before Forward Error Correction (FEC) while post FEC padding is performed after Forward Error Correction (FEC), e.g. according to the illustration shown in Figure 1. While this disclosure defines the terms pre&post-FEC and pre/post-FEC parameters, these terms should be understood in the meaning of pre and/or post FEC parameters, i.e., including the three cases that 1) both pre-FEC padding and post-FEC padding is applied; 2) only post-FEC padding is applied; and 3) only pre-FEC padding is applied.

According to a first aspect, the disclosure relates to a communication device, configured to: transmit and/or receive a data frame based on a set of pre&post-Forward Error Correction, FEC, parameters and a set of packet extension, PE, parameters, wherein the set of pre&post-FEC parameters is based on an extension of a set of pre&post-FEC parameters defined for a second radio transmission technology with respect to a size of resource units, RUs, supported by a first radio transmission technology, wherein the set of pre&post-FEC parameters is based on a combination of RUs that is supported by the first radio transmission technology and wherein the set of PE parameters is based on an extension of a set of PE parameters defined for the second radio transmission technology with respect to a constellation size, a number of total space time streams and a resource unit, RU, allocation size supported by the first radio transmission technology.

By transmitting/receiving a data frame based on such a new definition of pre&post-FEC parameters and PE parameters, the communication device improves performance of radio transmission in advanced communication schemes such as EHT WiFi, e.g. according to IEEE 802.11be. This new definition of packet extension and pre&post Forward Error Correction padding is compliant to the new radio transmission standard, for example EHT WiFi, e.g. according to IEEE 802.11be.

The first and second radio transmission technologies can be WiFi technologies, the second radio transmission technology can be an existing WiFi technology, while the first radio technology can be a new WiFi technology, e.g. a new WiFi technology having higher bandwidth, multi-resource units and/or higher constellation scheme. For example, the first radio transmission technology can be 802.11be WiFi and the second radio transmission technology can be 802.11ax WiFi.

The first and second radio transmission technologies can be the same (with different settings) or different (with different capabilities).

A multiple RU as defined by the new first radio transmission technology is formed from a combination of two or more RUs defined by the old second radio transmission technology.

In an exemplary implementation of the communication device, the communication device is configured to: determine where a post-padding begins in the data frame based on the set of pre&post-FEC parameters, wherein the set of pre&post-FEC parameters is based on: an integer number of data subcarriers for a last symbol of the data frame, N_{SD_Short}, as defined by an extended N_{SD_Short} table, wherein the extended N_{SD_Short} table is an extension of a N_{SD_Short} table defined by the second radio transmission technology with respect to additional values of N_{SD_Short} defined by the first radio transmission technology, an integer number of coded bits per symbol for the last symbol of the data frame, N_{CBPS_Short}, wherein N_{CBPS_Short} depends on N_{SD_Short}, and an integer number of data bits per symbol for the last symbol of the data frame, N_{DBPS_Short}, wherein N_{DBPS_Short} depends on N_{CBPS_Short}.

This provides the advantage that the set of pre&post-FEC parameters indicates where the post-padding begins in the data frame and hence post-padding can be efficiently performed by using that information.

Four pre-FEC padding boundaries partition the last OFDM symbol (or 2 last symbols if space-time-coding is used) of an HE PPDU and EHT PPDU into four symbol segments. The pre-FEC padding may pad toward one of the four possible boundaries. The post-FEC padding bits are then used to pad the remaining symbol segments. In other words, the pre-FEC padding bits ensure that the FEC output bits in the last OFDM symbols end up with one of the 4 segments‘ boundaries as exemplarily illustrated in Figure 2.

The pre&post-FEC parameters are also called “pre&post-FEC padding parameters” since these are the parameters that set the amount of padding bits in the last symbol of a data frame (or the last 2 symbols of a data frame when space-time-coding is applied). With pre&post-FEC padding, portions of ¼ of the last OFDM symbol (i.e. ¼, ½, ¾) are padded after encoding; these portions need not be decoded.

In an exemplary implementation of the communication device, the set of pre&post-FEC parameters is based on an extension of an N_{SD_Short} table defined for the second radio transmission technology with respect to combinations of RU values supported by the first radio transmission technology, wherein the N_{SD_Short} table comprises predefined numbers of N_{SD_Short} values.

This provides the advantage that the extended N_{SD_Short} table can be easily derived from the existing N_{SD_Short} table and efficiently used to perform pre&post-padding for the first radio transmission technology.

In an exemplary implementation of the communication device, the extended N_{SD_Short} table defines the numbers of N_{SD_Short} values for a dual-carrier modulation, DCM, switched on and/or a DCM switched off.

This provides the advantage that dual-carrier modulation can be supported by the new scheme.

In an exemplary implementation of the communication device, the extended N_{SD_Short} table includes one or more of the following combinations of RU values: 52 + 26, 106 + 26, 484 + 242, 996 + 484, 242 + 484 + 996, 484 + 2x996, 3x996, 484 + 3x996, 4x996.

This provides the advantage that multiple combinations of resource unit values can be supported by the new scheme.

In an exemplary implementation of the communication device, for an RU size of 52+26 a value of N_{SD_Short} is 18 for DCM=0, and is 8 for DCM=1, for an RU size of 106+26 a value of N_{SD_Short} is 30 for DCM=0, and is 14 for DCM=1, for an RU size of 484+242 a value of N_{SD_Short} is 180 or 174 for DCM=0, and is 90 for DCM=1, for an RU size of 996+484 a value of N_{SD_Short} is 360 for DCM=0, and is 180 for DCM=1, for an RU size of 242+484+996 a value of N_{SD_Short} is 420 for DCM=0, and is 210 for DCM=1, for an RU size of 484+2x996 a value of N_{SD_Short} is 600 or 606 or 612 for DCM=0, and is 300 or 306 for DCM=1, for an RU size of 3x996 a value of N_{SD_Short} is 720 or 726 or 738 for DCM=0, and is 360 or 366 for DCM=1, for an RU size of 484+3x996 a value of N_{SD_Short} is 840 or 846 or 852 for DCM=0, and is 420 or 426 for DCM=1, for an RU size of 4x996 a value of N_{SD_Short} is 978 or 984 or 990 for DCM=0, and is 486 or 492 for DCM=1. This implementation corresponds to Table 2 shown below.

Possible combinations of RUs are given in the following Example: N_{SD_Short} for 484+242 is exactly N_{SD_Short} (242)+ N_{SD_Short} (484); N_{SD_Short} for 52+26 is exactly N_{SD_Short} (52)+ N_{SD_Short} (26); N_{SD_Short} for 106+26 is exactly N_{SD_Short} (106)+ N_{SD_Short} (26); N_{SD_Short} for 996+484 is exactly N_{SD_Short} (996)+ N_{SD_Short} (484); N_{SD_Short} for 242+484+996 is exactly N_{SD_Short} (242)+ N_{SD_Short} (484) + N_{SD_Short} (996); N_{SD_Short} for 484+2x996 is exactly N_{SD_Short} (484)+ N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 3x996 is exactly N_{SD_Short} (996)+ N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 484+3x996 is exactly N_{SD_Short} (484)+ N_{SD_Short} (996) + N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 4x996 is exactly N_{SD_Short} (996)+ N_{SD_Short} (996) + N_{SD_Short} (996) + N_{SD_Short} (996).

In an exemplary implementation of the communication device, the communication device is configured to add a single padding bit after every $2XN_{DBPS}$ for the combination of RU values equal to 106 + 26, DCM switched-on, single stream and binary phase shift keying modulation with code-rate ½.

In an exemplary implementation of the communication device, the extended set of PE parameters is defined for at least one of an extended modulation scheme of 4K-QAM or higher, an extended number of spatial streams greater than 8 and an extended bandwidth of 240 MHz, 320 MHz or higher.

This provides the advantage that the communication device is suitable to be performed with the new features defined by the EHT WiFi standard.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on an extension of a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology, wherein the PPE thresholds field is extended by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits.

