

TECHNIQUES FOR BEAMFORMING

TECHNICAL FIELD

The present disclosure relates to techniques for Beamforming. The disclosure particularly
5 relates to a beamformer device transmitting a request with a set of sounding tone indices
to a beamformee device, and a beamformee device transmitting a report of beamforming
information to a beamformer device. The disclosure further relates to a beamformer device
receiving a beamforming report from a beamformee device.

10 BACKGROUND

Compressed Beamforming Report is part of sounding procedure, defined for transmission
of beamforming information from beamformee to beamformer. It is used by
IEEE 802.11n/ac/ax versions of WiFi standard, also known as 11n, 11ac, 11ax.

Compressed Beamforming Report consists of MIMO (Multiple-Input Multiple-Output)
15 Control Field that defines various parameters indication (e.g. N_c , N_g , Codebook size),
general feedback information (e.g. average SNR (signal-to-noise ratio) per stream) and
per-tone compressed data which includes precoder matrix and per-tone SNR (for MU
(multi-user) feedback type).

Starting from 802.11ax sounding may be performed on the entire bandwidth (BW) or part
20 of the BW (single or multiple Resource Allocations – RUs (Resource Units)). Thus,
specific set of tone (subcarrier) indices is defined for sounding of every portion of the
supported BW.

IEEE 802.11be, also known as 11be or WiFi6E, introduces a larger BW and larger MIMO
size, which require updated feedback parameters, frame format and also an exact
25 definition of compressed precoder matrix and SNR. Moreover, 802.11be introduces a new
tone plan (i.e. a structure of frequency division to basic units, RUs) which implies different
tone definition to be applied for sounding as well.

SUMMARY

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

- 5 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 index definition for a new tone plan. The disclosure presents an update for parameters and formats defined by HE (High Efficiency) WiFi, e.g. according to IEEE 802.11ax, to include new and extended cases introduced by
10 EHT WiFi, e.g. according to IEEE 802.11be.

The disclosure provides a new/extended definition for the following fields and parameters:

- New sounding indices definition for $BW \geq 80$ MHz;
- Extended definition of compressed precoder matrix values;
- Extended definition of SNR values.

- 15 In particular, the disclosure introduces a mechanism for adjusting tone indices to 802.11be tone plan.

A new tone plan introduced by 802.11be is for partial BW transmission (including punctured BW) while the full 80 MHz BW assigned to a single STA (Station) (or group of STAs) will reuse 802.11ax tone plan. This new tone plan can be defined in a partial BW
20 info field.

The disclosure introduces the following three optional solutions that will be described in detail hereinafter:

- Option 1: Introduce a new unified sounding indices set to be used for all the options (means that the new set should cover both a new tone plan and
25 802.11ax tone plan of full BW);
- Option 2: Introduce a new sounding indices set for partial BW sounding (by duplication of indices of 20 MHz portion) and add a center tones indices for full BW sounding;
- Option 3: Reuse 802.11ax sounding indices set but define which sounding RUs
30 correspond data RU defined by new tone plan.

A further idea of the disclosure is to define compressed beamforming matrix values and part of general parameters.

In summary, the disclosure defines indices for measurement and reported compressed beamforming precoder matrices for new bandwidth values and a new tone plan introduced
 5 by IEEE 802.11be standard. The disclosure also provides an exact definition of compressed precoder matrix form for MIMO schemes larger than 8x8 adopted by IEEE 802.11be.

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

	BW	bandwidth
10	MIMO	Multiple-Input Multiple-Output
	SNR	signal-to-noise ratio
	MU	multi-user
	SU	single-user
	Ng	number of tones, tone grouping factor
15	Nc	number of spatial streams
	Na	number of angles
	Nr	number of transmit antennas
	RU	resource unit
	OFDMA	Orthogonal Frequency Division Multiple Access
20	STA	Station according to WiFi notation
	AP	Access point according to WiFi notation
	S1 to S4	frequency segments
	NDP	Null Data Packet

Resource Unit (RU) is a unit in OFDMA terminology used in WiFi schemes to denote a
 25 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.

30 According to a first aspect, the disclosure relates to a beamformer device, configured to: transmit a request to a beamformee device, the request comprising a set of sounding tone indices, the set of sounding tone indices indicating tones for which a report of beamforming information is requested from the beamformee device, wherein the tones are defined

according to a first WiFi scheme, wherein the set of sounding tone indices is based on a first tone plan defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined by a second WiFi scheme for a full channel bandwidth.

Such a beamformer device can improve performance of beamforming in advanced communication schemes such as EHT by operating on a novel set of sounding tone indices that is based on the first tone plan for partial channel bandwidth and on the second tone plan for full channel bandwidth.

The beamformer device (also called beamformer) sends a sounding packet and requests a beamformee device (also called beamformee) to measure a channel on the specific BW which can be an entire BW or part of the BW that sounding packet is transmitted on.

Afterwards, beamformee is requested to transmit a compressed beamforming report, which includes beamforming info for those tones that were requested by beamformer. But the transmission of this report may be on the entire BW or any part of the BW, not related to reported tones at all.

For example, beamformer transmit sounding packet on 80 MHz and asks to report on first 10 MHz only, but the report will be transmitted using entire 80 MHz BW.

In this disclosure, a definition of set of tone indices is given to indicate which part of sounding BF is requested to be reported.

Regarding tone plans and WiFi schemes:

- a. There are two Wifi schemes: 11be (named first scheme) which supports BW of 80/160/240/320 MHz and 11ax (named second scheme) that only 80 MHz is relevant
- b. For any subset of 80 MHz BW, 11be WiFi scheme defined a new tone plan (named first tone plan)
- c. For full 80 MHz BW 11be reuse 11ax tone plan (named second tone plan)
- d. Any BW > 80 MHz supported by 11be will use a duplication of 80 MHz tone plan which means that within any 80 MHz segment rules b. and c. are valid

The first tone plan is partitioned into a plurality of resource units, RU, each RU allocating a respective portion of the channel bandwidth, wherein each RU is partitioned into a plurality of tones to be reported.

The set of sounding tone indices comprises for each RU a start sounding tone index defining a starting tone of the respective RU for reporting the beamforming information and an end sounding tone index defining an end tone of the respective RU for reporting the beamforming information.

- 5 In an exemplary implementation of the beamformer device, the first WiFi scheme is 802.11be WiFi, and the second WiFi scheme is 802.11ax WiFi.

This provides the advantage that the beamformer device can be applied with IEEE 802.11be WiFi schemes, which provide higher bandwidth and higher MIMO sizes than current versions of WiFi in order to improve performance.

- 10 In an exemplary implementation of the beamformer device, the first WiFi scheme is supporting channel bandwidths of 80 MHz, 160 MHz, 80 + 80 MHz, 240 MHz and 320 MHz.

This provides the advantage that the beamformer device supports such bandwidths as currently supported by EHT WiFi.

- 15 In an exemplary implementation of the beamformer device, the second WiFi scheme is supporting a channel bandwidth of 80 MHz.

This provides the advantage that the beamformer device is compliant with current version of IEEE 802.11ax WiFi supporting channel bandwidth of 80 MHz.

