Description

Title of Invention: COMMUNICATION APPARATUS AND COMMUNICATION METHOD FOR LAYERED TRANSMISSION

TECHNICAL FIELD

[001] The present disclosure generally relates to communication methods and apparatuses, and more particularly relates to methods and apparatuses for layered transmission.

BACKGROUND

[002] In the standardization of next-generation WLAN, a new radio access technology necessarily having backward compatibility with Institute of Electrical and Electronics Engineers (IEEE) 802.11a/b/g/n/ac/ax/be technologies has been discussed in the Ultra High Reliability Study Group (UHR SG).

[003] Multi-layer transmission is an efficient method to improve throughput as well as reliability at physical (PHY) layer. Different layers of transmission may be protected by different parameters (e.g., modulation rate, coding rate). Thus, different robustness or error rate can be provided to different layers of transmission.

[004] However, although single layer transmission mode is specified in IEEE 802.11 technical specification (TS), there has been no discussion on implementation of layered transmission.

[005] There is thus a need for communication apparatuses and methods that can solve the above-mentioned issues. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY

[006] Non-limiting and exemplary embodiments facilitate providing communication apparatuses and communication methods for layered transmission.

[007] According to an aspect of the present disclosure, there is provided a first communication apparatus comprising: circuitry, which in operation, generates a signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at a second communication apparatus; and a transmitter, which in operation, transmits the signal to the second communication apparatus.

[008] According to another aspect of the present disclosure, there is provided a second communication apparatus comprising: a receiver, which in operation, receives a signal from a first communication apparatus, the signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at the second communication apparatus; and circuitry, which, in operation, processes and decodes the signal to recover the two or more data streams.

[009] According to another aspect of the present disclosure, there is provided a communication method comprising: generating a signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at a second communication apparatus; and transmitting the signal to the second communication apparatus.

[0010] It should be noted that general or specific embodiments may be implemented as a system, a method, an integrated circuit, a computer program, a storage medium, or any selective combination thereof. Additional benefits and advantages of the disclosed embodiments will become apparent from the specification and drawings. The benefits and/or advantages may be individually obtained by the various embodiments and features of the specification and drawings, which need not all be provided in order to obtain one or more of such benefits and/or advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying figures where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with present embodiments.

[0012] FIG. 1A depicts an illustration of a 16-Quadrature Amplitude Modulation (16QAM) according to an example.

[0013] FIG. 1B depicts an illustration of a Quadrature Phase Shift Keying (QPSK) according to an example.

[0014] FIG. 2 depicts an illustration of a modulation procedure according to various embodiments of the present disclosure.

[0015] FIG. 3 depicts an illustration of a demodulation procedure according to various embodiments of the present disclosure.

[0016] FIG. 4 depicts a transmit block diagram for binary convolutional coding (BCC) encoding according to various embodiments of the present disclosure.

[0017] FIG. 5 depicts a transmit block diagram for Low-Density Parity-Check (LDPC) encoding according to various embodiments of the present disclosure.

[0018] FIG. 6A depicts an encoding procedure for a single transmission layer according to various embodiments of the present disclosure.

[0019] FIG. 6B depicts a flowchart for transmission of a m^{th} PSDU in a transmission layer according to various embodiments of the present disclosure.

[0020] FIG. 7 depicts an exemplary mapping procedure according to various embodiments of the present disclosure.

[0021] FIG. 8 depicts an even mapping procedure according to various embodiments of the present disclosure.

[0022] FIG. 9 depicts an uneven mapping procedure according to various embodiments of the present disclosure.

[0023] FIG. 10A depicts two data streams without length averaging applied between BCC/LDPC encoder and post-forward error correction (post-FEC) padding procedure according to various embodiments of the present disclosure.

[0024] FIG. 10B depicts two data streams with length averaging applied between BCC/LDPC encoder and post-FEC padding procedure according to various embodiments of the present disclosure.

[0025] FIG. 11A depicts two data streams without length averaging applied before pre-FEC padding procedure according to various embodiments of the present disclosure.

[0026] FIG. 11B depicts two data streams with length averaging applied before pre-FEC padding procedure according to various embodiments of the present disclosure.

[0027] FIG. 12 depicts an illustration of a 3-layer 64-QAM according to various embodiments of the present disclosure.

[0028] FIG. 13 depicts a Ultra High Reliability multi-user physical protocol data unit (UHR MU PPDU) format according to various embodiments of the present disclosure.

[0029] FIG. 14 depicts a flowchart for a non-access point (non-AP) station (STA) behavior in which modulation coding scheme (MCS) and multi-layer combination information is retrieved from a U-SIG field according to various embodiments of the present disclosure.

[0030] FIG. 15 depicts an input bits table for Multi-layer transmission (16-QAM, 64-QAM) according to various embodiments of the present disclosure.

[0031] FIG. 16 depicts an input bits table for Multi-layer transmission (256-QAM) according to various embodiments of the present disclosure.

[0032] Fig. 17 depicts an input bits table for Multi-layer transmission (1024-QAM) according to various embodiments of the present disclosure.

[0033] FIG. 18 depicts a first part of an input bits table for Multi-layer transmission (4096-QAM) according to various embodiments of the present disclosure.

[0034] FIG. 19 depicts a second part of the input bits table of FIG. 19 according to various embodiments of the present disclosure.

[0035] FIG. 20 depicts a table indicating a user field format according to various embodiments of the present disclosure.

[0036] Fig. 21 depicts a flowchart for a non-AP STA behavior in which modulation coding scheme (MCS) and multi-layer combination information is retrieved from a preamble of a User field according to various embodiments of the present disclosure.

[0037] FIG. 22 shows a flow diagram illustrating a communication method according to various embodiments of the present disclosure.

[0038] FIG. 23 shows a schematic, partially sectioned view of a communication apparatus that can be implemented for uplink multi-layer transmission in accordance with various embodiments of the present disclosure.

[0039] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale.

DETAILED DESCRIPTION

[0040] The following detailed description is merely exemplary in nature and is not intended to limit the embodiments or the application and uses of the embodiments. There is no intention to be bound by any theory presented in the preceding Background or this detailed description. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

[0041] Some embodiments of the present disclosure will be described, by way of example only, with reference to the drawings. Like reference numerals and characters in the drawings refer to like elements or equivalents.

[0042] In the following paragraphs, certain exemplifying embodiments are explained with reference to an access point (AP) and a station (STA) for service discovery for local area network.