This provides the advantage that the communication device is compliant to the new features defined by the IEEE 802.11be standard.

NSTS is a subfield of PPE thresholds field that defines the maximum number of space time streams supported by a Station.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on an extension of a resource unit allocation index field defined for the second radio transmission

technology, wherein the extended resource unit allocation index field comprises extended resource unit allocation sizes of 3x996 and/or 4x996 or higher.

This provides the advantage that the communication device is compliant to the new features defined by the IEEE 802.11be standard.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on an extension of a constellation index field defined for the second radio transmission technology, wherein the extended constellation index field comprises one or more extended constellations of 4096-QAM or higher.

This provides the advantage that the communication device is compliant to the new features defined by the IEEE 802.11be standard, in particular with a 4K-QAM constellation.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on reusing a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology, wherein the PPE thresholds field is defined for modulation schemes less or equal than 1K-QAM, a number of spatial streams less or equal than 8 and resource unit sizes less or equal than 2x996.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on reusing a PPE thresholds field defined for the second radio transmission technology and based on using a single bit indicating the use of a modulation scheme of 4K-QAM, or indicating a constellation of 4096-QAM in an extended constellation index field without using the single bit.

This provides the advantage that the communication device is compliant to the new features defined by the IEEE 802.11be standard, in particular with a 4K-QAM constellation.

Alternatively, the indication of the constellation by using the single bit is not used. That means, 4K-QAM can be indicated in EHT (802.11be) without any additional bit. So, the only change is the additional value of 4096 in the constellation index table (see Table 3 below). This option is backward compatible with HE (802.11ax) because an HE device will consider the indication “6“ as “NONE“ anyway because it does not know 4K-QAM.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits in order to support up to 16 spatial streams, or indicating a constellation of 4096-QAM in the extended constellation index field without using the single bit.

This provides the advantage that the communication device is compliant to the new features defined by the IEEE 802.11be standard, in particular with a 4K-QAM constellation and a number of 16 spatial

streams. Alternatively, the indication of the constellation by using the single bit is not used as mentioned above.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the size of a resource unit index bitmask to at least 6 bits, or indicating a constellation of 4096-QAM in the extended constellation index field without using the single bit.

This provides the advantage that the communication device is compliant to the new features defined by the IEEE 802.11be standard, in particular with a 4K-QAM constellation. Alternatively, the indication of the constellation by using the single bit is not used as mentioned above.

In an exemplary implementation of the communication device, the extended set of PE parameters is based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits, or indicating a constellation of 4096-QAM in the extended constellation index field without using the single bit.

This provides the advantage that the communication device is compliant to the new features defined by the IEEE 802.11be standard, in particular with a 4K-QAM constellation. Alternatively, the indication of the constellation by using the single bit is not used as mentioned above.

According to a second aspect, the disclosure relates to a communication method, comprising: transmitting and/or receiving a data frame based on a set of pre&post-Forward Error Correction, FEC, parameters and a set of packet extension, PE, parameters, wherein the set of pre&post-FEC parameters is based on an extension of a set of pre&post-FEC parameters defined for a second radio transmission technology with respect to a size of resource units, RUs, supported by a first radio transmission technology, wherein the set of pre&post-FEC parameters is based on a combination of RUs that is supported by the first radio transmission technology and wherein the set of PE parameters is based on an extension of a set of PE parameters defined for the second radio transmission technology with respect to a constellation size, a number of total space time streams and a resource unit, RU, allocation size supported by the first radio transmission technology.

By transmitting/receiving a data frame based on such a new definition of pre&post-FEC parameters and PE parameters, usage of such a communication method improves performance of radio transmission in advanced communication schemes such as EHT WiFi, e.g. according to IEEE 802.11be. This new definition of packet extension and pre&post Forward Error Correction padding is compliant to the new radio transmission standard, for example EHT WiFi, e.g. according to IEEE 802.11be.

According to a third aspect, the disclosure relates to a computer program product including computer executable code or computer executable instructions that, when executed, causes at least one computer

to execute the method according to the second aspect. Such a computer program product may include a non-transient readable storage medium storing program code thereon for use by a processor, the program code comprising instructions for performing the methods or the computing blocks as described hereinafter.

Using such a computer program product improves performance of radio transmission in advanced communication schemes such as EHT WiFi, e.g. according to IEEE 802.11be.

BRIEF DESCRIPTION OF THE DRAWINGS

Further embodiments of the invention will be described with respect to the following figures, in which:

Fig. 1 shows a schematic diagram 100 illustrating a communication device 100 according to the disclosure;

Fig. 2 shows a schematic diagram illustrating Post-FEC and PE in IEEE 802.11ax;

Fig. 3a shows a schematic diagram illustrating PPE Threshold field in IEEE 802.11ax;

Fig. 3b shows a schematic diagram illustrating PPE Threshold Info field in IEEE 802.11ax;

Fig. 4 shows guidelines for decision of packet extension padding duration in IEEE 802.11ax;

Fig. 5 shows a schematic diagram illustrating PPE Thresholds field format together with a PPE Thresholds Info field format according to the disclosure;

Fig. 6a shows a schematic diagram illustrating 4K-QAM additional capability bit according to the disclosure;

Fig. 6b shows a schematic diagram illustrating 4K-QAM additional capability bits according to the disclosure;

Fig. 7a shows a schematic diagram illustrating PPE Thresholds field format supporting 4K-QAM and more than 8 spatial streams according to the disclosure;

Fig. 7b shows a schematic diagram illustrating PPE Thresholds Info field format supporting 4K-QAM and more than 8 spatial streams according to the disclosure;

Fig. 8a shows a schematic diagram illustrating PPE Thresholds field format supporting 4K-QAM and additional RUs according to the disclosure;

Fig. 8b shows a schematic diagram illustrating PPE Thresholds Info field format supporting 4K-QAM and additional RUs according to the disclosure;

Fig. 9a shows a schematic diagram illustrating PPE Thresholds field format supporting 4K-QAM, additional RUs and more than 8 spatial streams according to the disclosure;

Fig. 9b shows a schematic diagram illustrating PPE Thresholds Info field format supporting 4K-QAM and additional RUs and more than 8 spatial streams according to the disclosure; and

Fig. 10 shows a schematic diagram of a communication method 1000 according to the disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following detailed description, reference is made to the accompanying drawings, which form a part thereof, and in which is shown by way of illustration specific aspects in which the disclosure may be practiced. It is understood that other aspects may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present disclosure is defined by the appended claims.

It is understood that comments made in connection with a described method may also hold true for a corresponding device or system configured to perform the method and vice versa. For example, if a specific method step is described, a corresponding device may include a unit to perform the described method step, even if such unit is not explicitly described or illustrated in the figures. Further, it is understood that the features of the various exemplary aspects described herein may be combined with each other, unless specifically noted otherwise.

The methods, devices and systems described herein may be implemented in wireless communication schemes, in particular communication schemes according to WiFi communication standards according to IEEE 802.11, in particular 802.11n/ac/ax/be amendments. The described devices may include integrated circuits and/or passives and may be manufactured according to various technologies. For example, the circuits may be designed as logic integrated circuits, analog integrated circuits, mixed signal integrated circuits, optical circuits, memory circuits and/or integrated passives.

The devices described herein may be configured to transmit and/or receive radio signals. Radio signals may be or may include radio frequency signals radiated by a radio transmitting device (or radio transmitter or sender). However, devices described herein are not limited to transmit and/or receive radio signals, also other signals designed for transmission in deterministic communication networks may be transmitted and/or received.

The devices and systems described herein may include processors or processing devices, memories and transceivers, i.e. transmitters and/or receivers. The term “processor” or “processing device” describes any device that can be utilized for processing specific tasks (or blocks or steps). A processor or processing device can be a single processor or a multi-core processor or can include a set of processors or can

include means for processing. A processor or processing device can process software or firmware or applications etc.