In an exemplary implementation of the beamformer device, the full channel bandwidth is 80 MHz; and the partial channel bandwidth is any subset of the full channel bandwidth.

- 20 This provides the advantage that the beamformer device can be applied on a variety of different bandwidths, either based on the full channel bandwidth or on subsets thereof.

- In an exemplary implementation of the beamformer device, the sounding tone indices are based on a new unified sounding index set that comprises sounding tone indices for both, the first tone plan for the partial channel bandwidth and the second tone plan for the full
25 channel bandwidth.

This provides the advantage that the beamformer device can provide new sounding tone indices for bandwidths greater than 80 MHz.

Such a beamformer device supports a solution according to Option 1 as mentioned above. Corresponding tables are described below with respect to Figures 5, 6 and 7.

This implementation describes the rules for option 1 which are that the sounding tone indices are based on a new unified sounding index set that comprises sounding tone indices for both, the first tone plan for the partial channel bandwidth and the second tone plan for the full channel bandwidth. Further explanation of the rules is given in the Figures
5 part of the description with respect to Figures 5 to 7 where the different tables with sounding tone indices are shown for this option 1.

In an exemplary implementation of the beamformer device, the sounding tone indices are based on a new sounding index set for the partial channel bandwidth and additional center tones indices for the full channel bandwidth.

10 This provides the advantage that the beamformer device can provide new sounding tone indices for a variety of bandwidths, in particular bandwidths greater than 80 MHz.

Such a beamformer device supports a solution according to Option 2 as mentioned above. Corresponding tables are described below with respect to Figures 8, 9 and 10.

This implementation describes the rules for option 2, which are that the sounding tone
15 indices are based on a new sounding index set for the partial channel bandwidth and additional center tones indices for the full channel bandwidth. Further explanation of the rules is given in the Figures part of the description with respect to Figures 8 to 10 where the different tables with sounding tone indices are shown for this option 2.

In an exemplary implementation of the beamformer device, the sounding tone indices are
20 based on a reuse of the sounding tone indices defined for resource units of the second tone plan and a definition which resource units of the second tone plan correspond to resource units of the first tone plan.

This provides the advantage that the beamformer device can efficiently reuse existing sounding tone indices for processing a variety of bandwidths, in particular bandwidths
25 greater than 80 MHz.

Such a beamformer device supports a solution according to Option 3 as mentioned above. Corresponding tables are described below with respect to Figures 11 and 12.

This implementation describes the rules for option 3, which are that the sounding tone indices are based on a reuse of the sounding tone indices defined for resource units of the
30 second tone plan and a definition which resource units of the second tone plan correspond to resource units of the first tone plan. Further explanation of the rules is given

in the Figures part of the description with respect to Figures 11 and 12 where the different tables with sounding tone indices are shown for this option 3.

- 5 In an exemplary implementation of the beamformer device, the set of sounding tone indices for a channel bandwidth greater than the full channel bandwidth, in particular for a channel bandwidth of 160 MHz, 80 + 80 MHz, 240 MHz or 320 MHz, is based on a duplication of rules defined for the set of sounding tone indices within each segment of the full channel bandwidth.

This provides the advantage that the beamformer device can be applied with WiFi schemes of high bandwidth, in particular bandwidths greater than 80 MHz.

- 10 Figure 11 described below shows indices definition for bandwidth greater than 80 MHz.

Duplication of rules means that rules defined for a specific bandwidth section are also valid for another bandwidth section. For example, rules defined for a bandwidth of 80 MHz can also be applied to the bandwidth section between 80 MHz and 100 MHz.

- 15 In an exemplary implementation of the beamformer device, the request to the beamformee device indicates a channel bandwidth, wherein the indicated channel bandwidth is a full channel bandwidth defined for the first WiFi scheme.

This provides the advantage that the beamformer device is informed of the channel bandwidth used by the beamformer device in order to efficiently report its beamforming parameters.

- 20 In an exemplary implementation of the beamformer device, the indicated channel bandwidth is a full channel bandwidth of 80 MHz, 80 + 80 MHz, 160 MHz, 240 MHz, 320 MHz or any partial bandwidth thereof.

This provides the advantage that the beamformer device can be applied with a variety of different bandwidths.

- 25 The first WiFi scheme, e.g. 802.11be, defines a plurality of full channel bandwidths, e.g. 80 MHz, 80 + 80 MHz, 160 MHz, 240 MHz, 320 MHz. This full channel bandwidth or a partial channel bandwidth of this full channel bandwidth is indicated by the beamformer device. A partial bandwidth is any portion of the full bandwidth, e.g. a partial bandwidth of 80 MHz full bandwidth may be 20 MHz or 40 MHz or 60 MHz or 77 MHz or any other
30 portion of 80 MHz. For example, a partial bandwidth of 320 MHz full bandwidth may be

any portion of 320 MHz, e.g. 80 MHz or 160 MHz or 200 MHz or 300 MHz or 319 MHz, or any other portion of 320 MHz.

In an exemplary implementation of the beamformer device, the set of sounding tone indices is defined per channel bandwidth and per number of tones, N_g , in particular for
5 $N_g=4$ and $N_g=16$.

This provides the advantage that the beamformer device is flexible with respect to the channel bandwidth and the number of tones.

According to a second aspect, the disclosure relates to a method for requesting beamforming information, the method comprising: transmitting, by a beamformer device, a
10 request to a beamformee device, the request comprising a set of sounding tone indices, the set of sounding tone indices indicating tones for which a report of beamforming information is requested from the beamformee device, wherein the tones are defined according to a first WiFi scheme, wherein the set of sounding tone indices is based on a first tone plan defined by the first WiFi scheme for a partial channel bandwidth and on a
15 second tone plan defined by a second WiFi scheme for a full channel bandwidth; and receiving the report of beamforming information from the beamformee device based on the set of sounding tone indices.

This method corresponds to the beamformer device described above for the first aspect of the disclosure.

20 Such a method for requesting beamforming information can improve performance of beamforming in advanced communication schemes such as EHT by operating on a novel set of sounding tone indices that is based on the first tone plan for partial channel bandwidth and on the second tone plan for full channel bandwidth.

The first WiFi scheme may be 802.11be WiFi, particularly supporting channel bandwidths
25 of 80 MHz, 160 MHz, 80 + 80 MHz, 240 MHz and 320 MHz. the second WiFi scheme may be 802.11ax WiFi, particularly supporting a channel bandwidth of 80 MHz.

According to a third aspect, the disclosure relates to a beamformee device, configured to: transmit a report of beamforming information to a beamformer device based on a set of sounding tone indices received from the beamformer device, wherein the set of sounding
30 tone indices are indicating tones for which a report of beamforming information is requested from the beamformee device, wherein the tones are defined according to a first

WiFi scheme, wherein the set of sounding tone indices is based on a first tone plan defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined by a second WiFi scheme for a full channel bandwidth.

5 Such a beamformee device can improve performance of beamforming in advanced communication schemes such as EHT by operating on a novel set of sounding tone indices that is based on the first tone plan for partial channel bandwidth and on the second tone plan for full channel bandwidth.