[0043] In the context of IEEE 802.11 (Wi-Fi) technologies, a station, which is interchangeably referred to as a STA, is a communication apparatus that has the capability to use the IEEE 802.11 protocol. Based on the IEEE 802.11-2020 definition, a STA can be any device that contains an IEEE 802.11-conformant media access control (MAC) and physical layer (PHY) interface to the wireless medium (WM).

[0044] For example, a station may be a laptop, a desktop personal computer (PC), a personal digital assistant (PDA), either an access point or not (e.g., either an AP STA or a non-AP STA), or a Wi-Fi phone in a wireless local area network (WLAN) environment. The station may be fixed or mobile. In the WLAN environment, the terms “STA”, “non-AP STA”, “client”, “wireless client”, “user”, “user device”, and “mobile terminal” are often used interchangeably.

[0045] Likewise, an AP, which may be interchangeably referred to as a wireless access point (WAP) in the context of IEEE 802.11 (Wi-Fi) technologies, is a communication apparatus that allows STAs in a WLAN to connect to a wired network. The AP usually connects to a router (via a wired network) as a standalone device, but it can also be integrated with or employed in the router.

[0046] As mentioned above, a STA in a WLAN may work as an AP at different occasions, and vice versa. This is because communication apparatuses in the context of IEEE 802.11 (Wi-Fi) technologies may include both STA hardware components and AP hardware components. In this manner, the communication apparatuses may switch between a STA mode and an AP mode, based on actual WLAN conditions and/or requirements.

[0047] For example, in a modulation procedure of an IEEE 802.11 signal, when 2^N-Quadrature Amplitude Modulation (2^N- QAM) is used, bits are modulated into a single modulation symbol. FIG. 1A depicts an illustration 100 of a 16-Quadrature Amplitude Modulation (16-QAM) (e.g., $N = 4$), in which 4-bits (e.g., B0 B1 B2 B3) are modulated into each of 16 modulation symbols with 16-QAM. On the other hand, FIG. 1B depicts an illustration 102 of a Quadrature Phase Shift Keying (QPSK) in which 2 bits (e.g., B0 B1) are modulated into each of 4 modulation symbols with QPSK.

Under a same channel status, error rate is lower when less bits are modulated into a single modulation symbol.

[0048] In the IEEE 802.11 technical specification (TS), N bits are modulated into a modulation symbol carried by a subcarrier by a 2^N- QAM modulator, and demodulation will output N bits for every received modulation symbol. While previous IEEE 802.11 TSs mainly aimed at realizing higher throughput, there is a desire to improve reliability, e.g., low latency and/or low frame loss rate, for the next generation IEEE 802.11 TS(s), e.g., UHR SG/IEEE802.11bn and/or future amendment standards. To meet such requirement for reliability, layered transmission (e.g., multi-layer transmission in which multiple data streams are mapped to different bits of a modulation symbol) may be a promising method and hierarchical modulation may be a good solution. Demodulation is achieved by hard-decision or soft-decision, outputting N bits or *N* LLR (log likelihood ratio) values corresponding to the *N* transmitted bits for every received modulation symbol. Under hard decision, a demodulator outputs N bits from a modulation symbol, and the N bits are input to an FEC decoder. Under soft decision, a demodulator outputs N LLR (log likelihood ratio) values and inputs the LLRs to an FEC decoder (e.g., an LDPC decoder). The FEC decoder then outputs N bits per modulation symbol after a decoding (error correction) process. The FEC decoder may process LLRs on a code word basis (e.g., several hundreds of LLRs as input) rather than per N LLRs/Nbits. However, based on the known hierarchical modulation principle, demodulation error rate may differ between bits that are demodulated from a single symbol. For example, bits B0B2 of 16-QAM as shown in FIG. 1A may enjoy a similar demodulation error rate as bits B0B1 of QPSK as shown in FIG. 1B.

[0049] The present disclosure seeks to address how layered transmission may be implemented. In an implementation, a STA may send a multi-layer transmission in a UHR PPDU by mapping multiple data streams (e.g., physical layer service data units (PSDUs), bit streams that are derived from PSDUs, for example, by encoding procedure, information streams, media access control (MAC) layer data streams, etc.) into different bits across each modulation symbol of a data field (e.g., a layered transmission). Multiple data streams may be specified by different priority levels, latency sensitivity, and other similar parameters. In a UHR PPDU, a signaling indicating layered transmission and transmit parameters may be contained. Data streams may be carried by different transmission layers and delivered by a media access control (MAC) layer to a physical (PHY) layer. Multiple PSDUs may be sent to a single STA, and the STA may recover the multiple data streams e.g., using multiple layered demodulators. It will be appreciated that a data stream

may be interchangeably referred to as a layer, a PSDU for layer *m*, information stream, etc. and "multiple" may be interchangeably referred to as "two or more". Further, layered transmission may be implemented but is not limited to hierarchical modulation (e.g., by mapping multiple data streams into different bits across each modulation symbol of a data field). In an implementation, layered transmission may be performed by mapping multiple data streams into different spatial streams (e.g., MIMO streams), each of which contains one or multiple modulation symbols, or by mapping multiple data streams into different frequency resources (e.g., resource units (RUs)), each of which contains one or multiple modulation symbols.

[0050] A STA may indicate the capability of supporting multi-layer transmission within a modulation symbol prior to a layered transmission. The capability may be indicated in an element (e.g., Layered Transmission element, UHR Capabilities element) carried in a Beacon or a Probe Request/Response frame. Advantageously, layered transmission improves reliability and ease of implementation for certain data streams.

[0051] FIG. 2 depicts an illustration 200 of a modulation procedure according to various embodiments of the present disclosure. A STA may transmit multiple data streams, for example, two data streams 202 and 204 in a layered transmission modulated with 16QAM. In a Multi-layer Mapper comprising multiple modules, for example two modules 206 and 208 in this case, the data stream 202 is mapped to bits B0B2 of each modulation symbol by the module 206, while the data stream 204 is mapped to bits B1B3 of each modulation symbol by the module 208. The first group (e.g., bits B0B2) and the second group (e.g., bits B1B3) of data bits may have a different decoding accuracy. After the mapping procedure, the data streams 202 and 204 are modulated by a 16-QAM modulator 210 into a sequence of modulation symbols 212. Further referring to the demodulation side as shown in illustration 300 of FIG. 3, a sequence of modulation symbols $r = X + Yj$ (e.g., the sequence of modulation symbols 301) are received and passed to two layered demodulators 302 and 304. Layer 1 demodulator 302 determines bits B0B2 306 based on a sign of X and Y, and outputs data stream 310 as its demodulated sequence. Layer 2 demodulator 304 determines bits B1B3 308 based on the sign and value of X and Y, and outputs data stream 312 as its demodulated sequence .