Communication devices are described in the following. Although, the new mechanisms are described with a focus on WiFi technologies, in particular IEEE 802.11ax and IEEE 802.11be, the new mechanisms may be applied to any new radio transmission schemes in which data fields are updated to support the new standard. It is understood that these new mechanisms described hereinafter are not limited to WiFi radio transmission.

Fig. 1 shows a schematic diagram 100 illustrating a communication device 100 according to the disclosure. Such a communication device 100 is configured to perform OFDM transmission (and/or reception). An example of an OFDM transmission chain for a last data symbol to be transmitted is shown in Figure 1. Excess Information bits 107 are provided to a Pre-FEC padding block 108 that applies Pre-FEC padding bits to the Excess Information bits 107 according to Pre-FEC padding. The resulting data 101 is applied to Forward Error Correction (FEC) 102, Post-FEC Padding 103, OFDM modulation 104 and Packet Extension (PE) 105 to provide the last data symbol 106 for transmission. Note that Figure 1 only illustrates the last data symbol to be transmitted. Pre/post-FEC and PE as illustrated in Figure 1 only relates to the last symbol. The analog blocks are used in the receiver to perform reception of data symbols 106 transmitted over radio channel.

In this disclosure, new mechanisms to extend Pre&post-FEC Padding 103 and PE 105 to new requirements of novel radio transmission standards are described. For example, such requirements are 240 MHz/320 MHz bandwidth, multi-RUs and 4K-QAM as introduced in IEEE 802.11bc for WiFi transmission.

The communication device 100 is configured to transmit and/or receive a data frame based on a set of pre&post-Forward Error Correction, FEC, parameters and a set of packet extension, PE, parameters. The set of pre&post-FEC parameters is based on an extension of a set of pre&post-FEC parameters defined for a second radio transmission technology with respect to a size of resource units, RUs, supported by a first radio transmission technology, wherein the set of pre&post-FEC parameters is based on a combination of RUs that is supported by the first radio transmission technology. The set of PE parameters is based on an extension of a set of PE parameters defined for the second radio transmission technology with respect to a constellation size, a number of total space time streams and a resource unit, RU, allocation size supported by the first radio transmission technology.

The first and second radio transmission technologies can be WiFi technologies, the second radio transmission technology can be an existing WiFi technology, while the first radio technology can be a new WiFi technology, e.g. a new WiFi technology having higher bandwidth, multi-resource units and/or higher constellation scheme. For example, the first radio transmission technology can be 802.11be WiFi and the second radio transmission technology can be 802.11ax WiFi.

The first and second radio transmission technologies can be the same (with different settings) or different (with different capabilities).

A multiple RU as defined by the new first radio transmission technology is formed from a combination of two or more RUs defined by the old second radio transmission technology.

The communication device 100 may be configured to determine where a post-padding begins in the data frame based on the set of pre&post-FEC parameters, wherein the set of pre&post-FEC parameters is based on: an integer number of data subcarriers for a last symbol of the data frame, N_{SD_Short}, as defined by an extended N_{SD_Short} table, wherein the extended N_{SD_Short} table is an extension of a N_{SD_Short} table defined by the second radio transmission technology with respect to additional values of N_{SD_Short} defined by the first radio transmission technology, an integer number of coded bits per symbol for the last symbol of the data frame, N_{CBPS_Short}, wherein N_{CBPS_Short} depends on N_{SD_Short}, and an integer number of data bits per symbol for the last symbol of the data frame, N_{DBPS_Short}, wherein N_{DBPS_Short} depends on N_{CBPS_Short}.

The set of pre&post-FEC parameters may be based on an extension of an N_{SD_Short} table defined for the second radio transmission technology with respect to combinations of RU values supported by the first radio transmission technology, wherein the N_{SD_Short} table comprises predefined numbers of N_{SD_Short} values (see Table 2 shown below with respect to Example #1 described below with respect to Figures 5 to 9).

The extended N_{SD_Short} table may define the numbers of N_{SD_Short} values for a dual-carrier modulation, DCM, switched on and/or a DCM switched off (see Table 2 shown below with respect to Example #1 described below with respect to Figures 5 to 9).

The extended N_{SD_Short} table may include one or more of the following combinations of RU values: 52 + 26, 106 + 26, 484 + 242, 996 + 484, 242 + 484 + 996, 484 + 2x996, 3x996, 484 + 3x996, 4x996 (see Table 2 shown below with respect to Example #1 described below with respect to Figures 5 to 9).

For example, a value of N_{SD_Short} for a combination of a first RU and a second RU that is supported by the first radio transmission technology may correspond to an addition of an N_{SD_Short} value for the first RU and an N_{SD_Short} value for the second RU, the first RU and the second RU being supported by the second radio transmission technology.

Possible combinations of RUs are exemplarily described in the following: For example: N_{SD_Short} for 484+242 is exactly N_{SD_Short} (242)+ N_{SD_Short} (484); N_{SD_Short} for 52+26 is exactly N_{SD_Short} (52)+ N_{SD_Short} (26); N_{SD_Short} for 106+26 is exactly N_{SD_Short} (106)+ N_{SD_Short} (26); N_{SD_Short} for 996+484 is exactly N_{SD_Short} (996)+ N_{SD_Short} (484); N_{SD_Short} for 242+484+996 is exactly N_{SD_Short} (242)+ N_{SD_Short} (484) + N_{SD_Short} (996); N_{SD_Short} for 484+2x996 is exactly N_{SD_Short} (484)+ N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 3x996 is exactly N_{SD_Short} (996)+ N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 484+3x996 is exactly N_{SD_Short} (484)+ N_{SD_Short} (996) + N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 4x996 is exactly N_{SD_Short} (996)+ N_{SD_Short} (996) + N_{SD_Short} (996) + N_{SD_Short} (996).

The communication device 100 may be configured to add a single padding bit after every $2XN_{DBPS}$ for the combination of RU values equal to 106 + 26, DCM switched-on, single stream and binary phase shift keying modulation with code-rate ½ (see Example #2 described below with respect to Figures 5 to 9).

The pre&post-FEC parameters are also called “pre&post-FEC padding parameters” since these are the padding bits for the last symbol of a data frame. With pre&post-FEC padding, portions of ¼ of the last OFDM symbol (i.e. ¼, ½, ¾) are padded after encoding; these portions need not be decoded.

The extended set of PE parameters may be defined for at least one of an extended modulation scheme of 4K-QAM or higher, an extended number of spatial streams greater than 8 and an extended bandwidth of 240 MHz, 320 MHz or higher (see Example #3 described below with respect to Figures 5 to 9).

The extended set of PE parameters may be based on an extension of a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology, wherein the PPE thresholds field is extended by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits (see Example #3a described below with respect to Figures 5 to 9).

NSTS is a subfield of PPE thresholds field that defines the maximum number of space time streams supported by a Station.

The extended set of PE parameters may be based on an extension of a resource unit allocation index field defined for the second radio transmission technology, wherein the extended resource unit allocation index field comprises extended resource unit allocation sizes of 3x996 and/or 4x996 or higher (see Example #3a described below with respect to Figures 5 to 9).

The extended set of PE parameters may be based on an extension of a constellation index field defined for the second radio transmission technology, wherein the extended constellation index field comprises one or more extended constellations of 4096-QAM or higher (see Example #3a described below with respect to Figures 5 to 9).

The extended set of PE parameters may be based on reusing a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology, wherein the PPE thresholds field is defined for modulation schemes less or equal than 1K-QAM, a number of spatial streams less or equal than 8 and resource unit sizes less or equal than 2x996 (see Example #3b described below with respect to Figures 5 to 9).

The extended set of PE parameters may be based on reusing a PPE thresholds field defined for the second radio transmission technology and based on using a single bit indicating the use of a modulation scheme of 4K-QAM (see Example #3c described below with respect to Figures 5 to 9).