This beamformee device has the same features as the beamformer device of the first aspect described above. But it is the entity that receives the request from the beamformer device and transmits the report to beamformer device.

The first WiFi scheme may be 802.11be WiFi, particularly supporting channel bandwidths of 80 MHz, 160 MHz, 80 + 80 MHz, 240 MHz and 320 MHz. The second WiFi scheme may be 802.11ax WiFi, particularly supporting a channel bandwidth of 80 MHz.

15 According to a fourth aspect, the disclosure relates to a method for reporting beamforming information, the method comprising: transmitting, by a beamformee device, a report of beamforming information to a beamformer device based on a set of sounding tone indices received from the beamformer device, wherein the set of sounding tone indices are indicating tones for which a report of beamforming information is requested from the beamformee device, wherein the tones are defined according to a first WiFi scheme, wherein the set of sounding tone indices is based on a first tone plan defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined by a second WiFi scheme for a full channel bandwidth.

20 Such a method for reporting beamforming information can improve performance of beamforming in advanced communication schemes such as EHT by operating on a novel set of sounding tone indices that is based on the first tone plan for partial channel bandwidth and on the second tone plan for full channel bandwidth.

This method corresponds to the beamformee device described above for the third aspect of the disclosure.

30 The first WiFi scheme may be 802.11be WiFi, particularly supporting channel bandwidths of 80 MHz, 160 MHz, 80 + 80 MHz, 240 MHz and 320 MHz. The second WiFi scheme may be 802.11ax WiFi, particularly supporting a channel bandwidth of 80 MHz.

According to a fifth aspect, the disclosure relates to a beamformer device, configured to:
receive a beamforming report from a beamformee device, wherein the beamforming
report comprises a compressed precoder matrix; and reconstruct a precoder matrix
reported by the beamformee device based on the compressed precoder matrix, wherein
5 the compressed precoder matrix is defined by a set of angles in a specific order that
implies a sequence of mathematical operations to be applied on a unit matrix to
reconstruct the precoder matrix, wherein the set of angles is determined based on an
extension of a given formula specified for a number of transmit antennas and a number of
spatial streams supported by a second WiFi scheme, in particular 802.11ax WiFi, to a
10 number of transmit antennas, N_r , and a number of spatial streams, N_c , supported by a
first WiFi scheme, in particular 802.11be WiFi.

Such a beamformer device can improve performance of beamforming in advanced
communication schemes such as EHT by using the extended formula which is extended
with respect to number of transmit antennas and number of spatial streams as supported
15 by EHT.

In an exemplary implementation of the beamformer device, the extension of the given
formula is specified for values of $8 < N_r \leq 16$ and values of $1 \leq N_c \leq 16$ corresponding to
matrices from 9×1 to 16×16 .

This provides the advantage that higher MIMO sizes can be implemented and optimally
20 controlled. I.e. the beamformer device can be applied in denser populated environments
having higher number of stations.

In an exemplary implementation of the beamformer device, the beamforming report
comprises SNR values of spatial streams reported by the beamformee device, wherein
each reported i -th SNR value, in particular for $i > 8$, corresponds to an SNR that results
25 from applying an i -th column of the reported precoder matrix by the beamformer device.

This provides the advantage that SNR values can be better controlled.

In an exemplary implementation of the beamformer device, the beamforming report
comprises SNR values of spatial streams for MIMO schemes larger than 8×8 .

This provides the advantage that the beamformer device can be applied with spatial
30 streams of high MIMO size and hence improve communication quality.

According to a seventh 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 aspects above. 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.

According to an eighth aspect, the disclosure relates to a beamformer device (110), configured to transmit a request of partial bandwidth, BW, for sounding feedback to a beamformee device (120), the requested partial BW for sounding feedback comprising a partial BW type, indicating the BW to be used for sounding feedback.

In an exemplary implementation of the beamformer device according to the eighth aspect the partial BW type can be 20 MHz, 40MHz or $n \times 80$ MHz, wherein n is an integer equal or larger than 1.

In an exemplary implementation of the beamformer device according to the eighth aspect the requested partial BW for sounding feedback is comprised in a Partial BW Info field.

In an exemplary implementation of the beamformer device according to the eighth aspect the Partial BW Info Field comprises 6 bits.

In an exemplary implementation of the beamformer device according to the eighth aspect the 2 least significant bits of the Partial BW Info Field indicate the type of partial BW.

In the following we show an exemplary mapping between the two least significant bits B0, B1 of the Partial BW Info Field and the requested partial BW. Any other mapping is also possible.

B0	B1	Requested partial BW	Resource Units
0	0	20 MHz	RU242
0	1	40 MHz	RU484
1	0	$n \times 80$ MHz (80/160/240/320 MHz)	
1	1	Reserved	Reserved

In an exemplary implementation of the beamformer device according to the eighth aspect the 4 most significant bits of the Partial BW Info Field indicate a specific BW corresponding the indicated partial BW type.

In the following we show an exemplary mapping between the four most significant bits B2, B3, B4 and B5 of the Partial BW Info Field and the location of the resource units. Any other mapping is also possible.

B2	B3	B4	B5	Location of the Resource Units
0	0	0	0	RU located at the lowest frequency
X	X	X	X	Reserved
1	1	1	1	RU located at the highest frequency

- 5 In an exemplary implementation of the beamformer device according to the eighth aspect if a partial BW type of 20 MHz is signaled, the 4 most significant bits of the Partial BW Info Field of the Partial BW Info Field indicate k-th RU242, where k is an integer equal or larger than 0. In particular, k may be an integer from 0 to 15.

- 10 In an exemplary implementation of the beamformer device according to the eighth aspect if a partial BW type of 40 MHz is signaled, the 4 most significant bits of the Partial BW Info Field indicate k-th RU484, where k is an integer equal or larger than 0, in particular from 0 to 7, or k-th RU242, where k is an integer equal or larger than 0. In particular, k may be an integer from 0 to 15.

- 15 In an exemplary implementation of the beamformer device according to the eighth aspect if a partial BW type of $n \times 80$ MHz is signaled, the 4 most significant bits of the Partial BW Info Field indicate a bitmap for 4 segments of 80MHz, wherein an indicated '1' means 80MHz is requested for sounding feedback.

- 20 In an exemplary implementation of the beamformer device according to the eighth aspect if a partial BW type of 20 MHz is signaled, for indicated k-th RU242, tone indices defined for k RU242 are used, wherein k is an integer equal or larger than 0.

In an exemplary implementation of the beamformer device according to the eighth aspect if a partial BW type of 40 MHz is signaled, for indicated k-th RU484, tone indices defined for $2 \times k$ and $2 \times k + 1$ RU242 are used and for indicated k-th RU242, tone indices defined for k and $k + 1$ RU242 are used, wherein k is an integer equal or larger than 0.

- 25 In an exemplary implementation of the beamformer device according to the eighth aspect if a partial BW type of $n \times 80$ MHz is signaled, tone indices defined for $4 \times k$, $4 \times k + 1$, $4 \times k + 2$, $4 \times k + 3$ RU242 are used, wherein n and k are integer equal or larger than 0.

