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INTELLECTUAL PROPERTY DEPARTMENT
5488 Marvell Lane
Santa Clara, CA 95054

Date Mailed: 08/27/2009

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Early Publication Request: No
Title

80MHz OFDM for WLAN

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Thoughts on 802.11ac Preamble

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Goals

- Preamble design that is backward compatible with 11a/n.
- Receiver design flow as close to 11n as possible.
  - 11ac device will also apply legacy 11n.
- Higher Data Rate of 11ac makes the preamble overhead more sensitive for the overall throughput→

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Backward Compatibility

- "Spoof" legacy 11a and 11n devices to set CCA correctly on receiving 11ac preamble.

- (TBD) A GF mode may be defined for higher efficiency, do not need to consider 11a/n receiver, but may need MAC protection as in 11n.

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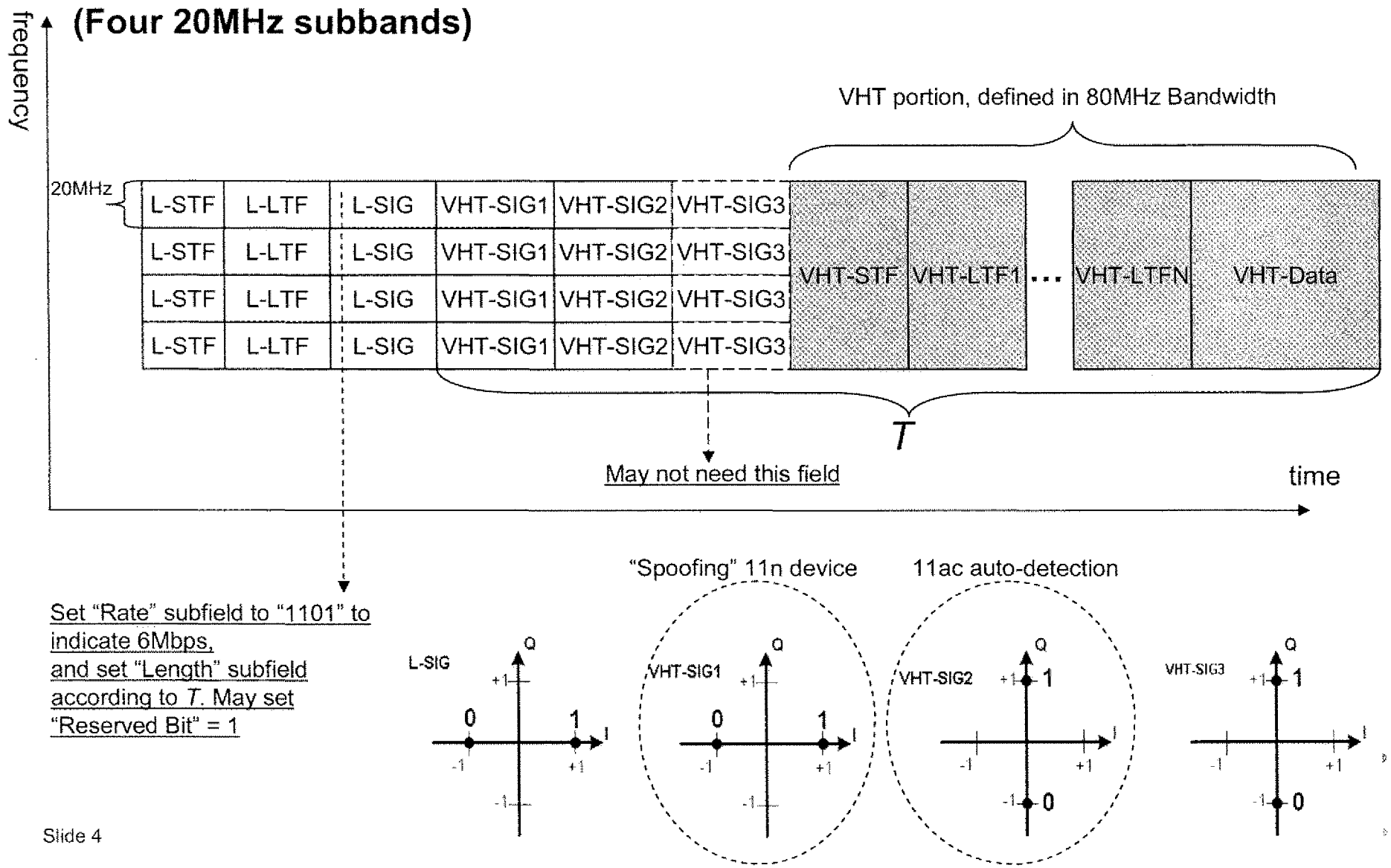
1. Preamble with 11a/n spoofing — Mixed Mode