The extended set of PE parameters may be based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits in order to support up to 16 spatial streams (see Example #3d described below with respect to Figures 5 to 9).

The extended set of PE parameters may be based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index

field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the size of a resource unit index bitmask to at least 6 bits (see Example #3e described below with respect to Figures 5 to 9).

The extended set of PE parameters may be based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits (see Example #3f described below with respect to Figures 5 to 9).

Fig. 2 shows a schematic diagram illustrating Post-FEC and PE in IEEE 802.11ax.

In order to relax processing requirements with 4X symbol duration, considering SIFS (Short Interframe Space) time for responding, some padding at the end of the packet that does not contain any information is inserted. This padding artificially increases the packet, allowing the receiver to complete the decoding processing. In 802.11ax Packet Extension (PE) and pre&post-FEC padding were introduced. These 2 mechanisms considered the maximal combination of number of spatial streams (8), RU size (2X996) and QAM modulation (1K). As 802.11be is going to support higher values, i.e. 16 spatial streams, 4X996 and 4K-QAM, the definitions, signalling and usage of PE & pre&post-FEC padding needs to be revised as presented in this disclosure.

In the current 802.11ax standard (IEEE P802.11ax™/D6.1), there are 4 sizes of resource units (RUs) that are relevant to Packet Extension: 242, 484, 996, and 2X996. In addition, up to eight spatial streams are supported and the highest supported modulation is 1K-QAM. Therefore, theoretically, a receiver may need to process a PPDU (Physical Protocol Data Unit) that contains 8 spatial stream, over 160MHz (RU=2X996) with 1K-QAM modulation. This case may be laborious and require some extra time and/or extra HW to complete.

In order to relax processing requirements with 4X symbol duration, considering SIFS time for responding, 802.11ax introduced Packet Extension (PE) and pre&post-FEC padding.

In Figure 2, four scenarios 210, 220, 230, 240 are shown having different lengths of padding bits in the last OFDM symbol of the packet (left side of Fig. 2) and packet extension segment that may follow the last OFDM symbol (right side of Fig. 2). In all scenarios it is assumed that the packet consists of N_{SYM} OFDM symbols so that the last OFDM symbol's index is N_{SYM}.In the first scenario 210, number of FEC output bits 211 in the last OFDM symbol occupy ¼ of the symbol and is small with respect to number of Post FEC Padding bits 212 which occupy ¾ of the symbol. After OFDM modulation 201, data field 213 in the last OFDM symbol is provided such that no packet extension is required, therefore not applied.

In the second scenario 220, number of FEC output bits 221 in the last OFDM symbol occupy ½ of the symbol and is about the same length than number of Post FEC Padding bits 222 which occupy ½ of the symbol as well. After OFDM modulation 201, data field 223 in the last OFDM symbol is provided such that still no packet extension is required, therefore not applied.

In the third scenario 230, number of FEC output bits 231 in the last OFDM symbol occupy ¾ of the symbol and is long with respect to number of Post FEC Padding bits 232 which occupy ¼ of the symbol. After OFDM modulation 201, data field 233 in the last OFDM symbol is provided and a packet extension, PE 234 of 4 microseconds is required, therefore appended to data field 233.

In the fourth scenario 240, number of FEC output bits 241 in the last OFDM symbol occupy the whole symbol, therefore is provided without Post FEC Padding bits. After OFDM modulation 201, data field 243 in the last OFDM symbol is provided and a packet extension, PE 244 of 8 microseconds is required, therefore appended to data field 243.

With Pre&post-FEC padding, portions of ¼ of the last OFDM symbol (i.e. ¼, ½, ¾) are padded after encoding; these portions need not to be decoded.

Figure 2 shows the post-FEC and PE defined in 802.11ax for 8usec (microseconds) nominal packet padding.

There are several parameters defined in the 802.11ax specification, which are used to determine where (post-FEC) padding begins:

Parameter N_{SD_Short}, defined explicitly in the 802.11ax specification and shown here below in Table 1, defines the number of tones, used within the last OFDM symbol, and is always approximately ¼ the number of tones; the rest of the tones within the last symbol are used as post-FEC. Parameter NCBPS_Short is dependent on N_{SD_Short}. Parameter N_{DBPS_Short} is dependent on N_{CBPS_Short}. Note that not all RU sizes are an integer multiple of 4. The values of N_{SD_Short} were also chosen such that N_{CBPS_Short}, N_{DBPS_Short} and
N_{DBPS_Short} /N_{ES} are integers.

Table 1 below shows the values of parameter N_{SD_Short}, depending on RU size and DCM (Dual Carrier Modulation) switched on (DCM=1) or switched-off (DCM=0).

RU Size		N_{SD_Short}	
		DCM=0	DCM=1
26-tone		6	2
52-tone		12	6
106-tone		24	12
242-tone		60	30
484-tone		120	60
996-tone		240	120
2x996-tone		492	246

Table 1: NSD_Short for various RU sizes

DCM (Dual Carrier Modulation) is a technique, supported in IEEE 802.11ax, where the same bits are transmitted twice (in two modulated QAMs on two tones that are relatively far from each-other) in order to increase the diversity. This means the effective coding rate is halved, compared to when DCM is not used. There are two cases where the number of info data bits per symbol (N_{DBPS}) used within an OFDM symbol, for DCM=1, is not exactly half the corresponding number of coded data bits per symbol (N_{CBPS}) for DCM=0 (these are MCS 0 with RU size 106-tones and MCS 0 with RU size 242-tones). Hence, the 802.11ax spec mandates that for these two cases, an additional padding bit is added to every OFDM symbol, and this bit can be set to 0 or 1.

Fig. 3a shows a schematic diagram illustrating PPE Threshold field 310 in IEEE 802.11ax.

The PPE Threshold field 310 includes a NSTS field 311 of 3bits size indicating the number of stations, a RU Index Bitmask 312 of 4bits size, a PPE Thresholds Info field 320 of variable size and a PPE Pad field 314 of size 0 to 7 bits.

Packet Extension Threshold can be defined as follows:

A Station (STA) can report its required nominal packet extension for each combination of N_{STS}, RU size and modulation. The STA reports a PPE Thresholds field 310, as shown in Figure 2, where:

- N_{STS}, 311, is the maximum number of STSs defined in the report;

- RU index 312 defines the RU sizes for which the thresholds are included as shown in Table 9-321e of IEEE 802.11ax (see below).

RU allocation index	RU allocation size
0	242
1	484
2	996
3	2x996

Table 9-321e of IEEE 802.11ax – RU allocation index

PPE Thresholds defines 2x3 bits per combination of RU and N_{STS}, where each 3 bits corresponds to a modulation, as shown in Figure 3b.

A STA receiving this frame compares the values for PPET8 and PPET16 and determines nominal packet padding for each combination.

After receiving the PPE Thresholds field from a second STA, the first STA uses the combination of the PPET8 N_{STSn} RU_b subfield and PPET16 N_{STSn} RU_b subfield values to determine the nominal packet padding for HE PPDUs that are transmitted to the second STA using N_{STS} = n and an RU allocation corresponding to RU Allocation Index b, for each value of N_{STS} and RU specified by the field (see Figure 4). The nominal packet padding is used in computing the PE field duration (see 27.3.13 of 802.11ax spec (Packet extension)).

Fig. 3b shows a schematic diagram illustrating PPE Threshold Info field 320 in IEEE 802.11ax. The PPE Threshold Info field 320 includes a PPET16 NSTS1 RUx field 321 of 3bits size, a PPET8 NSTS1 RUx field 322 of 3bits size, further bit fields, a PPET16 NSTS1 RUm field 323 of 3bits size, a PPET8 NSTS1 RUm field 324, further bit fields, a PPET16 NSTSn RUm field 325 of 3bits size and a PPET8 NSTSn RUm field 326 of 3bits size.