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 sounding procedure 100 defined for transmission of beamforming information between beamformer 110 and beamformee 120;
- Fig. 2 shows a tone plan 200 defined by IEEE 802.11ax standard with resource unit locations of 80 MHz;
- Fig. 3 shows a resource unit index table 300 with start and end indices definition for Sounding in IEEE 802.11ax standard;
- Fig. 4 shows a tone plan 400 defined by IEEE 802.11be standard for 80 MHz;
- Fig. 5 shows a resource unit index table 500 with RU start and end indices definition for Unified Indices Set of $N_g=4$ and 80 MHz bandwidth according to the first optional solution of the disclosure;
- Fig. 6 shows a resource unit index table 600 with RU start and end indices definition for Unified Indices Set of $N_g=16$ and 80 MHz bandwidth according to the first optional solution of the disclosure;
- Fig. 7 shows a superset of subcarrier indices 700 for compressed beamforming of 80 MHz bandwidth according to the first optional solution of the disclosure;
- Fig. 8 shows a resource unit index table 800 with RU start and end indices definition for Partial bandwidth of $N_g=4$ and 80 MHz bandwidth according to the second optional solution of the disclosure;
- Fig. 9 shows a resource unit index table 900 with RU start and end indices definition for Partial bandwidth of $N_g=16$ and 80 MHz bandwidth according to the second optional solution of the disclosure;
- Fig. 10 shows a superset of subcarrier indices 1000 for partial bandwidth compressed beamforming of 80 MHz bandwidth according to the second optional solution of the disclosure;

- Fig. 11 shows a cross-reference table 1100 for resource unit indices of 80 MHz bandwidth according to the third optional solution of the disclosure;
- Fig. 12 shows an indices definition table 1200 for bandwidths greater than 80 MHz according to the third optional solution of the disclosure;
- 5 Fig. 13 shows an exemplary angles definition table, T9, 1300 illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=9$ according to the disclosure;
- Fig. 14 shows an exemplary angles definition table, T10, 1400 illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas
- 10 $N_r=10$ according to the disclosure;
- Figs. 15 and 16 show an exemplary angles definition table, T11a, T11b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=11$ according to the disclosure, the first part T11a, 1500 of the table is shown in Fig. 15 and the second part T11b, 1600 of the table is shown in Fig. 16;
- 15 Figs. 17 and 18 show an exemplary angles definition table, T12a, T12b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=12$ according to the disclosure, the first part T12a, 1700 of the table is shown in Fig. 17 and the second part T12b, 1800 of the table is shown in Fig. 18;
- Figs. 19 and 20 show an exemplary angles definition table, T13a, T13b illustrating the order
- 20 of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=13$ according to the disclosure, the first part T13a, 1900 of the table is shown in Fig. 19 and the second part T13b, 2000 of the table is shown in Fig. 20;
- Figs. 21 and 22 show an exemplary angles definition table, T14a, T14b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit
- 25 antennas $N_r=14$ according to the disclosure, the first part T14a, 2100 of the table is shown in Fig. 21 and the second part T14b, 2200 of the table is shown in Fig. 22;
- Figs. 23 and 24 show an exemplary angles definition table, T15a, T15b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=15$ according to the disclosure, the first part T15a, 2300 of the table is shown
- 30 in Fig. 23 and the second part T15b, 2400 of the table is shown in Fig. 24;

Figs. 25, 26 and 27 show an exemplary angles definition table, T16a, T16b, T16c illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=16$ according to the disclosure, the first part T16a, 2500 of the table is shown in Fig. 25, the second part T16b, 2600 of the table is shown in Fig. 26 and the third
5 part T16c, 2700 of the table is shown in Fig. 27;

Fig. 28 shows a schematic diagram of a method 2800 for requesting beamforming information according to the disclosure; and

Fig. 29 shows a schematic diagram of a method 2900 for reporting beamforming information according to the disclosure.

10 Fig. 30 shows a schematic diagram of a Partial BW Info Field.

Fig. 31 shows a schematic diagram of a modified STA Info Subfield.

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.
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20 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
25 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 versions
30 of the WiFi standard and 802.11be version of the WiFi standard. 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.

- 5 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.
- 10 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.
- 15 A processor or processing device can process software or firmware or applications etc.

Fig. 1 shows a schematic diagram 100 illustrating a sounding procedure 100 defined for transmission of beamforming information between beamformer 110 and beamformee 120.

Beamforming depends on channel calibration procedures, called *channel sounding* in the 802.11 WiFi standard, to determine how to radiate energy in a preferred direction.

- 20 Channel sounding 100 consists of three major steps:

In a first step, the beamformer 110 begins the process by transmitting a Null Data Packet (NDP) Announcement frame 111, which is used to gain control of the channel and identify beamformees. Beamformees 120 will respond to the NDP Announcement 111, while all other stations will simply defer channel access until the sounding sequence is complete.

- 25 In a second step, the beamformer 110 follows the NDP Announcement 111 with a null data packet (NDP) 112. The value of an NDP 112 is that the receiver can analyze the OFDM training fields to calculate the channel response, and therefore the steering matrix. For multi-user transmissions, multiple NDPs 112 may be transmitted.

- In a third step, the beamformee 120 analyzes the training fields in the received NDP 112
- 30 and calculates a feedback matrix. The feedback matrix which is reported by the

beamformee 120 in compressed beamforming report 121 enables the beamformer 110 to calculate the steering matrix to direct transmissions toward the beamformee 120.

5 The sounding procedure 100 may be performed on the entire bandwidth or part of the BW. A specific set of tone (subcarrier) indices is defined for sounding of every portion of the supported bandwidth. IEEE 802.11be WiFi introduces a larger bandwidth and larger MIMO size which require updated feedback parameters, frame format and also an exact definition of compressed precoder matrix and SNR. Moreover, 802.11be introduces a new tone plan which implies different tone definition to be applied for sounding as well.

10 In the following, a beamformer device 110 and a beamformee device 120 are described which improve performance of beamforming in advanced communication schemes such as EHT WiFi, for example according to IEEE 802.11be.

15 Such a novel beamformer device 110 is configured to transmit a request 111 (e.g. by NDP Announcement) to a beamformee device 120. The request comprises a set of sounding tone indices indicating tones for which a report 121 of beamforming information is requested from the beamformee device 120. The tones are defined according to a first WiFi scheme. The set of sounding tone indices is based on a first tone plan (e.g. a first tone plan 400 as shown in Fig. 4) defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan (e.g. a second tone plan 200 as shown in Fig. 2) defined by a second WiFi scheme for a full channel bandwidth.

20 The first WiFi scheme may be 802.11be WiFi, and the second WiFi scheme may be 802.11ax WiFi.

The first WiFi scheme may support channel bandwidths of 80 MHz, 160 MHz, 80 + 80 MHz, 240 MHz and 320 MHz.

The second WiFi scheme may support a channel bandwidth of 80 MHz.

25 The full channel bandwidth may be 80 MHz, for example. The partial channel bandwidth may be any subset of the full channel bandwidth, for example.