Slide 4

Discussions

- VHT-SIG1 modulated using BPSK, VHT-SIG2 with QBPSK
  - "Spoofing": 11a/n receiver treats the packet as "11a".
    - **11n receiver will consume lower power when decoding a "11a" PPDU.**
  - Autodetection: 11ac device detects VHT packet by looking at the constellation points of VHT-SIG2.
    - **Or may use "Reserved bit" of L-SIG for 11ac auto-detection, then modulation (BPSK vs QBPSK) of VHT-SIG2 doesn't matter.**
  - Existence of VHT-SIG3 depends on the length of VHT-SIG.
    - **Modulation (BPSK vs QBPSK) of VHT-SIG3 doesn't matter.**
    - **Maybe limit to two OFDM symbols so the number of PHY optional modes can be constrained?**
- Similar receiver flow as 11n.
- Phase rotated four 20MHz subbands in 80MHz mode, across the whole PPDU, e.g. [pi/2 0 0 pi/2].
- VHT-(S)LTF may be straightforward extension of HT-(S)LTF in the case of 80MHz (4 duplications of 20MHz L-LTS with +-1 inserted at "DC/Guard tones" for each of the subbands), and the same as 11n in 20/40MHz.

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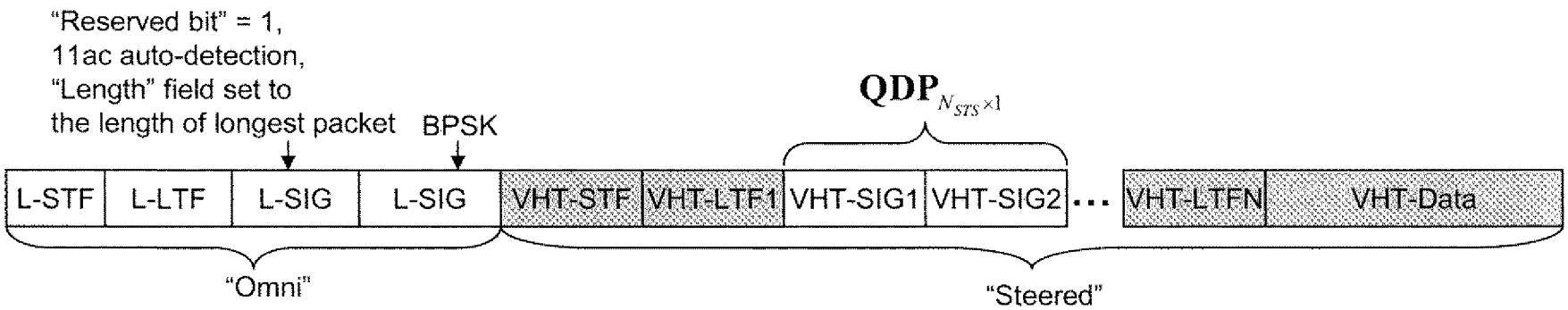
2. Issues with DL-MUMIMO