Fig. 4 shows guidelines 400 for decision of packet extension padding duration in IEEE 802.11ax. Figure 4 shows how a transmitting STA decides which PE is required by the receiving STA based on the thresholds field info.

However, the above procedure is limited to the number of spatial streams, the bandwidth and the highest modulation defined in IEEE 802.11ax. The new WiFi standard IEEE 802.11be will support the following advanced features: 240MHz/320MHz; Multi-RUs (e.g. RU242+RU484 are combined to a new RU with a new size); 4K-QAM; and 16 spatial streams. The current WiFi specification IEEE 802.11ax does not have a solution for these cases, therefore it cannot be used as is in the new WiFi standard IEEE 802.11be.

In the following, appropriate pre&post-FEC and packet extension mechanisms are introduced to support the new WiFi standard IEEE 802.11be. These mechanisms according to the disclosure are suitable to the new features that are added to the new standard IEEE 802.11be. Figures 5 to 9 illustrate the new frame formats for using these new pre&post-FEC and packet extension mechanisms.

In particular, Fig. 5 shows the new PPE Thresholds field format 510 together with the new PPE Thresholds Info field format 520. The PPE Thresholds field format 510 includes a 4bit N_{STS} 511, a 6bit RU Index Bitmask 512, a variable PPE Thresholds Info field 520 and a 0 to 7bit PPE Pad field 514. The PPE Thresholds Info field 520 includes a 3bit PPET16 N_{STS1} RU_x field 521, a 3bit PPET8 $NSTS_1$ RU_x field 522, further fields, a 3bit PPET16 N_{STS1} RU_m field 523, a 3bit PPET8 N_{STS1} RU_m field 524, further fields, a 3bit PPET16 N_{STSn} RU_m field 525 and a 3bit PPET8 N_{STSn} RU_m field 526.

Fig. 6a shows the new frame format 610 with 4K-QAM additional capability bit. The new frame format 610 includes a 1bit 4K-QAM Delta field 611 and a 7bit PPE Pad field 612. Fig. 6b shows the new frame format 620 with 4K-QAM additional capability bits. The new frame format 620 includes a variable bit size 4K-QAM Delta field 621 and a 0 to 7bit PPE Pad field 622.

Fig. 7a shows the new PPE Thresholds field format 710 supporting 4K-QAM and more than 8 spatial streams. The PPE Thresholds field format 710 includes a 1bit 4K-QAM Delta field 711, a 4bit N_{STS} 712, a 4bit RU Index Bitmask 713, a variable bit-size PPE Thresholds Info field 720 and a 0 to 7bit PPE Pad field 715.

Fig. 7b shows the new PPE Thresholds Info field format 720 supporting 4K-QAM and more than 8 spatial streams. The PPE Thresholds Info field 720 includes a 3bit PPET16 N_{STS1} RU_x field 721, a 3bit PPET8 N_{STS1} RU_x field 722, further fields, a 3bit PPET16 N_{STS1} RU_m field 723, a 3bit PPET8 N_{STS1} RU_m field 724, further fields, a 3bit PPET16 N_{STSn} RU_m field 725 and a 3bit PPET8 N_{STSn} RU_m field 726.

Fig. 8a shows the new PPE Thresholds field format 810 supporting 4K-QAM and additional RUs. The PPE Thresholds field format 810 includes a 1bit 4K-QAM Delta field 811, a 3bit N_{STS} 812, a 6bit RU Index Bitmask 813, a variable bit-size PPE Thresholds Info field 820 and a 0 to 7bit PPE Pad field 815.

Fig. 8b shows the new PPE Thresholds Info field format 820 supporting 4K-QAM and additional RUs. The PPE Thresholds Info field 820 includes a 3bit PPET16 N_{STS1} RU_x field 821, a 3bit PPET8 N_{STS1} RU_x field 822, further fields, a 3bit PPET16 N_{STS1} RU_m field 823, a 3bit PPET8 N_{STS1} RU_m field 824, further fields, a 3bit PPET16 N_{STSn} RU_m field 825 and a 3bit PPET8 N_{STSn} RU_m field 826.

Fig. 9a shows the new PPE Thresholds field format 910 supporting 4K-QAM, additional NRUs and more than 8 spatial streams. The PPE Thresholds field format 910 includes a 1bit 4K-QAM Delta field 911, a 4bit N_{STS} 912, a 6bit RU Index Bitmask 913, a variable bit-size PPE Thresholds Info field 920 and a 0 to 7bit PPE Pad field 915.

Fig. 9b shows the new PPE Thresholds Info field format 920 supporting 4K-QAM and additional RUs and more than 8 spatial streams. The PPE Thresholds Info field 920 includes a 3bit PPET16 N_{STS1} RU_x field 921, a 3bit PPET8 N_{STS1} RU_x field 922, further fields, a 3bit PPET16 N_{STS1} RU_m field 923, a 3bit PPET8 N_{STS1} RU_m field 924, further fields, a 3bit PPET16 N_{STSn} RU_m field 925 and a 3bit PPET8 N_{STSn} RU_m field 926.

In the following, introduction of pre&post-FEC and packet extension mechanisms is described with respect to Figures 5 to 9 to support IEEE 802.11be.

1. Support is added for new values of N_{SD_Short} that correspond to the size of the new multi-RU sizes.

    a. The following rows shown below (see Table 2) are added to the N_{SD_Short} table. These values are the linear combination of the respective, existing 802.11ax RU values, since the requirements mentioned earlier are met.

    b. The equation (right side on Table 2) defines how the value of N_{SD_Short} is determined based on 802.11ax values, (for the 802.11ax defined RUs)

RU Size	N_{SD_Short}		Equation
	DCM=0	DCM=1	
52+26	18	8	RU52+RU26
106+26	30	14	RU106+RU26
484+242	180 or 174	90	RU484+RU242
996+484	360	180	RU996+RU484
242+484+996	420	210	RU242+RU484+RU996
484+2x996	600 or 606 or 612	300 or 306	RU484+2xRU996
3x996	720 or 726 or 738	360 or 366	3xRU996
484+3x996	840 or 846 or 852	420 or 426	RU484+3xRU996
4x996	978 or 984 or 990	486 or 492	4xRU996

Table 2: N_{SD_Short} new values

2. For the case of 106+26, the following parameters with DCM=1, a single stream and MCS 0 apply:

    - N_{CBPS} =51+12=63
    - N_{DBPS} =25+6=31

Hence, similar to 106 and 242-tone RUs, in 106+26 MRU: 63=2x31+1, so after every 2xNDBPS coded bits, a single padding bit (either 0 or 1) is added.

3. Addressing the accommodation of 4K-QAM, NSS>8 and 240/320MHz in the PPE Threshold field in the following scenarios

    a. Full support within 11be (only within EHT capabilities, doesn‘t rely on HE capabilities).

        I. Change the PPE Thresholds field (including sub-fields) to accommodate 4K-QAM (see Table 3 below), 2x1992 tones RU size (see Table 4 below) and 16 streams (see Figure 5), as shown below.

        II. Note: Multi-RU are not defined here, it is relied instead on larger RUs

        III. New values with respect to IEEE 802.11ax are Constellation index 6 with transmission constellation 4096-QAM in Table 3, RU allocation index 4 with RU allocation size 3x996 in Table 4, RU allocation index 5 with RU allocation size 4x996 in Table 5, N_{STS} field 511 having a number of 4 bits and RU index bitmask 512 having a number of 6 bits in Figure 5.