30 According to the first optional solution described above, the sounding tone indices may be based on a new unified sounding index set, e.g. a set 500, 600, 700 as described below with respect to Figures 5, 6 and 7, that comprises sounding tone indices for both, the first tone plan 400 for the partial channel bandwidth and the second tone plan 200 for the full channel bandwidth.

According to the second optional solution described above, the sounding tone indices may be based on a new sounding index set, e.g. a set 800, 900, 1000 as described below with respect to Figures 8, 9 and 10, for the partial channel bandwidth and additional center tones indices for the full channel bandwidth.

- 5 According to the third optional solution described above, the sounding tone indices may be based on a reuse of the sounding tone indices, e.g. the sounding tone indices 1100, 1200 described below with respect to Figures 11 and 12, defined for resource units of the second tone plan 200 and a definition which resource units of the second tone plan 200 correspond to resource units of the first tone plan 400.
- 10 The set of sounding tone indices for a channel bandwidth greater than the full channel bandwidth, for example for a channel bandwidth of 160 MHz, 80 + 80 MHz, 240 MHz or 320 MHz, may be based on a duplication of rules defined for the set of sounding tone indices within each segment of the full channel bandwidth, e.g. as described below with respect to Figures 11 and 12.
- 15 The request to the beamformee device 120 may indicate a channel bandwidth. The indicated channel bandwidth may be a full channel bandwidth defined for the first WiFi scheme.

For example, the indicated channel bandwidth may be a full channel bandwidth of 80 MHz, 80 + 80 MHz, 160 MHz, 240 MHz, 320 MHz or any partial bandwidth thereof.

- 20 The set of sounding tone indices may be defined per channel bandwidth and per number of tones, N_g , for example for $N_g=4$ and $N_g=16$.

Such a novel beamformee device 120 shown in Figure 1 is configured to transmit a report 121 of beamforming information to a beamformer device 110 based on a set of sounding tone indices received from the beamformer device 110. The set of sounding tone indices are indicating tones for which a report of beamforming information is requested from the beamformee device 120. The tones are defined according to a first WiFi scheme. The set of sounding tone indices is based on a first tone plan defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined by a second WiFi scheme for a full channel bandwidth.

- 25 As described above, a further idea of the disclosure is to define compressed beamforming matrix values and part of general parameters.
- 30 As described above, a further idea of the disclosure is to define compressed beamforming matrix values and part of general parameters.

This can be implemented by a novel beamformer device 110, configured to: receive a beamforming report 121 from a beamformee device 120, wherein the beamforming report 121 comprises a compressed precoder matrix; and reconstruct a precoder matrix reported by the beamformee device 120 based on the compressed precoder matrix. The compressed
 5 precoder matrix is defined by a set of angles in a specific order that implies a sequence of mathematical operations to be applied on a unit matrix to reconstruct the precoder matrix. The set of angles is determined based on an extension of a given formula specified for a number of transmit antennas and a number of spatial streams supported by a second WiFi scheme, for example 802.11ax WiFi, to a number of transmit antennas, N_r , and a number
 10 of spatial streams, N_c , supported by a first WiFi scheme, for example 802.11be WiFi.

The specific formula may be given in section 20.3.12.3.6 of 802.11n standard and defined by each version of 802.11 with respect to allowed N_r and N_c values.

Specific values for the set of angles are given in tables T9, T10, T11a/b, T12a/b, T13a/b, T14a/b, T15a/b and T16a/b/c for different numbers of transmit antennas, N_r , as shown in
 15 Figures 13 to 27.

The extension of the given formula may be specified for values of $8 < N_r \leq 16$ and values of $1 \leq N_c \leq 16$ corresponding to matrices from 9×1 to 16×16 .

The beamforming report 121 may comprise SNR values of spatial streams reported by the beamformee device 120. Each reported i -th SNR value, in particular for $i > 8$, corresponds to
 20 an SNR that results from applying an i -th column of the reported precoder matrix by the beamformer device 120.

The beamforming report 121 may comprise SNR values of spatial streams for MIMO schemes larger than 8×8 .

Fig. 2 shows a tone plan 200 defined by IEEE 802.11ax standard with resource unit locations of 80 MHz, also denoted hereinafter as second tone plan.
 25

802.11ax standard introduced OFDMA format where the entire bandwidth is divided into blocks defined as Resource Units (RUs). Transmitted signal may be combined of multiple allocations where different RUs allocated for different stations. The RU sizes are defined by number of frequency tones and can be of 26/52/106/242/484/996 tones as shown in Figure
 30 2. The bandwidth of 80 MHz includes 9 RUs of 26, 4 RUs of 52 and so on as depicted in Figure 2.

Fig. 3 shows a resource unit index table 300 with start (S) and end (E) indices definition for Sounding in IEEE 802.11ax standard.

Sounding procedure (as shown in Figure 1) defines sampling of frequency for channel measurement and report that can be every 4 or 16 (N_g) tones. In order to align between
 5 RUs definition and sounding sampling parameter, an explicit definition of set of tone indices is provided by standard for sounding procedure.

For each RU a start sounding tone index, i.e. RU Index Start, (denoted by S in Figure 3) and end sounding tone index, i.e. RU Index End, (denoted by E in Figure 3) is defined to ensure all the tones of RUs are covered. Sounding start/end indices are different from
 10 regular tone indices used for data transmission, see example in Figure 3. The set of indices is defined per bandwidth (in Figure 3 shown for bandwidths of 20 MHz, 40 MHz, 80 MHz, 160 MHz, and 80+80 MHz) and per N_g value

Fig. 4 shows a tone plan 400 defined by IEEE 802.11be standard for 80 MHz, also denoted hereinafter as first tone plan.

15 The IEEE 802.11be standard introduces the three main changes in terms of bandwidth over 802.11ax: A larger BW is supported of 240 MHz and 320 MHz. A new tone plan 400 as illustrated in Figure 4 is defined for 80 MHz bandwidth for all the cases except the case when full bandwidth is allocated to a single station (STA) (or a group of STAs). All the bandwidths greater than 80 MHz are defined as a duplication of 80 MHz bandwidth.

20 Indices defined by sounding procedure of 802.11ax (see Figure 1) are no longer aligned to locations of RUs as given by the new tone plan 400. Thus, sounding procedure definitions need to be updated to follow the new tone plan 400 and also a new rule of duplication of the tone plan 400 for bandwidth.

Figures 5, 6 and 7 describe the solution according to option 1 for the new index definition
 25 for the new tone plan. Option 1 introduces a new unified sounding indices set to be used for all the options, that means that the new set covers both a new tone plan and 802.11ax tone plan of full BW.

Fig. 5 shows a resource unit index table 500 with RU start and end indices definition for Unified Indices Set of $N_g=4$ and 80 MHz bandwidth. Fig. 6 shows a resource unit index
 30 table 600 with RU start and end indices definition for Unified Indices Set of $N_g=16$ and 80

MHz bandwidth. Fig. 7 shows a corresponding superset of subcarrier indices 700 for compressed beamforming of 80 MHz bandwidth.

The unified indices set is a new set introduced for entire 80 MHz bandwidth while all the RUs of 26 tones are covered by single RU Start/End index pair and in addition center tones of 996 RU are covered as additional tones.