[0052] FIG. 4 depicts a transmit block diagram 400 for binary convolutional coding (BCC) encoding in a layered transmission according to various embodiments of the present disclosure. The layered transmission may comprise two or more transmission layers from Layer 1 to Layer

M, each layer comprising a data stream which undergoes a pre-FEC PHY padding procedure 402, a scrambler 404, a BCC encoder 406, a post-FEC PHY padding procedure 408, and a stream parser 410 which parses the data stream into one or more initial streams. Each initial stream may be processed by a BCC interleaver 412, and then rearranged and/or combined with other initial streams from other layers. Each of the rearranged and/or combined initial streams may be processed by a multi-layer mapper 414 to form a spatial stream which is processed by a constellation mapper 416 and may then be processed by a cyclic shift diversity (CSD) per spatial stream (SS) procedure 418. Each of the spatial streams may be further processed by a spatial and frequency mapper 420, an inverse discrete Fourier transform (IDFT) process 422, an insert guard interval (GI) and window process 424 and an analog and radio frequency (RF) conversion process 426 to modulate the spatial streams into a sequence of modulation symbols.

[0053] Further, FIG. 5 depicts a transmit block diagram 500 for Low-Density Parity-Check (LDPC) encoding according to various embodiments of the present disclosure. While largely similar to the transmit block diagram 400 for BCC encoding, transmit block diagram 500 comprises an LDPC encoder 502 instead of the BCC encoder 406, and does not include the BCC interleaver process 412.

[0054] In an implementation, a STA may be configured to transmit M data streams carried by M transmission layers within a modulation symbol modulated with 2^N- QAM, where N is an even number defined by IEEE 802.11 spec, $M \leq \frac{N}{2}$. Referring to illustration 600 of FIG. 6A depicting an exemplary encoding procedure for a single transmission layer, pre-FEC PHY padding 602 and post-FEC PHY padding 604 may be appended to each data stream before Multi-layer Mapper 606.

[0055] For an m^{th} $(1 \leq m \leq M)$ PSDU of two or more PSDUs targeted at one or more STAs contained in a UHR MU PPDU, in this case, the PSDU is transmitted by an m^{th} transmission layer targeted at a STA u, and the pre-FEC PHY padding and post-FEC PHY padding process may be described as follows. A STA transmitting the two or more PSDUs first computes the number of bits left in the last OFDM symbol for the m^{th} transmission layer for a STA u, for example based on the equation below:

$$N_{Excess,u,m} = \left(8 \cdot APEP_LENGTH_{u,m} + N_{Tail,u,m} + N_{Service}\right) mod\ N_{DBPS,u,m}$$

where

$APEP_LENGTH_{u,m}$ is the TXVECTOR parameter APEP_LENGTH for the m^{th} transmission layer for STA u;

$N_{Tail,u,m}$ is the number of tail bits per encoder for the m^{th} transmission layer for STA u;

$N_{Service}$ is the number of bits in the SERVICE field; and

$N_{DBPS,u,m}$ is the number of data bits per symbol for the m^{th} transmission layer for STA u.

[0056] FIG. 6B depicts a flowchart for transmission of a m^{th} PSDU in a transmission layer according to the above equation. In step 610, the STA transmitting the two or more PSDUs may calculate a PSDU length for each layer of each STA receiving the two or more PSDUs. In step 612, the STA may modulate and transmit, within a UHR PPDU, the PSDUs each of which has the PSDU length calculated in step 610.

[0057] Based on $N_{Excess,u,m}$, the initial number of symbol segments in the last OFDM symbol is computed, e.g., initial pre-FEC padding factor value $a_{init,u,m}$, and the initial number of OFDM symbols $N_{SYM,init,u,m}$ for the m^{th} transmission layer for STA u based on the following equation:

$$a_{init,u,m} = \begin{cases} 4, \ if \ N_{Excess,u,m} = 0 \\ \min\left(\left\lceil \frac{N_{Excess,u,m}}{N_{DBPS,\,short,\,u,m}} \right\rceil, \ 4\right), \ otherwise \end{cases}$$

$$N_{SYM,init,u,m} = \left\lceil \frac{8 \cdot APEP_LENGTH_{u,m} + N_{Tail,u,m} + N_{Service}}{N_{DBPS,u,m}} \right\rceil$$

where

$N_{DBPS,,short,\,u,m} = N_{CBPS,\,short,\,u,m} \cdot R_{u,m}$, in which $R_{u,m}$ is the coding rate for the m^{th} transmission layer for the STA u; and

$N_{CBPS,\,short,\,u,m}$ is the number of coded data bits per symbol for the m^{th} transmission layer for the STA u.

[0058] Among all the transmission layers, a set of the layer indices I with the longest encoded packet duration is derived and one value from the set is selected as m_{max} based on the formula

$I = are\ max_{m=0}^{M-1}(N_{SYM,init,\,u,m} - 1 + \frac{a_{init,u,m}}{4})$. Thereafter, the $a_{init,u}$ and $N_{SYM,init,u}$ values among all transmission layers are derived by the formula $N_{SYM,init,u} = N_{SYM,init,u,m_{max}}$ and $a_{init,u} = a_{init,u,m_{max}}$. Given the a_{init} value, the initial number of data bits per symbol and the initial number of coded bits per symbol in the last OFDM symbol for the $\boldsymbol{m^{th}}$ transmission layer for the STA u are defined in the following equations:

$$N_{DBPS,\,last,\,init,\,u,\,m} = \begin{cases} a_{init,u} N_{DBPS,\,short,\,u,m},\ if\ a_{init,u} < 4 \\ N_{DBPS,u,\,m},\ if\ a_{init,u} = 4 \end{cases}$$

$$N_{CBPS,\,last,\,init,\,u,m} = \begin{cases} a_{init,u} N_{CBPS,\,short,\,u,m},\ if\ a_{init,u} < 4 \\ N_{CBPS,\,u,m},\ if\ a_{init,u} = 4 \end{cases}$$

[0059] For the m^{th} transmission layer for the STA $\boldsymbol{u}$ with LDPC encoding, the number of pre-FEC padding bits is computed with equation $N_{PAD,\,Pre-FEC,\,u,m} = (N_{SYM,init,u} - 1)N_{DBPS,u,m} + N_{DBPS,\,last,\,init,\,u,m} - 8 \cdot APEP_LENGTH_{u,m} - N_{Service}$. On the other hand, for the m^{th} transmission layer for the STA u with BCC encoding, the N_{DBPS} of the last symbol is updated as $N_{PAD,\,Pre-FEC,\,u,m} = (N_{SYM,init,u} - 1)N_{DBPS,m} + N_{DBPS,\,last,\,init,\,u,m} - 8 \cdot APEP_LENGTH_{u,m} - N_{Tail,u,m} - N_{Service}$. Further, the number of post-FEC padding bits in the last symbol for the m^{th} transmission layer is computed by $N_{PAD,\,Post-FEC,\,m} = N_{CBPS,\ m} - N_{CBPS,\,last,\,m}$.