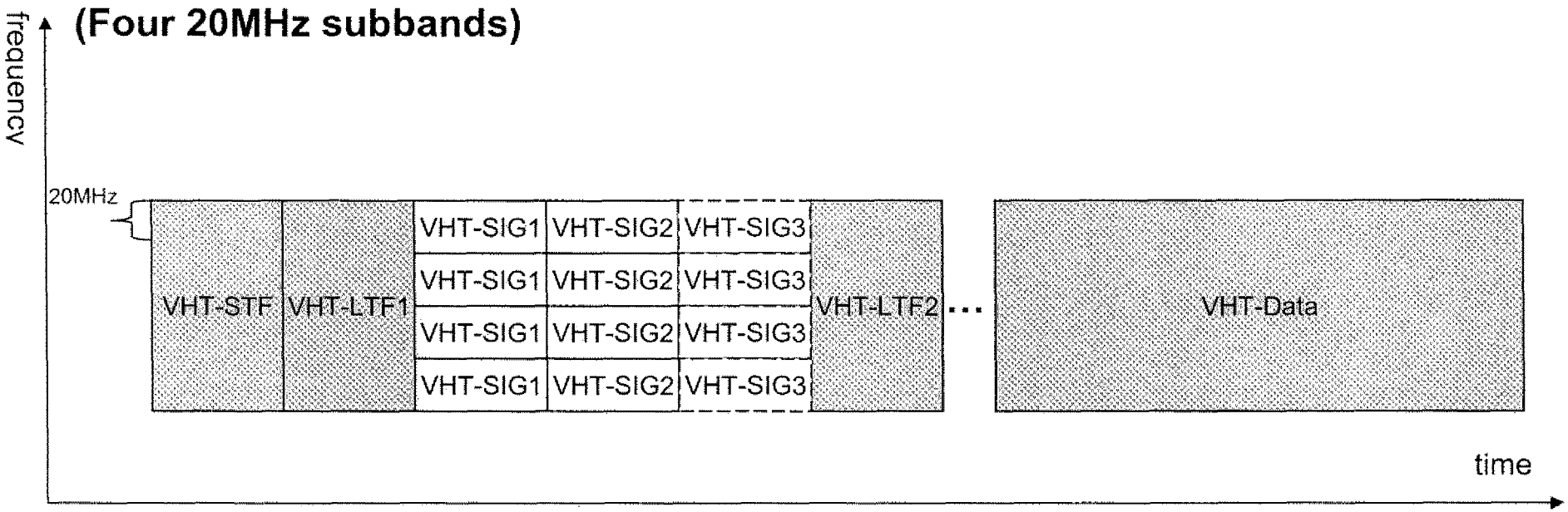
- Different from 11n TxBF, in DL-MUMIMO VHT-SIG needs to be spatially multiplexed for different clients, so we have to "steer" from the beginning of the PPDU → "Hidden Node" problem due to directional transmission.

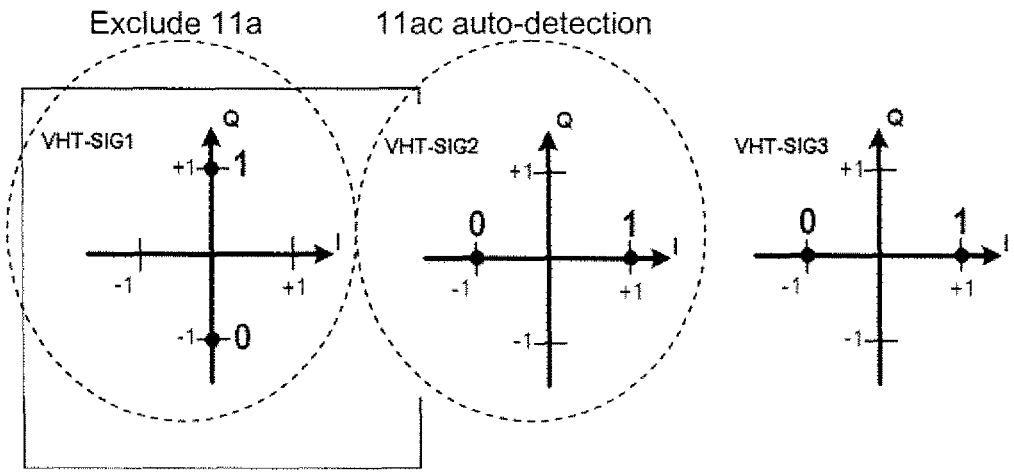
- Option 1—PHY Protection: Change the preamble structure to allow "omni" transmission in legacy portion, e.g.