The rules for applying this option 1 are as follows:

- RU Start/End Index corresponds to 26RUs defined by new tone plan of 80 MHz bandwidth (see Figure 4);
- For $N_g = 4$, if indicated RUs cover entire bandwidth, indices of center portion are used as well.

The indices for $N_g = 4$ and $N_g = 16$ are shown in Figures 5 and 6, respectively.

And the superset of indices for 80 MHz is shown in Figure 7.

Figures 8, 9 and 10 describe the solution according to option 2 for the new index definition for the new tone plan. Option 2 introduces a new sounding indices set for partial bandwidth sounding, by duplication of indices of 20 MHz portion, and adding center tones indices for full BW sounding.

Fig. 8 shows a resource unit index table 800 with RU start and end indices definition for Partial bandwidth of $N_g=4$ and 80 MHz bandwidth. Fig. 9 shows a resource unit index table 900 with RU start and end indices definition for Partial bandwidth of $N_g=16$ and 80 MHz bandwidth. Fig. 10 shows a corresponding superset of subcarrier indices 1000 for partial bandwidth compressed beamforming of 80 MHz bandwidth.

In this Option 2, a set of indices for partial BW sounding is defined. The indices are defined as a duplication of 20 MHz portions. The rules for applying this options are as follows:

- RU Start/End Index corresponds to 26RUs defined by new tone plan of 80 MHz BW (see Fig. 4);
- If indicated RUs cover entire bandwidth, use additional center portion indices.

The indices for $N_g = 4$ and $N_g = 16$ are shown in Figures 8 and 9, respectively.

And the superset of indices for partial bandwidth compressed beamforming 80 MHz is shown in Figure 10.

Figures 11 and 12 describe the solution according to option 3 for the new index definition for the new tone plan. Option 3 introduces reusing 802.11ax sounding indices set but
5 defining which sounding RUs correspond data RU defined by new tone plan.

Fig. 11 shows a cross-reference table 1100 for resource unit indices of 80 MHz bandwidth according to the third optional solution of the disclosure.

In this option 3, the definition of indices in 802.11ax standard is reused (see Tables 9-93c-d of IEEE 802.11ax). The corresponding indices for the new tone plan (see Figure 4) are
10 given in Figure 11. This means that every 26RU indicated for sounding use indexes defined in 802.11ax using RUs indices as shown in Figure 11.

Fig. 12 shows an indices definition table 1200 for bandwidths greater than 80 MHz according to the third optional solution of the disclosure.

IEEE 802.11be defines that the tone plan for every bandwidth greater than 80 MHz will be
15 a duplication of 80 MHz. Every suggested option of new indices set is applicable for a bandwidth greater than 80 MHz as a duplication of indices for multiple 80 MHz segments, both for partial BW sounding and full BW sounding.

Thus, the indices for compressed beamforming of a bandwidth greater than 80 MHz can be given as depicted in Figure 12. S1 corresponds to lower frequency segment, S2-S4
20 correspond to frequency segments in ascending order.

As described above, a further idea of the disclosure is to define compressed beamforming matrix values and part of general parameters.

This can be implemented by a novel beamformer device 110 as described above with respect to Figure 1. This novel beamformer device 110 is configured to receive a
25 beamforming report 121 from a beamformee device 120. The beamforming report 121 comprises a compressed precoder matrix. The novel beamformer device 110 is configured to reconstruct a precoder matrix reported by the beamformee device 120 based on the compressed precoder matrix. The compressed precoder matrix is defined by a set of angles in a specific order that implies a sequence of mathematical operations to be applied on a
30 unit matrix to reconstruct the precoder matrix. The set of angles is determined based on an extension of a given formula specified for a number of transmit antennas and a number of

spatial streams supported by a second WiFi scheme, for example 802.11ax WiFi, to a number of transmit antennas, N_r , and a number of spatial streams, N_c , supported by a first WiFi scheme, for example 802.11be WiFi. The specific formula may be given in section 20.3.12.3.6 of 802.11n standard and defined by each version of 802.11 with respect to
 5 allowed N_r and N_c values.

Specific values for the set of angles are given in tables T9, T10, T11a/b, T12a/b, T13a/b, T14a/b, T15a/b and T16a/b/c for different numbers of transmit antennas, N_r , as shown in Figures 13 to 27.

The compressed precoder matrix is defined by a set of angles in a specific order that implies
 10 a sequence of mathematical operations that beamformer should apply on the unit matrix to reconstruct precoder matrix reported by beamformee. The angles are obtained by the formula given in section 20.3.12.3.6 of IEEE 802.11n standard and defined by each version of IEEE 802.11 with respect to allowed N_r and N_c values. The definition includes N_a (number of angles) and also the exact order of angles for feedback report transmission.
 15 Thus, the disclosure extends this definition for schemes larger than 8x8 as defined in IEEE 802.11be. The full definition of all the angles for all the possible MIMO size is shown below with respect to Figures 13 to 27.

The beamforming report includes also SNR values for the reported spatial streams. In Single-User feedback format only average SNR (over entire bandwidth) is reported, while
 20 in Multi-User format, both average SNR and SNR per-tone are reported. The number of SNR values equal N_c while the i -th SNR value corresponds to expected SNR if beamformer applies a i -th column of the reported precoder matrix. This scheme can be extended for $N_c > 8$ according to the following rule:

- For any $i > 8$, reported i -th SNR value (average and per-tone) corresponds to an expected
 25 SNR if beamformer applies a i -th column of the reported precoder matrix.

Fig. 13 shows an exemplary angles definition table, T9, 1300 illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=9$.

The angles definition table, T9, 1300 defines the order of angles in the compressed
 30 beamforming feedback matrix subfield for a number of transmit antennas $N_r=9$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 9. The corresponding size of the feedback matrix V is also depicted in Figure 13 for the chosen parameters $N_r=9$ and

$N_c=1$ to 9. Furthermore, a number of angles, N_a , ranging from 16 to 72, is given in table T9, 1300.

Fig. 14 shows an exemplary angles definition table, T10, 1400 illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=10$.

The angles definition table, T10, 1400 defines the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=10$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 10. The corresponding size of the feedback matrix V is also depicted in Figure 14 for the chosen parameters $N_r=10$ and $N_c=1$ to 10. Furthermore, a number of angles, N_a , ranging from 18 to 90, is given in table T10, 1400.

Figs. 15 and 16 show an exemplary angles definition table, T11a, T11b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=11$, the first part T11a, 1500 of the table is shown in Fig. 15 and the second part T11b, 1600 of the table is shown in Fig. 16.

The angles definition table, T11a, T11b defines the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=11$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 11. The corresponding size of the feedback matrix V is also depicted in Figures 15 and 16 for the chosen parameters $N_r=11$ and $N_c=1$ to 11. Furthermore, a number of angles, N_a , ranging from 20 to 110, is given in table T11a, T11b.

Figs. 17 and 18 show an exemplary angles definition table, T12a, T12b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=12$ according to the disclosure, the first part T12a, 1700 of the table is shown in Fig. 17 and the second part T12b, 1800 of the table is shown in Fig. 18.