[0060] For a STA receiving the UHR PPDU, the PSDU length for the PSDU carried by the $\boldsymbol{m^{th}}$ transmission layer may be recovered as follows:

$$PSDU_LENGTH_{u,m} = \left\lfloor \frac{(N_{SYM,RX,u} - 1)N_{DBPS,u,m} + N_{DBPS,last,RX,u,m} - N_{service} - N_{tail,u,m}}{8} \right\rfloor$$

where $N_{SYM,RX,u} = N_{SYM} - 1$ (e.g., if the STA u is using LDPC coding, LDPC Extra Symbol Segment field is set to 1, and Pre-FEC Padding Factor field is 1), or N_{SYM} if otherwise; and N_{SYM} is calculated by the equation:

$$N_{SYM} = \left\lfloor \frac{\frac{L_LENGTH + 3}{3} \times 4 - T_{PREAMBLE}}{T_{SYM}} \right\rfloor - b_{PE-Disambiguity}$$

where

L_LENGTH is the value indicated by the LENGTH field of L-SIG field;

$T_{PREAMBLE}$ is the time duration of the preamble; and

$b_{PE-Disambiguity}$ is the value indicated by the PE Disambiguity subfield for a UHR MU PPDU, or the value indicated by the PE Disambiguity subfield in the Common Info field in the Trigger frame for a UHR TB PPDU.

[0061] For a UHR TB PPDU sent in response to a Trigger frame, an AP may indicate all parameters needed for calculating the pre-FEC and post-FEC padding bits. For a m^{th} $(1 \leq m \leq M)$ PSDU of two or more PSDUs contained in an UHR TB PPDU with BCC encoding, UHR MU padding and encoding process may be performed with initial parameters based on equation $N_{SYM,init,m} = N_{SYM,m}$ and $a_{init,m} = a_m$, where $N_{SYM,m}$ and a_m are parameters indicated in the Trigger frame. For a m^{th} $(1 \leq m \leq M)$ PSDU of two or more PSDUs contained in an UHR TB PPDU with LDPC encoding, the UHR MU padding and encoding process may be performed with initial parameters. If the LDPC Extra Symbol Segment field in the Trigger frame is 1, the initial parameter may be set as follows:

$$\begin{cases} a_{init,m} = 4 \ \ and \ \ N_{SYM,init,m} = N_{SYM,m} - 1, & if \ a_m \\ a_{init,m} = a_m - 1 \ and \ \ N_{SYM,init,m} = N_{SYM,m}, & otherwise \end{cases}$$

[0062] If the LDPC Extra Symbol Segment field in the Trigger frame is 0, the initial parameter may be set based on equation $N_{SYM,init,m} = N_{SYM,m}$ and $a_{init,m} = a_m$, where $N_{SYM,m}$ and a_m are parameters indicated in the Trigger frame.

[0063] In an implementation, in a transmit procedure for multi-layer transmission, a Multi-layer Mapper may determine a distribution way of multiple data streams to one or more spatial streams. Referring to illustration 700 of FIG. 7 depicting an exemplary transmit procedure, data bits of a m^{th} data stream after post-FEC padding 702 may be parsed/rearranged into $N_{ss,init,m}$ initial streams by a Stream Parser 704. After stream parsing, $N_{ss,init,m}$ initial streams of data bits are rearranged together with initial streams of data bits of other transmission layer(s) by a Multi-layer Mapper 706 into N_{ss} spatial streams of data bits. It will be appreciated that the number of initial steams $N_{ss,init,m}$ and the number of spatial streams N_{ss} may be different.

[0064] For a Multi-layer Mapper, there may be two options for mapping data streams to spatial streams. In an option 1, even mapping may be implemented in which a same number of initial streams of data bits are rearranged from each data stream, and a number of initial streams for

each data stream is same as the number of spatial streams ($N_{ss,init,1} = N_{ss,init,m} = N_{ss,init,M} = N_{SS}$). For example, referring to mapping procedure 800 as shown in FIG. 8, the total number of transmission layers/data streams = 2 (e.g., data streams 802 and 804), the total number of initial streams per transmission layer/data stream = 1 (e.g., initial stream 806 parsed from data stream 802 and initial stream 808 parsed from data stream 804), and the total number of spatial streams $N_{SS} = 1$ (e.g., spatial stream 810). Thus, multiple data streams are evenly carried by each spatial stream, advantageously enabling easy calculation and easy implementation for a STA transmitting the data streams. However, some resources may be wasted if there is a significant difference in length among multiple data streams.

[0065] In an option 2, uneven mapping may be implemented in which a number of initial streams of data bits that are parsed/rearranged from each data stream may be different. Further, a total number of initial streams that are parsed/rearranged from each data stream may also be different from a total number of spatial streams. Thus, an uneven number of data streams may be carried by each spatial stream. For example, referring to uneven mapping procedure 900 of FIG. 9, the number of transmission layers/data streams = 2 (e.g., data streams 902 and 904), the total number of spatial streams $N_{SS} = 2$ (e.g., spatial streams 912 and 914), the total number of initial streams for data stream 902 = 1 (e.g., initial stream 906), the total number of initial streams for data stream 904 = 2 (e.g., initial streams 908 and 910). While more signaling between the MAC layer and PHY layer may be needed, data length can advantageously be balanced even when there is a significant difference in length among two or more data streams. High priority data may also be mapped to a specific spatial stream only to improve transmission performance particularly for high priority data streams.