- Option 2—MAC Protection:
  - (pls add some general description for MAC protection of DL-MUMIMO)

3. Green Field (TBD)



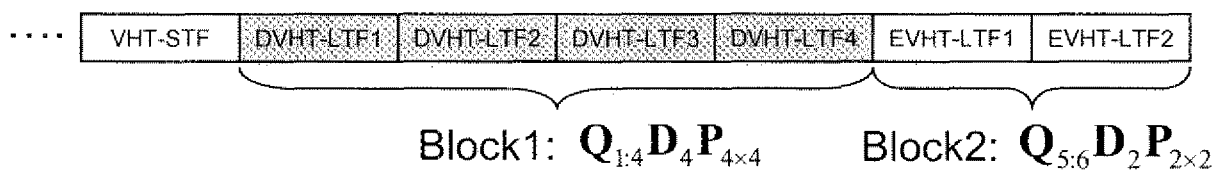


Slide 7

4. Sounding PPDU Preamble

- Sounding PPDU could be used in TxBF or DL-MUMIMO in 11ac.
  - May need to sound up to 8 spatial dimensions (N_{Tx}).

- <u>NDP sounding</u> similar as in 11n, extending to up to 8 VHT-LTFs.
  - Use "staggered" structure if $N_{Tx}>4$, limit to the following combinations of ($N_{DVHTLTF}$, $N_{EVHTLTF}$)
    - **(4,1) if $N_{Tx} = 5$**
    - **(4,2) if $N_{Tx} = 6$**
    - **(4,4) if $N_{Tx} = 7$ or 8**
  - 3-bit N_{ESS} subfield in VHT-SIG to signal N_{ESS} up to 4.
  - E.g NDP with MM format, $N_{TX}=6$



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80MHz OFDM for WLAN

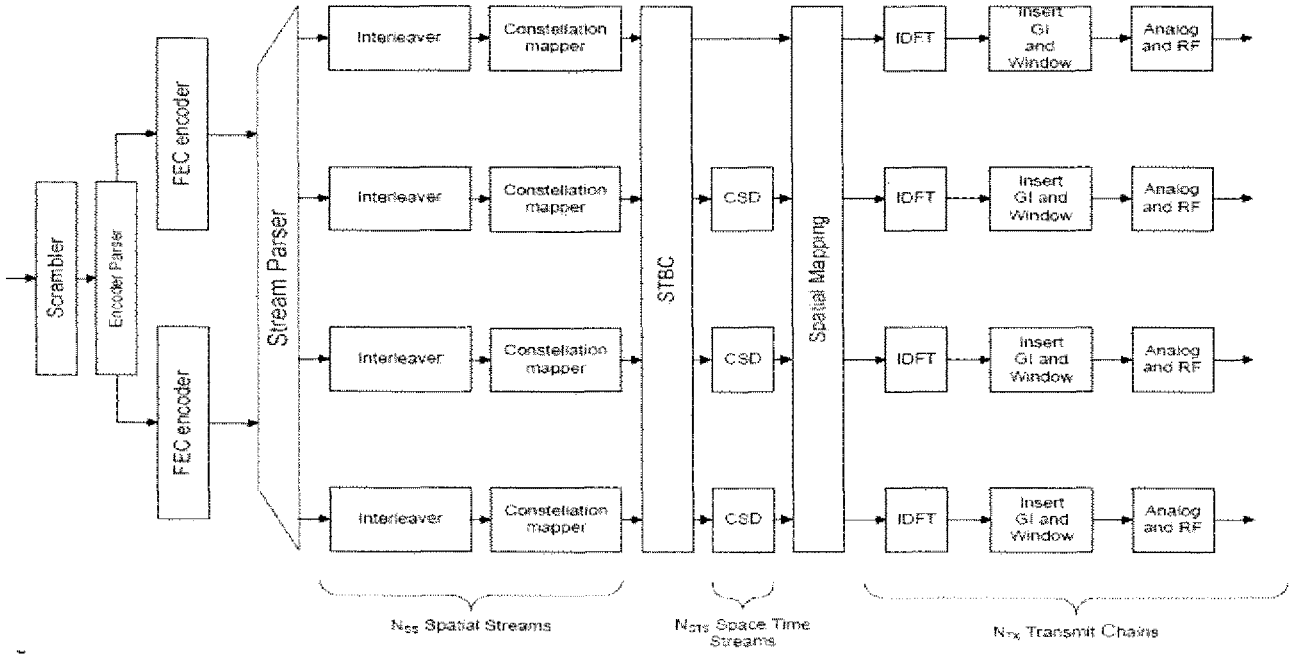
Hongyuan Zhang, Hui-Ling Lou ,Rohit U. Nabar, Sudhir Sri nivasa, Mao Yu