The angles definition table, T12a, T12b defines the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=12$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 12. The corresponding size of the feedback matrix V is also depicted in Figures 17 and 18 for the chosen parameters $N_r=12$ and $N_c=1$ to 12. Furthermore, a number of angles, N_a , ranging from 22 to 132, is given in table T12a, T12b.

Figs. 19 and 20 show an exemplary angles definition table, T13a, T13b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=13$ according to the disclosure, the first part T13a, 1900 of the table is shown in Fig. 19 and the second part T13b, 2000 of the table is shown in Fig. 20.

- 5 The angles definition table, T13a, T13b defines the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=13$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 13. The corresponding size of the feedback matrix V is also depicted in Figures 19 and 20 for the chosen parameters $N_r=13$ and $N_c=1$ to 13. Furthermore, a number of angles, N_a , ranging from 24 to 156, is
10 given in table T13a, T13b.

Figs. 21 and 22 show an exemplary angles definition table, T14a, T14b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=14$ according to the disclosure, the first part T14a, 2100 of the table is shown in Fig. 21 and the second part T14b, 2200 of the table is shown in Fig. 22.

- 15 The angles definition table, T14a, T14b defines the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=14$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 14. The corresponding size of the feedback matrix V is also depicted in Figures 21 and 22 for the chosen parameters $N_r=14$ and $N_c=1$ to 14. Furthermore, a number of angles, N_a , ranging from 26 to 182, is
20 given in table T14a, T14b.

Figs. 23 and 24 show an exemplary angles definition table, T15a, T15b illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=15$ according to the disclosure, the first part T15a, 2300 of the table is shown in Fig. 23 and the second part T15b, 2400 of the table is shown in Fig. 24.

- 25 The angles definition table, T15a, T15b defines the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=15$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 15. The corresponding size of the feedback matrix V is also depicted in Figures 23 and 24 for the chosen parameters $N_r=15$ and $N_c=1$ to 15. Furthermore, a number of angles, N_a , ranging from 28 to 210, is
30 given in table T15a, T15b.

Figs. 25, 26 and 27 show an exemplary angles definition table, T16a, T16b, T16c illustrating the order of angles in the compressed beamforming feedback matrix subfield for a number

of transmit antennas $N_r=16$ according to the disclosure, the first part T16a, 2500 of the table is shown in Fig. 25, the second part T16b, 2600 of the table is shown in Fig. 26 and the third part T16c, 2700 of the table is shown in Fig. 27.

5 The angles definition table, T16a, T16b, T16c defines the order of angles in the compressed beamforming feedback matrix subfield for a number of transmit antennas $N_r=16$ and for different numbers of N_c , i.e. spatial streams ranging from 1 to 16. The corresponding size of the feedback matrix V is also depicted in Figures 25, 26 and 27 for the chosen parameters $N_r=16$ and $N_c=1$ to 16. Furthermore, a number of angles, N_a , ranging from 30 to 240, is given in table T16a, T16b, T16c.

10 Fig. 28 shows a schematic diagram of a method 2800 for requesting beamforming information according to the disclosure.

The method 2800 comprises: transmitting 2801, by a beamformer device, e.g. beamformer device 110 shown in Fig. 1, a request to a beamformee device, e.g. beamformee device 120 shown in Fig. 1, the request comprising a set of sounding tone indices, the set of
15 sounding tone indices indicating tones for which a report of beamforming information is requested from the beamformee device, wherein the tones are defined according to a first WiFi scheme, wherein the set of sounding tone indices is based on a first tone plan defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined by a second WiFi scheme for a full channel bandwidth.

20 The method 2800 further comprises: receiving 2802 the report of beamforming information from the beamformee device based on the set of sounding tone indices.

The first tone plan may be defined as shown in Fig. 4 and the second tone plan may be defined as shown in Fig. 2.

25 The first WiFi scheme may be 802.11be WiFi, particularly supporting channel bandwidths of 80 MHz, 160 MHz, 80 + 80 MHz, 240 MHz and 320 MHz. The second WiFi scheme may be 802.11ax WiFi, particularly supporting a channel bandwidth of 80 MHz.

Fig. 29 shows a schematic diagram of a method 2900 for reporting beamforming information according to the disclosure.

30 The method 2900 comprises: transmitting 2901, by a beamformee device, e.g. beamformee device 120 shown in Fig. 1, a report of beamforming information to a beamformer device, e.g. beamformer device 110 shown in Fig. 1, based on a set of

sounding tone indices received from the beamformer device, wherein the set of sounding tone indices are indicating tones for which a report of beamforming information is requested from the beamformee device, wherein the tones are defined according to a first WiFi scheme, wherein the set of sounding tone indices is based on a first tone plan
5 defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined by a second WiFi scheme for a full channel bandwidth.

The first tone plan may be defined as shown in Fig. 4 and the second tone plan may be defined as shown in Fig. 2.

10 This method corresponds to the beamformee device described above for the third aspect of the disclosure.

The first WiFi scheme may be 802.11be WiFi, particularly supporting channel bandwidths of 80 MHz, 160 MHz, 80 + 80 MHz, 240 MHz and 320 MHz. The second WiFi scheme may be 802.11ax WiFi, particularly supporting a channel bandwidth of 80 MHz.

15 Fig. 30 shows a schematic diagram of the Partial BW Info Field 3000. The Partial BW Info Field 3000 comprises 6 bits B0 – B5. The two least significant bits 3001 (B0 and B1) of the Partial BW Info Field indicate the type of partial BW, i.e. the resolution type. The four most significant bits 3002 (B2, B3, B4 and B5) of the Partial BW Info Field indicate a specific BW corresponding the indicated partial BW type, the RU Index and/or a Segment Bitmap. It should be understood that also the two most significant bits (B4, B5) can indicate the
20 resolution type, whereas the four least significant bits (B0, B1, B2, B3) can indicate the specific BW corresponding the indicated partial BW type, the RU Index and/or a Segment Bitmap.

Fig. 31 shows a schematic diagram of a modified STA Info Subfield 3100, wherein the bits B11 – B16 have been replaced by the Partial BW Info Field 3000.