[0066] In an implementation, a first data stream of two or more data streams may be mapped into a first group of data bits in each modulation symbol, and a second data stream of the two or more data streams may be mapped into a second group of data bits in each modulation symbol, the first group and the second group of data bits having a different protection level (e.g., decoding accuracy, Euclid distance in constellation space, bit error rate, receiver sensitivity). The first data stream and the second data stream may be carried by the plurality of modulation symbols in a same spatial stream. In an implementation where the first data stream is carried by two or more modulation symbols in a first group of spatial streams, the second data stream may be carried by two or more modulation symbols in a second group of spatial streams, wherein the first group of spatial streams and the second group of spatial streams are not overlapped (e.g., each group

includes different stream numbers). In an implementation where the first data stream is carried by two or more modulation symbols in a first group of spatial streams, the second data stream may be carried by two or more modulation symbols in a second group of spatial streams, wherein the second group of spatial streams may comprise one or more same spatial streams as the first group of spatial streams. In an implementation, a first set of modulation symbols in a first group of spatial streams may carry multiple data streams (layers) while a second set of modulation symbols in a second group of spatial streams may carry a single data stream (layer).

[0067] In an implementation, when there is a significant difference in length among multiple data streams, length averaging method may be applied to avoid long padding bits. In a first option, length averaging may be applied between the BCC/LDPC encoder and the post-FEC padding procedure. Code blocks from a first data stream may be cut and appended to a second data stream which contains less code blocks than the first data stream. A STA transmitting the data streams may decide whether to apply length averaging based on transmission situations (e.g., the STA may apply length averaging only when a data stream carrying low latency traffic contains less code blocks). For example, referring to illustration 1000 of FIG. 10A, a first data stream 1002 is encoded into 3 code blocks (code blocks no. 0 to 2) and a second data stream 1004 is encoded into 6 code blocks (code blocks no. 0 to 5). With length averaging being applied as shown in illustration 1006 of FIG. 10B, code blocks no. 3 and 5 of second data stream 1004 are cut and appended to the code blocks of the first data stream 1002, and padding is applied to the code blocks of second data stream 1004 such that the code blocks of both data streams are of the same length.

[0068] For signaling support, 1 to 2 bits may be used to indicate whether length averaging is applied, and to indicate the number of code blocks that are appended to a data stream. An example of a 2-bit signaling for length averaging is shown in Table 1 below.

Value	Whether averaging is applied	Code block factor
0	No	0
1	Yes	1/2
2	Yes	1/3
3	Yes	1/4

Table 1

[0069] The receiver may recover PSDU length for each data stream before BCC/LDPC decoder based on code block factor according to the following equations:

$$PSDU_LENGTH_{u,m,init} = \left\lfloor \frac{(N_{SYM,RX,u} - 1)N_{DBPS,u,m} + N_{DBPS,last,RX,u,m} - N_{service} - N_{tail,u,m}}{8} \right\rfloor$$

$$PSDU_LENGTH_{u,m} = PSDU_LENGTH_{u,m,init} \cdot CodeBlockFactor$$

[0070] In a second option, length averaging may be applied before pre-FEC padding procedure. Octets from a first data stream may be cut and appended to a second data stream that contains less octets that the first data stream. A STA transmitting the data streams may decide whether to apply length averaging based on transmission situations (e.g., the STA may apply length averaging only when a data stream carrying low latency traffic contains less code blocks). For example, referring to illustration 1100 of FIG. 11A, a first data stream 1102 is encoded into 3 octets and a second data stream 1104 is encoded into 6 octets. With length averaging being applied as shown in illustration 1106 of FIG. 11B, octets no. 3 and 5 of second data stream 1104 are cut and appended to the octets of the first data stream 1102, and padding is applied to the octets of second data stream 1104 such that the octets of both data streams are of the same length. Signaling support as shown in Table 1 may also be applied for this length averaging implementation.

[0071] In an implementation, in a UHR PPDU, a STA may be configured to map two or more data streams into a plurality of bits of each modulation symbol in a fixed manner. For each constellation mapper, the number and selection of input bits contained in each transmission layer may be fixed or predefined. The fixed/predefined bits for each layer may be selected based on a constellation mapper distribution. For example, when multi-layer transmission is applied, it is predefined that two transmission layers are carried by each modulation symbol. An exemplary input bits and Similar Demodulation Error Rate (SDER) table for different levels of QAM may be shown as in Table 2A below. Further examples are shown in Tables 2B to 2E below. Table 2B shows a variation of Table 2A in which the modulation mappings for Layer 1 are defined so that the layer has a robust SDER (e.g., QPSK. Alternatively (not shown in the table), 16-QAM with repetition or lower code rate) for all QAM levels, which advantageously enables Layer 1 to be

robust against sudden changes in channel conditions. In Table 2C, a lower QAM (e.g., lower by 1 level for each QAM level) is used for Layer 1, which advantageously enables utilization of radio resources while providing more robustness (e.g., 1/10 to 1/100 of packet error rate) for Layer 1. In Table 2D, there is an almost even split in assignment of input bits among the layers, which advantageously enables less complex resource assignment by the MAC layer. In Table 2E, there is an even split of input bits among the layers (save for an addition of a “weak bit” in Layer 1 for 64QAM (e.g., bit B5) and 1024 QAM (e.g., bit B9)) which advantageously enables a less complex and easier operation by the MAC layer. It will be appreciated that any of the modulation mapping for multi-layer examples depicted in Figs.15-19 can be adapted to a fixed/predetermined implementation of input bits as shown in Tables 2A-2E.

QAM Level	**Input bits (Layer 1)**	**Input bits (Layer 2)**	**SDER (Layer 1)**
16-QAM	B0B2	B1B3	QPSK
64-QAM	B0B3	B1B2B4B5	QPSK
256-QAM	B0B4	B1B2B3B5B6B7	QPSK
1024-QAM	B0B1B5B6	B2B3B4B7B8B9	16-QAM
4096-QAM	B0B1B6B7	B2B3B4B5B8B9B10B11	16-QAM

Table 2A

QAM Level	**Input bits (Layer 1)**	**Input bits (Layer 2)**	**SDER (Layer 1)**
16-QAM	B0B2	B1B3	QPSK
64-QAM	B0B3	B1B2B4B5	QPSK
256-QAM	B0B4	B1B2B3B5B6B7	QPSK
1024-QAM	B0B5	B1B2B3B4B6B7B8B9	QPSK
4096-QAM	B0B6	B1-B5;B7-B11	QPSK

Table 2B

QAM Level	Input bits (Layer 1)	Input bits (Layer 2)	SDER (Layer 1)
16-QAM	B0B2	B1B3	QPSK
64-QAM	B0B1B3B4	B2B5	16-QAM
256-QAM	B0B1B4B5	B2B3B6B7	64-QAM
1024-QAM	B0-B3;B5-B8	B4B9	256-QAM
4096-QAM	B0-B4;B6-B10	B5B11	1024-QAM