Constellation Index	Corresponding Transmission Constellation
0	BPSK
1	QPSK
2	16-QAM
3	64-QAM
4	256-QAM
5	1024-QAM
6	4096-QAM
7	None

Table 3: Constellation Index

RU Allocation Index	RU Allocation Size
0	242
1	484
2	996
3	2x996
4	3x996
5	4x996

Table 4: RU Allocation Index

b. For STAs that are compatible to HE i.e. supports up to 8 spatial streams, BW up to 160MHz and modulation up to 1K-QAM: PPE Thresholds table from HE capabilities is sufficient.

c. For STAs that are compatible to HE as in item b0 and in addition support 4K-QAM, two solutions can be applied, such that it is not required to transmit the 'full' capability in HE and EHT, but rather capability in HE and then only the additional capability ('delta') in EHT – this is true for all cases below (including items 'd', 'e' etc.):

I. The capability field 610 will include an additional bit 611 as shown in Figure 6a that

i. Means, if set to '1', that all cases where combinations of N_{SS} and N_{RU} yield PPET8='1K-QAM' and PPET16='NONE', should be translated to PPET16='4K-QAM'

ii. If this bit is set to '0', then PPET16 remains 'NONE'

iii. New values 611 with respect to IEEE 802.11ax are shown in Fig. 6a.

II. The capability field 620 will include an additional bit 621 per combination of N_{SS} and N_{RU} as shown in Figure 6b that

iv. Means, if set to ‘1’, that for each specific case, where combinations of N_{SS} and N_{RU} yield PPET8=‘1K-QAM’ and PPET16=‘NONE’, should be translated to PPET16=‘4K-QAM’

v. If this bit 621 is set to ‘0’, then PPET16 remains ‘NONE’

vi. Thus, a total of $N_{SS}*N_{RU}$ bits is added.

vii. New values 621 with respect to IEEE 802.11ax are shown in Fig. 6b.

III. As an alternative to items I and II above (or further option or embodiment), the capability fields 610 in Fig. 6a and 620 in Fig. 6b will **not** include the additional bits 611, 621. In this option, 4K-QAM can be indicated in EHT (802.11be) without any additional bit 611, 621. So, the only change is the additional value of 4096 in Table 3 shown above. This option is backward compatible with HE (802.11ax) because an HE device will consider the indication “6“ as “NONE“ anyway because it does not know 4K-QAM.

d. For STAs that are capable of supporting 4K-QAM and beyond 8 spatial streams the scheme shown in Figures 7a and 7b can be applied:

I. Transmit single 4K-QAM delta bit as before

II. For each combination of N_{SS} and N_{RU} that was not defined, need to define the PPET8/16 value

III. Constellation index is modified identical to Table 3

IV. Thus, $1+(N_{SS}-8)*N_{RUs,11ax}*6$ bits are added

V. New values 711 with respect to IEEE 802.11ax are shown in Fig. 7a.

e. For STAs that are capable of supporting 4K-QAM and additional RUs (respective to 802.11ax) the scheme shown in Figures 8a and 8b can be applied:

I. Transmit single 4K-QAM delta bit as before

II. For each combination of N_{SS} and N_{RU} that was not defined, need to define the PPET8/16 value

III. Constellation index is modified identical to Table 3

IV. Thus, $1+N_{SS}*(N_{RUs,11be}-N_{RUs,11ax})*6$ bits are added

V. New values 811 with respect to IEEE 802.11ax are shown in Fig. 8a.

f. For STAs that are capable of supporting 4K-QAM, additional RUs (respective to 802.11ax) and beyond 8 spatial streams, the scheme shown in Figures 9a and 9b can be applied:

I. Transmit single 4K-QAM delta bit as before

II. For each combination of NSS and NRU that was not defined, need to define the PPET8/16 value

III. Constellation index is modified identical to Table 3

IV. Thus, $1+[N_{SS}*(N_{RUs,11be}-N_{RUs,11ax})+(N_{SS}-8)*N_{RUs,11ax}]*6$ bits are added.

V. New values 911 with respect to IEEE 802.11ax are shown in Fig. 9a.

By using these changes, a communication device 100 can be provided as described above with respect to Fig. 1.

Such communication device 100 is configured to: transmit and/or receive a data frame based on a set of pre&post-Forward Error Correction, FEC, parameters and a set of packet extension, PE, parameters. The set of pre&post-FEC parameters is based on an extension of a set of pre&post-FEC parameters defined for a second radio transmission technology with respect to a size of resource units, RUs, supported by a first radio transmission technology, wherein the set of pre&post-FEC parameters is based on a combination of RUs that is supported by the first radio transmission technology. The set of PE parameters is based on an extension of a set of PE parameters defined for the second radio transmission technology with respect to a constellation size, a number of total space time streams and a resource unit, RU, allocation size supported by the first radio transmission technology.

The communication device 100 may be configured to: determine where a post-padding begins in the data frame based on the set of pre&post-FEC parameters, wherein the set of pre&post-FEC parameters is based on: an integer number of data subcarriers for a last symbol of the data frame, N_{SD_Short}, as defined by an extended N_{SD_Short} table, wherein the extended N_{SD_Short} table is an extension of a N_{SD_Short} table defined by the second radio transmission technology with respect to additional values of N_{SD_Short} defined by the first radio transmission technology, an integer number of coded bits per symbol for the last symbol of the data frame, N_{CBPS_Short}, wherein N_{CBPS_Short} depends on N_{SD_Short}, and an integer number of data bits per symbol for the last symbol of the data frame, N_{DBPS_Short}, wherein N_{DBPS_Short} depends on N_{CBPS_Short}.

The pre&post-FEC parameters are also called “pre&post-FEC padding parameters” since these are the padding bits for the last symbol of a data frame. With pre&post-FEC padding, portions of ¼ of the last OFDM symbol (i.e. ¼, ½, ¾) are padded after encoding; these portions need not be decoded.

Different options apply for this set of pre&post-FEC parameters and this set of PE parameters as described in the following:

In a first option (Example #1), new rows are added to the N_{SD_Short} table as shown above in Table 2. These values are the linear combination of the respective, existing 802.11ax RU values, since the requirements mentioned earlier are met. The equation defines how the value of N_{SD_Short} is determined based on 802.11ax values (for the 11ax defined RUs).

The extended N_{SD_Short} table (see Table 2) may include one or more of the following combinations of RU values: 52 + 26, 106 + 26, 484 + 242, 996 + 484, 242 + 484 + 996, 484 + 2x996, 3x996, 484 + 3x996, 4x996.

A value of N_{SD_Short} for a combination of a first RU and a second RU that is supported by the first radio transmission technology may correspond to an addition of an N_{SD_Short} value for the first RU and an N_{SD_Short} value for the second RU, the first RU and the second RU being supported by the second radio transmission technology.

For example, possible combinations are the following: N_{SD_Short} for 484+242 is exactly N_{SD_Short} (242)+ N_{SD_Short} (484); N_{SD_Short} for 52+26 is exactly N_{SD_Short} (52)+ N_{SD_Short} (26); N_{SD_Short} for 106+26 is exactly N_{SD_Short} (106)+ N_{SD_Short} (26); N_{SD_Short} for 996+484 is exactly N_{SD_Short} (996)+ N_{SD_Short} (484); N_{SD_Short} for 242+484+996 is exactly N_{SD_Short} (242)+ N_{SD_Short} (484) + N_{SD_Short} (996); N_{SD_Short} for 484+2x996 is exactly N_{SD_Short} (484)+ N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 3x996 is exactly N_{SD_Short} (996)+ N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 484+3x996 is exactly N_{SD_Short} (484)+ N_{SD_Short} (996) + N_{SD_Short} (996) + N_{SD_Short} (996); N_{SD_Short} for 4x996 is exactly N_{SD_Short} (996)+ N_{SD_Short} (996) + N_{SD_Short} (996) + N_{SD_Short} (996).

In a second option (Example #2), for the case of 106+26, there are the following parameters with DCM=1, a single stream and MCS 0:

- N_{CBPS} =51+12=63
- N_{DBPS} =25+6=31

Hence, similar to 106 and 242-tone RUs, in 106+26 MRU: 63=2x31+1, so after every 2xN_{DBPS} coded bits, a single padding bit (either 0 or 1) is added.