25 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
30 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

5 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

10 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

15 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

20 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

25 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 beamformer device (110), configured to:
transmit a request to a beamformee device (120), the request comprising a set of
5 sounding tone indices, the set of sounding tone indices indicating tones for which a report
(121) of beamforming information is requested from the beamformee device (120),
wherein the tones are defined according to a first WiFi scheme,
wherein the set of sounding tone indices is based on a first tone plan (400) defined
by the first WiFi scheme for a partial channel bandwidth and on a second tone plan (200)
10 defined by a second WiFi scheme for a full channel bandwidth.
2. The beamformer device (110) of claim 1,
wherein the first WiFi scheme is 802.11be WiFi, and
wherein the second WiFi scheme is 802.11ax WiFi.
3. The beamformer device (110) of claim 1 or 2,
15 wherein the first WiFi scheme is supporting channel bandwidths of 80 MHz, 160
MHz, 80 + 80 MHz, 240 MHz and 320 MHz.
4. The beamformer device (110) of one of the preceding claims,
wherein the second WiFi scheme is supporting a channel bandwidth of 80 MHz.
5. The beamformer device (110) of one of the preceding claims,
20 wherein the full channel bandwidth is 80 MHz; and
wherein the partial channel bandwidth is any subset of the full channel bandwidth.
6. The beamformer device (110) of one of the preceding claims,
wherein the sounding tone indices are based on a new unified sounding index set
(500, 600, 700) that comprises sounding tone indices for both, the first tone plan (400) for
25 the partial channel bandwidth and the second tone plan (200) for the full channel
bandwidth.
7. The beamformer device (110) of one of claims 1 to 5,
wherein the sounding tone indices are based on a new sounding index set (800,
900, 1000) for the partial channel bandwidth and additional center tones indices for the full
30 channel bandwidth.
8. The beamformer device (110) of one of claims 1 to 5,

- wherein the sounding tone indices are based on a reuse of the sounding tone indices (1100, 1200) defined for resource units of the second tone plan (200) and a definition which resource units of the second tone plan (200) correspond to resource units of the first tone plan (400).
- 5 9. The beamformer device (110) of one of claims 6 to 8,
 wherein the set of sounding tone indices for a channel bandwidth greater than the
 full channel bandwidth, in particular for a channel bandwidth of 160 MHz, 80 + 80 MHz,
 240 MHz or 320 MHz, is based on a duplication of rules defined for the set of sounding
 tone indices within each segment of the full channel bandwidth.
- 10 10. The beamformer device (110) of one of the preceding claims,
 wherein the request to the beamformee device (120) indicates a channel
 bandwidth,
 wherein the indicated channel bandwidth is a full channel bandwidth defined for
 the first WiFi scheme.
- 15 11. The beamformer device (110) of claim 10,
 wherein the indicated channel bandwidth is a full channel bandwidth of 80 MHz, 80
 + 80 MHz, 160 MHz, 240 MHz, 320 MHz or any partial bandwidth thereof.
12. The beamformer device (110) of one of the preceding claims,
 wherein the set of sounding tone indices is defined per channel bandwidth and per
20 number of tones, N_g , in particular for $N_g=4$ and $N_g=16$.
13. A method (2800) for requesting beamforming information, the method comprising:
 transmitting (2801), by a beamformer device (110), a request to a beamformee
 device, the request comprising a set of sounding tone indices, the set of sounding tone
 indices indicating tones for which a report of beamforming information is requested from
25 the beamformee device, wherein the tones are defined according to a first WiFi scheme,
 wherein the set of sounding tone indices is based on a first tone plan defined by
 the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined
 by a second WiFi scheme for a full channel bandwidth; and
 receiving (2802) the report of beamforming information from the beamformee
30 device based on the set of sounding tone indices.
14. A beamformee device (120), configured to:

- transmit a report (121) of beamforming information to a beamformer device (110) based on a set of sounding tone indices received from the beamformer device (110), wherein the set of sounding tone indices are indicating tones for which a report of beamforming information is requested from the beamformee device (120), wherein the tones are defined according to a first WiFi scheme, wherein the set of sounding tone indices is based on a first tone plan defined by the first WiFi scheme for a partial channel bandwidth and on a second tone plan defined by a second WiFi scheme for a full channel bandwidth.
- 5
15. A beamformer device (110), configured to:
- 10 receive a beamforming report (121) from a beamformee device (120), wherein the beamforming report (121) comprises a compressed precoder matrix; and reconstruct a precoder matrix reported by the beamformee device (120) based on the compressed precoder matrix, wherein the compressed precoder matrix is defined by a set of angles in a specific order that implies a sequence of mathematical operations to be applied on a unit matrix to reconstruct the precoder matrix, wherein the set of angles is determined based on an extension of a given formula specified for a number of transmit antennas and a number of spatial streams supported by a second WiFi scheme, in particular 802.11ax WiFi, to a number of transmit antennas, N_r , and a number of spatial streams, N_c , supported by a first WiFi scheme, in particular 802.11be WiFi.
- 15
- 20
16. The beamformer device (110) of claim 15, wherein the extension of the given formula is specified for values of $8 < N_r \leq 16$ and values of $1 \leq N_c \leq 16$ corresponding to matrices from 9×1 to 16×16 .
- 25
17. The beamformer device (110) of claim 15 or 16, wherein the beamforming report comprises SNR values of spatial streams reported by the beamformee device, wherein each reported i -th SNR value, in particular for $i > 8$, corresponds to an SNR that results from applying an i -th column of the reported precoder matrix by the beamformer device.
- 30
18. The beamformer device (110) of claim 17, wherein the beamforming report comprises SNR values of spatial streams for MIMO schemes larger than 8×8 .

19. A beamformer device (110), configured to:
transmit a request of partial bandwidth, BW, for sounding feedback to a
beamformee device (120), the requested partial BW for sounding feedback comprising a
partial BW type, indicating the BW to be used for sounding feedback.
- 5 20. The beamformer device (110) of claim 19,
wherein the partial BW type can be 20 MHz, 40MHz or $n \times 80$ MHz, wherein n is
an integer equal or larger than 1.
21. The beamformer device (110) of claim 19 or 20,
wherein the requested partial BW for sounding feedback is comprised in a Partial
10 BW Info field.
22. The beamformer device (110) of claim 21,
wherein the Partial BW Info Field (3000) comprises 6 bits.
23. The beamformer device (110) of claim 21 or 22,
wherein the 2 least significant bits (3001) of the Partial BW Info Field indicate the
15 type of partial BW.
24. The beamformer device (110) of claim 21 or 22,
wherein the 4 most significant bits (3002) of the Partial BW Info Field indicate a
specific BW corresponding the indicated partial BW type.
25. The beamformer device (110) of at least one of claims 19 to 24, wherein
20 if a partial BW type of 20 MHz is signaled, the 4 most significant bits of the Partial
BW Info Field of the Partial BW Info Field indicate k -th RU242, where k is an integer equal
or larger than 0,
if a partial BW type of 40 MHz is signaled, the 4 most significant bits of the Partial
BW Info Field indicate k -th RU484, where k is an integer from 1 to 8 or k -th RU242, where
25 k is an integer equal or larger than 0,
if a partial BW type of $n \times 80$ MHz is signaled, the 4 most significant bits of the
Partial BW Info Field indicate a bitmap for 4 segments of 80MHz, wherein an indicated '1'
means 80MHz is requested for sounding feedback.
26. The beamformer device (110) of at least one of claims 19 to 25, wherein
30 if a partial BW type of 20 MHz is signaled, for indicated k -th RU242, tone indices
defined for k RU242 are used, wherein k is an integer equal or larger than 0,

- if a partial BW type of 40 MHz is signaled, for indicated k-th RU484, tone indices defined for $2 \times k$ and $2 \times k + 1$ RU242 are used and for indicated k-th RU242, tone indices defined for k and k+1 RU242 are used, wherein k is an integer equal or larger than 0, or
- if a partial BW type of n x 80 MHz is signaled, tone indices defined for $4 \times k$, $4 \times k + 1$, $4 \times k + 2$, $4 \times k + 3$ RU242 are used, wherein n and k are integer equal or larger than 0.
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