Table 2C

QAM Level	Input bits (Layer 1)	Input bits (Layer 2)	SDER (Layer 1)
16-QAM	B0B2	B1B3	QPSK
64-QAM	B0B3	B1B2B4B5	QPSK
256-QAM	B0B1B4B5	B2B3B6B7	16-QAM
1024-QAM	B0B1B5B6	B2B3B4B7B8B9	16-QAM
4096-QAM	B0-B2; B6-B8	B3-B5; B9-B11	64-QAM

Table 2D

QAM Level	Input bits (Layer 1)	Input bits (Layer 2)	SDER (Layer 1)
16-QAM	B0B2	B1B3	QPSK
64-QAM	B0B3; B5	B1B2B4	QPSK~16QAM
256-QAM	B0B1B4B5	B2B3B6B7	16-QAM
1024-QAM	B0B1B5B6; B9	B2B3B4B7B8	16-QAM~64QAM
4096-QAM	B0-B2; B6-B8	B3-B5; B9-B11	64-QAM

Table 2E

[0072] Advantageously, there is minor change to PHY signaling and ease of implementation. However, since the combination for mapping is fixed in this case, performance and application may be limited in some scenarios.

[0073] FIG. 12 depicts an illustration 1200 of a 3-layer 64-QAM according to various embodiments of the present disclosure. The distribution of first layer B0B3 1202 in the constellation mapper is consistent with a QPSK distribution as shown in illustration 102 of FIG. 1B. The distribution of second layer B1B4 1204 in the constellation mapper is consistent with a 16-QAM distribution as shown in illustration 100 of FIG. 1A. The remaining B2B5 is the third layer. In this case, as input bits for each level QAM are predefined, 1-bit signaling is enough to indicate multi-layer transmission within a modulation symbol. For a UHR MU PPDU, for example referring to UHR MU PPDU 1300 of FIG. 13, a User field of UHR-SIG field 1302 may indicate whether multi-layer transmission within a modulation symbol is applied to a receiver non-AP STA e.g., via a single bit B15 in a Multi-layer Flag subfield of the User field format as shown in entry 1306 of table 1304. For a UHR TB PPDU, modulation rate and whether to apply multi-layer transmission within a modulation symbol may be determined by an AP and informed to each STA engaged in the UHR TB PPDU transmission using a Trigger frame which triggers the UHR TB PPDU transmission. A receiver non-AP STA may retrieve information regarding multi-layer transmission and MCS information from the UHR-SIG field 1302, demodulate payload portion with multiple layered demodulators based on the retrieved information and obtain the two or more data streams.

[0074] FIG. 14 depicts a flowchart for a non-AP STA behavior in which MCS and multi-layer combination information is retrieved from a U-SIG field according to various embodiments of the present disclosure. The process starts at step 1402. At step 1404, a UHR PPDU is received. At step 1406, MCS and Multi-layer Flag information is retrieved from U-SIG. At step 1408, it is determined whether data transmitted to the non-AP STA is a multi-layer transmission. If it is determined that the transmission is not a multi-layer transmission, the process proceeds to step 1410 in which the data field is processed with the demodulator in a same manner as the IEEE 802.11be TS and the process ends at step 1414. Otherwise, the process proceeds from step 1408 to step 1412 instead to process the data field with double demodulators based on MCS, and then the process ends at step 1414.

[0075] In an implementation, in a UHR PPDU, a STA transmitting multiple data streams may map the multiple data streams into bits of each modulation symbol in a flexible manner. For each constellation mapper, the number and selection of input bits contained in each layer may be flexible and indicated in the preamble. The transmitter may select an MCS and multi-layer combinations based on channel status and estimated performance (e.g., SDER) of a multi-layer combination. The SDER for a m^{th} layer may be calculated by the following equation: $SDER_m = DER_{MR} - DegradationFactor$, where DER_{MR} is the demodulation error rate for a specific modulation rate equivalent to the m^{th} layer, and $DegradationFactor$ is an adjusting parameter estimated by the transmitter based on the environment of the transmission. An effect of this mapping configuration is that more bits are utilized for PHY signaling. Advantageously, the combination is flexible to fit different scenarios.

[0076] For example, when multi-layer transmission is applied, the number of transmission layers carried by each modulation symbol and input bits contained in each transmission layer may be indicated. Examples of input bits and SDER tables for different levels of QAM are shown in input bits table 1500 of FIG. 15 for 16-QAM and 64-QAM multi-layer transmission, input bits table 1600 of FIG. 16 for 256-QAM multi-layer transmission, input bits table 1700 of FIG. 17 for 1024-QAM multi-layer transmission, and input bits tables 1800 and 1900 of FIGs. 18 and 19 respectively for a 4096-QAM multi-layer transmission. According to the example input bits tables 1500 to 1900 for multi-layer transmission, when the MCS is indicated, up to 24 entries may be required to indicate a corresponding assignment for each of the multiple layers.

[0077] For signaling support, 5 bits may be utilized to indicate Multi-layer Combinations including a number of layers and selected bits for each layer. For a UHR MU PPDU, the User field of UHR-SIG may indicate MCS and Multi-layer Combinations applied to a receiver non-AP STA. For an UHR TB PPDU, MCS and Multi-layer Combinations may be determined by the AP and informed to each STA engaged in the UHR TB PPDU transmission using a Trigger frame which triggers the UHR TB PPDU transmission. A non-AP STA receiving the multi-layer transmission may retrieve information regarding MCS and Multi-layer Combinations information from UHR-SIG field of the UHR TB PPDU, demodulates payload portion with multiple layered demodulators based on it and obtains multiple data streams. In an alternative implementation for signaling support, bits assignment for multi-layer transmission may be limited (e.g., no more than 3 layers) to reduce signaling bits. For example, the TS may define (and/or a STA may implement) a mapping table indicating index definition for selected indices (e.g., selected indices from the

tables as shown in Figs.15-19). In another implementation, the TS may define (and/or a STA may implement), for example, up to 4 indices or combinations of indices for each QAM type (e.g., indices 1,2,5,6 for 256-QAM in Figure.16). It will be appreciated that the above examples are not exhaustive, and other implementations or variations for signaling support and bits assignment for multi-layer transmission are also possible. 5 bits are sufficient to indicate both MCS and Multi-layer Combinations information, for example bits B11-B15 as shown in row 2002 in user field format table 2000 of FIG. 20.