The communication device 100 may be configured to add a single padding bit after every 2XN_{DBPS} for the combination of RU values equal to 106 + 26, DCM switched-on, single stream and binary phase shift keying modulation with code-rate ½.

The pre&post-FEC parameters are also called “pre&post-FEC padding parameters” since these are the padding bits for the last symbol of a data frame. With pre&post-FEC padding, portions of ¼ of the last OFDM symbol (i.e. ¼, ½, ¾) are padded after encoding; these portions need not be decoded.

In a third option (Example #3), the accommodation of 4K-QAM, N_{SS}>8 and 240/320MHz is addressed in the PPE Threshold field, considering the following scenarios:

- Full support within 11be (only within EHT capabilities, does not rely on HE capabilities) – described in Example #3a

- Relying on HE capabilities, then differentiation between different cases as shown in Table 5 can be performed:

Case	Max RU Size	Max N_{SS}	Max Modulation	Described in
1	⩾2x996	⩾8	⩾1K-QAM	Example #3b
2	⩾2x996	⩾8	4K-QAM	Example #3c
3	⩾2x996	>8	4K-QAM	Example #3d
4	>2x996	⩾8	4K-QAM	Example #3e
5	>2x996	>8	4K-QAM	Example #3f

Table 5: different Examples when relying on HE capabilities

In the communication device 100, the extended set of PE parameters may be defined for at least one of an extended modulation scheme of 4K-QAM or higher, an extended number of spatial streams greater than 8 and an extended bandwidth of 240 MHz, 320 MHz or higher.

The extended set of PE parameters may be based on an extension of a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology, The PPE thresholds field may be extended by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits.

NSTS is a subfield of PPE thresholds field that defines the maximum number of space time streams supported by a Station.

In case 0 of third option (Example #3a), full support within EHT is provided. The procedure corresponds to Table 3 and Table 4 shown above together with Figure 5, i.e.: Change the PPE Thresholds field 510 (including sub-fields 511, 512, 520, 514) to accommodate 4K-QAM, 2x1992 tones RU size and 16 streams, as shown in Table 3 and Table 4. Note: Multi-RU are not defined here, it is relied instead on larger RUs.

In the communication device 100, the extended set of PE parameters may be based on an extension of a resource unit allocation index field defined for the second radio transmission technology. The extended resource unit allocation index field may comprise extended resource unit allocation sizes of 3x996 and/or 4x996 or higher.

The extended set of PE parameters may be based on an extension of a constellation index field defined for the second radio transmission technology. The extended constellation index field may comprise one or more extended constellations of 4096-QAM or higher.

In case 1 of third option (Example #3b), HE capabilities are re-used for STAs that support up to 8SS, 160MHz BW and 1K-QAM. PPE Thresholds table from HE capabilities is hence sufficient.

In the communication device 100, the extended set of PE parameters may be based on reusing a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology. The PPE thresholds field may be defined for modulation schemes less or equal than 1K-QAM, a number of spatial streams less or equal than 8 and resource unit sizes less or equal than 2x996.

In case 2 of third option (Example #3c), HE capabilities is sufficient to describe everything but 4K-QAM. The solution is to transmit a single bit 611 as shown in Figure 6a, that means, if set to ‘1’, that all cases where combinations of NSTS and RU_index yield PPET8=‘1K-QAM’ and PPET16=‘NONE’, should be translated to PPET16=‘4K-QAM’. If this bit is set to ‘0’, then PPET16 remains ‘NONE’. Thus, one bit is added.

In the communication device 100, the extended set of PE parameters may be based on reusing a PPE thresholds field defined for the second radio transmission technology and based on using a single bit 611 indicating the use of a modulation scheme of 4K-QAM.

In case 3 of third option (Example #3d), HE capabilities is sufficient to describe everything but 4K-QAM & beyond 8 streams. In this case as illustrated by Figures 7a and 7b, single 4K-QAM delta bit is transmitted as before (see case 2). For each combination of N_{SS} and N_{RU} that was not defined, need to define the PPET8/16 value. Constellation index is modified identically to Example #3a. Thus, $1+(N_{SS}-8)*N_{RUs,11ax}*6$ bits are added.

PPE threshold field format 810 is illustrated in Figures 7a and 7b. In one Example, following parameters apply: Nss=12, RUs index bitmask 1110 (corresponding to supporting 20MHz, 40MHz & 80MHz). In an Example, the following extension duration required for Nsts=9 apply: For RU=20: PPET16 is required when the modulation is 1KQAM and PPET8 is required in 64QAM. For RU=40: PPET16 is required when the modulation is 4KQAM and PPET8 is required in 64QAM. For RU=80: PPET16 is never required and PPET8 is required in 256QAM. In this example, Table 3 shown above applies in which the new line for constellation index 6 and transmission constellation 4096-QAM is added as shown in Table 3.

In the communication device 100, the extended set of PE parameters may be based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits in order to support up to 16 spatial streams.

In case 4 of third option (Example #3e), HE capabilities is sufficient to describe everything but 4K-QAM & additional RUs. In this case as illustrated by Figures 8a and 8b, single 4K-QAM delta bit 811 is

transmitted as before. For each combination of N_{SS} and N_{RU} that was not defined, need to define the PPET8/16 value. Constellation index is modified identical to Example #3a. Thus, $1+N_{SS}*(N_{RUs,11be}-N_{RUs,11ax})*6$ bits are added.

In one Example, as shown in Figures 8a and 8b, PPE threshold field 810 and PPE Thresholds Info field format 820 are as shown in Figures 8a and 8b. The following parameters apply: Nss=4, RUs index bitmask 000110 (corresponding to supporting 160MHz & 240MHz). It also applies that Max Nsts=4.

In the communication device 100, the extended set of PE parameters may be based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the size of a resource unit index bitmask to at least 6 bits.

In case 5 of third option (Example #3f), HE capabilities is sufficient to describe everything but 4K-QAM, additional RUs and beyond 8 streams, so we need to account for all combinations. In this case as illustrated by Figures 8a and 8b, single 4K-QAM delta bit is transmitted as before. For each combination of N_{SS} and N_{RU} that was not defined, need to define the PPET8/16 value. Constellation index is modified identical to Example #3a. Thus, $1+[N_{SS}*(N_{RUs,11be}-N_{RUs,11ax})+(N_{SS}-8)*N_{RUs,11ax}]*6$ bits are added.

In the communication device 100 the extended set of PE parameters may be based on: using a single bit indicating the use of a modulation scheme of 4K-QAM, including a constellation of 4096-QAM in an extended constellation index field, and extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits.

Fig. 10 shows a schematic diagram of a communication method 1000 according to the disclosure.

The communication method 1000 comprises transmitting and/or receiving 1001 a data frame based on a set of pre&post-Forward Error Correction, FEC, parameters and a set of packet extension, PE, parameters, e.g. as described above with respect to Figures 1 to 9. The set of pre&post-FEC parameters is based on an extension of a set of pre&post-FEC parameters defined for a second radio transmission technology with respect to a size of resource units, RUs, supported by a first radio transmission technology. The set of pre&post-FEC parameters is based on a combination of RUs that is supported by the first radio transmission technology and the set of PE parameters is based on an extension of a set of PE parameters defined for the second radio transmission technology with respect to a constellation size, a number of total space time streams and a resource unit, RU, allocation size supported by the first radio transmission technology.

The first and second radio transmission technologies can be WiFi technologies, the second radio transmission technology can be an existing WiFi technology, while the first radio technology can be a new WiFi technology, e.g. a new WiFi technology having higher bandwidth, multi-resource units and/or higher constellation scheme. For example, the first radio transmission technology can be IEEE 802.11be WiFi and the second radio transmission technology can be IEEE 802.11ax WiFi.

The first and second radio transmission technologies can be the same (with different settings) or different (with different capabilities).

A multiple RU as defined by the new first radio transmission technology is formed from a combination of two or more RUs defined by the old second radio transmission technology.