Overview

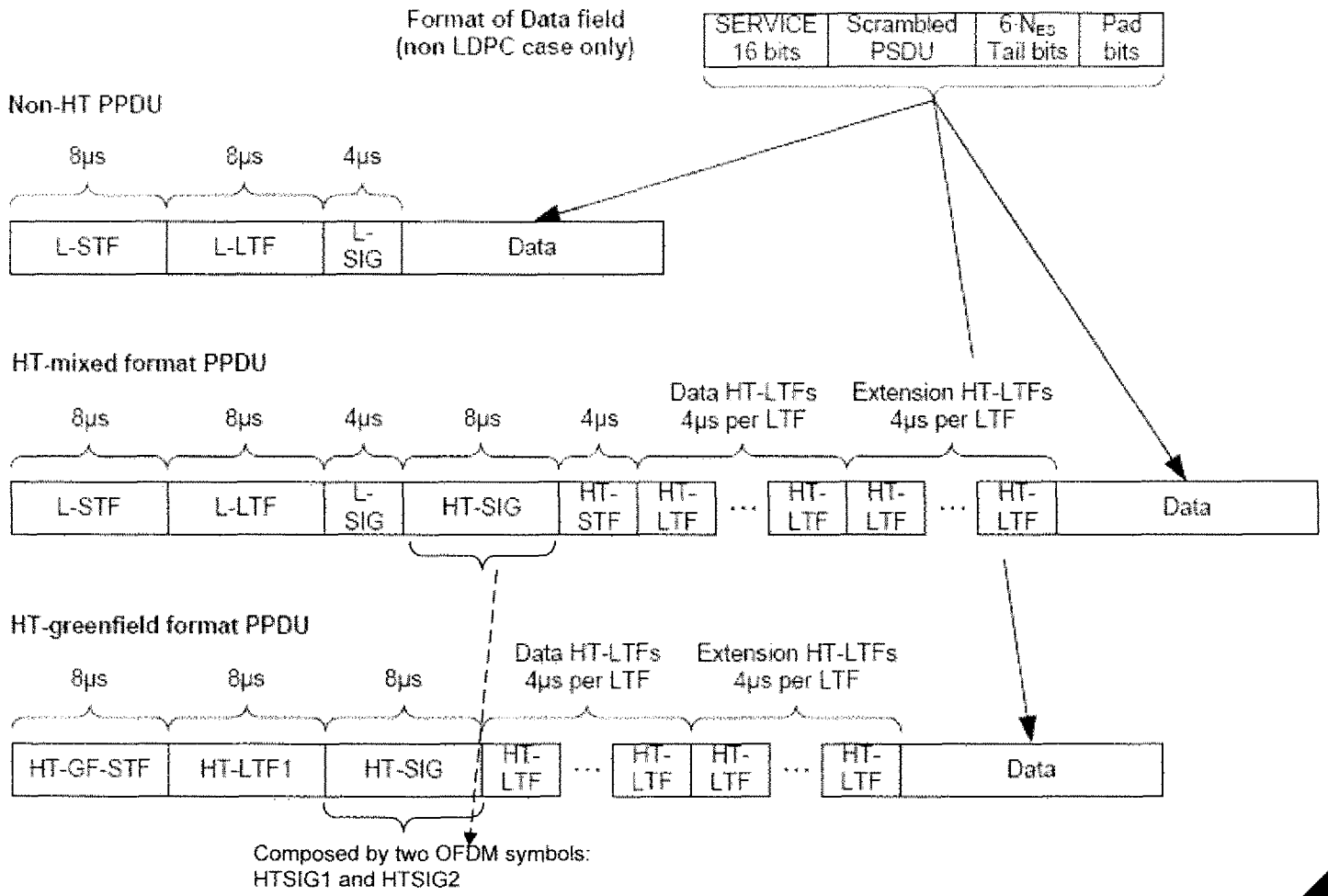
- Wireless Local Area Network (WLAN) has experienced rapid evolution over the past decade
  - IEEE 802.11a/b/g standards
  - IEEE 802.11n Draft: soon to be ratified
- Subsequent standards have focused primarily on improving single-user data throughput
  - 802.11b (11Mbps)
  - 802.11a/g (54Mbps)
  - 802.11n (600Mbps)
- We propose athe OFDM with 80MHz bandwidth to improve single-user throughout in WLAN.
  - E.g. to facilitate high-speed video streaming
- We believe this concept will find acceptance in next-generation WLAN (the emerging 802.11ac), which will be operated in the 5GHz bands—overlapping with legacy 802.11a/n systems.