[0078] Fig. 21 depicts a flowchart 2100 for a non-AP STA behavior in which MCS and multi-layer combination information is retrieved from a preamble of a User field according to various embodiments of the present disclosure. The process starts at step 2102. At step 2104, a UHR PPDU is received. At step 2106, MCS and Multi-layer combination information is retrieved from a preamble of the UHR PPDU. At step 2108, it is determined whether data transmitted to the non-AP STA is a multi-layer transmission. If it is determined that the transmission is not a multi-layer transmission, the process proceeds to step 2110 in which the data field is processed with the demodulator in a same manner as the IEEE 802.11be TS and the process ends at step 2114. Otherwise, the process proceeds from step 2108 to step 2112 instead to process the data field with multiple demodulators based on MCS, and then the process ends at step 2114.

[0079] FIG. 22 shows a flow diagram 2200 illustrating a communication method according to various embodiments. At step 2202, a signal comprising a plurality of modulation symbols is generated, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at a second communication apparatus. At step 2204, the signal is transmitted to the second communication apparatus.

[0080] FIG. 23 shows a schematic, partially sectioned view of a communication apparatus 2300 that can be implemented for service discovery for local area network in accordance with the various embodiments. The communication apparatus 2300 may be implemented as a mobile terminal, application host, router, server, STA or AP according to various embodiments.

[0081] Various functions and operations of the communication apparatus 2300 are arranged into layers in accordance with a hierarchical model. In the model, lower layers report to higher layers and receive instructions therefrom in accordance with IEEE specifications. For the sake of simplicity, details of the hierarchical model are not discussed in the present disclosure.

[0082] As shown in FIG. 23, the communication apparatus 2300 may include circuitry 2314, at least one radio transmitter 2302, at least one radio receiver 2304 and multiple antennas 2312 (for the sake of simplicity, only one antenna is depicted in FIG. 23 for illustration purposes). The circuitry may include at least one controller 2306 for use in software and/or hardware aided execution of tasks it is designed to perform, including control of communications with one or more other devices in a wireless network. The at least one controller 2306 may control at least one transmission signal generator 2308 for generating frames to be sent through the at least one radio transmitter 2302 to one or more other STAs or APs and at least one receive signal processor 2310 for processing frames received through the at least one radio receiver 2304 from the one or more other STAs or APs. The at least one transmission signal generator 2308 and the at least one receive signal processor 2310 may be stand-alone modules of the communication apparatus 2300 that communicate with the at least one controller 2306 for the above-mentioned functions. Alternatively, the at least one transmission signal generator 2308 and the at least one receive signal processor 2310 may be included in the at least one controller 2306. It is appreciable to those skilled in the art that the arrangement of these functional modules is flexible and may vary depending on the practical needs and/or requirements. The data processing, storage and other relevant control apparatus can be provided on an appropriate circuit board and/or in chipsets.

[0083] In various embodiments, when in operation, the at least one radio transmitter 2302, at least one radio receiver 2304, and at least one antenna 2312 may be controlled by the at least one controller 2306. Furthermore, while only one radio transmitter 2302 is shown, it will be appreciated that there can be more than one of such transmitters.

[0084] In various embodiments, when in operation, the at least one radio receiver 2304, together with the at least one receive signal processor 2310, forms a receiver of the communication apparatus 2300. The receiver of the communication apparatus 2300, when in operation, provides functions required for processing an information container. While only one radio receiver 2304 is shown, it will be appreciated that there can be more than one of such receivers.

[0085] The communication apparatus 2300, when in operation, provides functions required for layered transmission. For example, the communication apparatus 2300 may be a first communication apparatus, and the circuitry 2314 may, in operation, generate a signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams,

the two or more data streams being targeted at a second communication apparatus. The transmitter 2302 may, in operation, transmit the signal to a second communication apparatus.

[0086] The circuitry 2314 may be configured to map a first data stream of the two or more data streams into a first group of data bits in each modulation symbol, and a second data stream of the two or more data streams into a second group of data bits in each modulation symbol, the first group and the second group of data bits having a different decoding accuracy. A first data stream and a second data stream may be carried by the plurality of modulation symbols in a same spatial stream. The first data stream and the second data stream may be carried by the plurality of modulation symbols in a same spatial stream. The first data stream may be carried by two or more modulation symbols in a first group of spatial streams, the second data stream may be carried by two or more modulation symbols in a second group of spatial streams, and the second group of spatial streams may comprise one or more same spatial streams as the first group of spatial streams. The signal may further comprise a field indicating a total number of groups of data bits and a total number of data bits contained in each group of data bits. The circuitry 2314 may be configured to append one or more code blocks of the first data stream to the second data stream comprising less code blocks than the first data stream between a BCC/LDPC encoder and a post-FEC padding procedure. The circuitry 2314 may be configured to append one or more octets of the first data stream to the second data stream comprising less octets than the first data stream before a pre-FEC padding procedure.

[0087] The circuitry 2314 may be configured to parse each data stream of the two or more data streams into one or more initial streams and rearrange all initial streams of the two or more data streams into one or more spatial streams. A total number of initial streams may be different from a total number of spatial streams. A same number of initial streams may be parsed from each data stream, and a total number of initial streams may be parsed from each data stream is same as a total number of spatial streams. A different number of initial streams may be parsed from each data stream, and a total number of initial streams parsed from each data stream may be different from a total number of spatial streams.

[0088] A number of data streams that are carried by each modulation symbol and a selection of data bits in each modulation symbol for mapping to each data stream may be fixed or predefined, and the signal may comprise a 1-bit field indicating whether two or more data streams are carried within a modulation symbol. A number and selection of data bits in each modulation symbol for

mapping to each data stream may be flexible, and the signal may comprise a 5-bit field indicating the number and selection of data bits in each modulation symbol. Each of the two or more data streams may be a physical layer service data unit (PSDU).

[0089] The communication apparatus 2300 may be a second communication apparatus. The receiver 2304 may, in operation, receive a signal from a first communication apparatus, the signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at the second communication apparatus. The circuitry 2314 may, in operation, process and decode the signal to recover the two or more data streams.

[0090] The circuitry 2314 may be configured to demodulate each modulation symbol of the plurality of modulation symbols in the signal in parallel. The circuitry 2314 may be configured to demodulate two or more data streams from each modulation symbol in the signal.