The present disclosure also supports a computer program product including computer executable code or computer executable instructions that, when executed, causes at least one computer to execute the performing and computing steps described herein, in particular the methods and procedures described above. Such a computer program product may include a readable non-transitory storage medium storing program code thereon for use by a computer. The program code may perform the processing and computing steps described herein, in particular the methods and procedures described above.

While a particular feature or aspect of the disclosure may have been disclosed with respect to only one of several implementations, such feature or aspect may be combined with one or more other features or aspects of the other implementations as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the terms "include", "have", "with", or other variants thereof are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term "comprise". Also, the terms "exemplary", "for example" and "e.g." are merely meant as an example, rather than the best or optimal. The terms “coupled” and “connected”, along with derivatives may have been used. It should be understood that these terms may have been used to indicate that two elements cooperate or interact with each other regardless whether they are in direct physical or electrical contact, or they are not in direct contact with each other.

Although specific aspects have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations may be substituted for the specific aspects shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the specific aspects discussed herein.

Although the elements in the following claims are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those elements, those elements are not necessarily intended to be limited to being implemented in that particular sequence.

Many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the above teachings. Of course, those skilled in the art readily recognize that there are numerous applications of the invention beyond those described herein. While the present invention has been described with reference to one or more particular embodiments, those skilled in the art recognize that many changes may be made thereto without departing from the scope of the present invention. It is therefore to be understood that within the scope of the appended claims and their equivalents, the invention may be practiced otherwise than as specifically described herein.

CLAIMS:

1. A communication device (100), configured to:

transmit and/or receive a data frame based on a set of pre&post-Forward Error Correction, FEC, parameters and a set of packet extension, PE, parameters,

wherein the set of pre&post-FEC parameters is based on an extension of a set of pre&post-FEC parameters defined for a second radio transmission technology with respect to a size of resource units, RUs, supported by a first radio transmission technology, wherein the set of pre&post-FEC parameters is based on a combination of RUs that is supported by the first radio transmission technology and

wherein the set of PE parameters is based on an extension of a set of PE parameters defined for the second radio transmission technology with respect to a constellation size, a number of total space time streams and a resource unit, RU, allocation size supported by the first radio transmission technology.

2. The communication device (100) of claim 1, configured to:

determine where a post-padding begins in the data frame based on the set of pre&post-FEC parameters, wherein the set of pre&post-FEC parameters is based on:

an integer number of data subcarriers for a last symbol of the data frame, N_{SD_Short}, as defined by an extended N_{SD_Short} table, wherein the extended N_{SD_Short} table is an extension of a N_{SD_Short} table defined by the second radio transmission technology with respect to additional values of N_{SD_Short} defined by the first radio transmission technology,

an integer number of coded bits per symbol for the last symbol of the data frame, N_{CBPS_Short}, wherein N_{CBPS_Short} depends on N_{SD_Short}, and

an integer number of data bits per symbol for the last symbol of the data frame, N_{DBPS_Short}, wherein N_{DBPS_Short} depends on N_{CBPS_Short}.

3. The communication device (100) of one of the preceding claims,

wherein the set of pre&post-FEC parameters is based on an extension of an N_{SD_Short} table defined for the second radio transmission technology with respect to combinations of RU values supported by the first radio transmission technology,

wherein the N_{SD_Short} table comprises predefined numbers of N_{SD_Short} values.

4. The communication device (100) of claim 3,

wherein the extended N_{SD_Short} table defines the numbers of N_{SD_Short} values for a dual-carrier modulation, DCM, switched on and/or a DCM switched off.

5. The communication device (100) of one of the preceding claims, wherein:

for an RU size of 52+26 a value of N_{SD_Short} is 18 for DCM=0, and is 8 for DCM=1,

for an RU size of 106+26 a value of N_{SD_Short} is 30 for DCM=0, and is 14 for DCM=1,

for an RU size of 484+242 a value of N_{SD_Short} is 180 or 174 for DCM=0, and is 90 for DCM=1,

for an RU size of 996+484 a value of N_{SD_Short} is 360 for DCM=0, and is 180 for DCM=1,

for an RU size of 242+484+996 a value of N_{SD_Short} is 420 for DCM=0, and is 210 for DCM=1,

for an RU size of 484+2x996 a value of N_{SD_Short} is 600 or 606 or 612 for DCM=0, and is 300 or 306 for DCM=1,

for an RU size of 3x996 a value of N_{SD_Short} is 720 or 726 or 738 for DCM=0, and is 360 or 366 for DCM=1,

for an RU size of 484+3x996 a value of N_{SD_Short} is 840 or 846 or 852 for DCM=0, and is 420 or 426 for DCM=1,

for an RU size of 4x996 a value of N_{SD_Short} is 978 or 984 or 990 for DCM=0, and is 486 or 492 for DCM=1.

6. The communication device (100) of one of the preceding claims, configured to:

add a single padding bit after every $2XN_{DBPS}$ for the combination of RU values equal to 106 + 26, DCM switched-on, single stream and binary phase shift keying modulation with code-rate ½).

7. The communication device (100) of one of the preceding claims,

wherein the extended set of PE parameters is defined for at least one of an extended modulation scheme of 4K-QAM or higher, an extended number of spatial streams greater than 8 and an extended bandwidth of 240 MHz, 320 MHz or higher.

8. The communication device (100) of one of the preceding claims,

wherein the extended set of PE parameters is based on an extension of a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology,

wherein the PPE thresholds field is extended by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits.

9. The communication device (100) of one of the preceding claims,

wherein the extended set of PE parameters is based on an extension of a resource unit allocation index field defined for the second radio transmission technology,

wherein the extended resource unit allocation index field comprises extended resource unit allocation sizes of 3x996 and/or 4x996 or higher.

10. The communication device (100) of one of the preceding claims,

wherein the extended set of PE parameters is based on an extension of a constellation index field defined for the second radio transmission technology,

wherein the extended constellation index field comprises one or more extended constellations of 4096-QAM or higher.

11. The communication device (100) of one of claims 1 to 7,

wherein the extended set of PE parameters is based on reusing a PHY packet extension, PPE, thresholds field defined for the second radio transmission technology,

wherein the PPE thresholds field is defined for modulation schemes less or equal than 1K-QAM, a number of spatial streams less or equal than 8 and resource unit sizes less or equal than 2x996.

12. The communication device (100) of one of claims 1 to 7,

wherein the extended set of PE parameters is based on reusing a PPE thresholds field defined for the second radio transmission technology and based on:

using a single bit indicating the use of a modulation scheme of 4K-QAM, or

indicating a constellation of 4096-QAM in an extended constellation index field without using the single bit.

13. The communication device (100) of one of claims 1 to 7, wherein the extended set of PE parameters is based on:

using a single bit indicating the use of a modulation scheme of 4K-QAM,

including a constellation of 4096-QAM in an extended constellation index field, and

extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits in order to support up to 16 spatial streams, or

indicating a constellation of 4096-QAM in the extended constellation index field without using the single bit.

14. The communication device (100) of one of claims 1 to 7, wherein the extended set of PE parameters is based on:

using a single bit indicating the use of a modulation scheme of 4K-QAM,

including a constellation of 4096-QAM in an extended constellation index field, and

extending a PPE thresholds field defined for the second radio transmission technology by extending the size of a resource unit index bitmask to at least 6 bits, or

indicating a constellation of 4096-QAM in the extended constellation index field without using the single bit.

15. The communication device (100) of one of claims 1 to 7, wherein the extended set of PE parameters is based on:

using a single bit indicating the use of a modulation scheme of 4K-QAM,

including a constellation of 4096-QAM in an extended constellation index field, and

extending a PPE thresholds field defined for the second radio transmission technology by extending the NSTS subfield size to at least 4 bits and the RU index bitmask size to at least 6 bits, or

indicating a constellation of 4096-QAM in the extended constellation index field without using the single bit.