[0091] The present disclosure can be realized by software, hardware, or software in cooperation with hardware. Each functional block used in the description of each embodiment described above can be partly or entirely realized by an integrated circuit (IC) such as LSI (Large Scale Integration), and each process described in each embodiment may be controlled partly or entirely by a same LSI or a combination of LSIs. The LSI may be individually formed as chips, or one chip may be formed so as to include a part or all of the functional blocks. The LSI may include a data input and output coupled thereto. The LSI here may be referred to as an IC, a system LSI, a super LSI, an ultra-LSI, a very-large-scale integration (VLSI), or a system on a chip (SoC) depending on the integration scales. However, the technique of implementing an integrated circuit is not limited to the LSI and may be realized by using a dedicated circuit, a general-purpose processor, or a special-purpose processor. In addition, a FPGA (Field Programmable Gate Array) that can be programmed after the manufacture of the LSI or a reconfigurable processor in which the connections and the settings of circuit cells disposed inside the LSI can be reconfigured may be used. The present disclosure can be realized as digital processing and/or analogue processing. The functional blocks could be integrated with various integrated circuit technologies which are not limited to those mainly used at present. Biotechnology can also be applied.

[0092] The present disclosure can be realized by any kind of apparatus, device or system having a function of communication, which is referred to as a communication apparatus.

[0093] Some non-limiting examples of such communication apparatus may include a phone (e.g., cellular (cell) phone, smart phone), a tablet, a personal computer (PC) (e.g., laptop, desktop, netbook), a camera (e.g., digital still/video camera), a digital player (digital audio/video player), a wearable device (e.g., wearable camera, smart watch, tracking device, head mounted display (HMD), smart glasses), a game console, a digital book reader, a telehealth/telemedicine (remote health and medicine) device, and a vehicle providing communication functionality (e.g., automotive, airplane, ship), and various combinations thereof.

[0094] The communication apparatus is not limited to be portable or movable, and may also include any kind of apparatus, device or system being non-portable or stationary, such as a smart home device (e.g., an appliance, lighting, smart meter, control panel), a vending machine, and any other “things” in a network of an “Internet of Things (IoT)”.

[0095] The communication may include exchanging data through, for example, a cellular system, a wireless LAN system, a satellite system, etc., and various combinations thereof.

[0096] The communication apparatus may comprise a device such as a controller or a sensor which is coupled to a communication apparatus performing a function of communication described in the present disclosure. For example, the communication apparatus may comprise a controller or a sensor that generates control signals or data signals which are used by a communication apparatus performing a communication function of the communication apparatus.

[0097] The communication apparatus also may include an infrastructure facility, such as a base station, an access point, and any other apparatus, device or system that communicates with or controls apparatuses such as those in the above non-limiting examples.

[0098] Thus, it can be seen that the present embodiments provide communication apparatuses and methods for layered transmission.

[0099] While exemplary embodiments have been presented in the foregoing detailed description of the present embodiments, it should be appreciated that a vast number of variations exist. It should further be appreciated that the exemplary embodiments are examples, and are not intended to limit the scope, applicability, operation, or configuration of this disclosure in any

way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing exemplary embodiments, it being understood that various changes may be made in the function and arrangement of steps and method of operation described in the exemplary embodiments and modules and structures of devices described in the exemplary embodiments without departing from the scope of the subject matter as set forth in the appended claims.

CLAIMS

1. A first communication apparatus comprising:

circuitry, which in operation, generates a signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at a second communication apparatus; and

a transmitter, which in operation, transmits the signal to the second communication apparatus.

2. The first communication apparatus of claim 1, wherein the circuitry is configured to map a first data stream of the two or more data streams into a first group of data bits in each modulation symbol, and a second data stream of the two or more data streams into a second group of data bits in each modulation symbol, the first group and the second group of data bits having a different decoding accuracy.

3. The first communication apparatus of claim 1, wherein a first data stream and a second data stream are carried by the plurality of modulation symbols in a same spatial stream.

4. The first communication apparatus of claim 2, wherein the first data stream and the second data stream are carried by the plurality of modulation symbols in a same spatial stream.

5. The first communication apparatus of claim 2, wherein the first data stream is carried by two or more modulation symbols in a first group of spatial streams, the second data stream is carried by two or more modulation symbols in a second group of spatial streams, and the second group of spatial streams comprises one or more same spatial streams as the first group of spatial streams.

6. The first communication apparatus of claim 1 or 2, wherein the signal further comprises a field indicating a total number of groups of data bits and a total number of data bits contained in each group of data bits.

7. The first communication apparatus of claim 2 or 3, wherein the circuitry is configured to append one or more code blocks of the first data stream to the second data stream

comprising less code blocks than the first data stream between a binary convolutional coding/ Low-Density Parity-Check (BCC/LDPC) encoder and a post-forward error correction (post-FEC) padding procedure.

8. The first communication apparatus of claim 2 or 3, wherein the circuitry is configured to append one or more octets of the first data stream to the second data stream comprising less octets than the first data stream before a pre-FEC padding procedure.

9. The first communication apparatus of claim 1, wherein the circuitry is configured to parse each data stream of the two or more data streams into one or more initial streams; and rearrange all initial streams of the two or more data streams into one or more spatial streams.

10. The first communication apparatus of claim 9, wherein a total number of initial streams is different from a total number of spatial streams.

11. The first communication apparatus of claim 9, wherein a same number of initial streams are parsed from each data stream, and a total number of initial streams parsed from each data stream is same as a total number of spatial streams.

12. The first communication apparatus of claim 9, wherein a different number of initial streams are parsed from each data stream, and a total number of initial streams parsed from each data stream is different from a total number of spatial streams.

13. The first communication apparatus of claim 1, wherein a number of data streams that are carried by each modulation symbol and a selection of data bits in each modulation symbol for mapping to each data stream are fixed or predefined, and the signal comprises a 1-bit field indicating whether two or more data streams are carried within a modulation symbol.

14. The first communication apparatus of claim 2, wherein a number and selection of data bits in each modulation symbol for mapping to each data stream are flexible, and the signal comprises a 5-bit field indicating the number and selection of data bits in each modulation symbol.

15. The first communication apparatus of claim 1, wherein each of the two or more data streams is a physical layer service data unit (PSDU).

16. A second communication apparatus comprising:

a receiver, which, in operation, receives a signal from a first communication apparatus, the signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at the second communication apparatus;

circuitry, which, in operation, processes and decodes the signal to recover the two or more data streams.

17. The second communication apparatus of claim 16, wherein the circuitry is configured to demodulate each modulation symbol of the plurality of modulation symbols in the signal in parallel.

18. The second communication apparatus of claim 16, wherein the circuitry is configured to demodulate two or more data streams from each modulation symbol in the signal.

19. A communication method comprising:

generating a signal comprising a plurality of modulation symbols, each modulation symbol carrying two or more data streams, the two or more data streams being targeted at a second communication apparatus; and

transmitting the signal to the second communication apparatus.