Legacy 802.11a/n OFDM Background

- CSMA/CA MAC; OFDM PHY.
- At any time, 40MHz, or 20MHz bandwidth OFDM signal is transmitted from transmitter to receiver.
- Different users may be multiplexed by CSMA, or operated in different bands (with different AP or in different BSS).
- In 11n [1], MIMO may be applied, i.e. multiple spatial streams may be transmitted/received over multiple antennas on both side, in each of the tones of OFDM signal.



Legacy 11a/n PHY Frame Format [1][2]



Proposed 80MHz OFDM for Next Gen WLAN (802.11ac)—Overview

- To gain the single user P2P throughput, a very high throughput (VHT) PHY mode with 80MHz bandwidth OFDM modulation may be proposed for next Gen WLAN systems.

- Similar Frame Format as 802.11n 20/40MHz OFDM PHY

- Guarantees backward compatibility:
  - Legacy 20/40MHz OFDM device is at least able to receive the preamble and/or signal field of the 80MHz OFDM signal, in one of the PHY modes ("mixed mode").
  - Green field VHT PHY format may be defined only for VHT device to receive, without considering legacy 11a devices

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80MHz OFDM Frame Format Overview

- Mixed Mode and Green Field, similar to 11n HT OFDM frame format in 40MHz.
  - 11n receiver may not "spoof" for CCA protection.
- May define two new backward compatible formats, that allows 11n receiver to "spoof" for CCA protection according to HT-Length and MCS.
- Preamble (training fields and signal fields) are repeated in the four 20MHz subbands→for backward compatibility.
- Change the signal field content and/or modulation to signal the VHT 80MHz OFDM frame.
- Any MCS defined in 802.11n (HT rates) can be applied with 80MHz bandwidth.
  - MCS32 may be excluded for 80MHz, since it is about transmitting legacy 20MHz 11a signal in upper/lower bands of 40MHz HT rates

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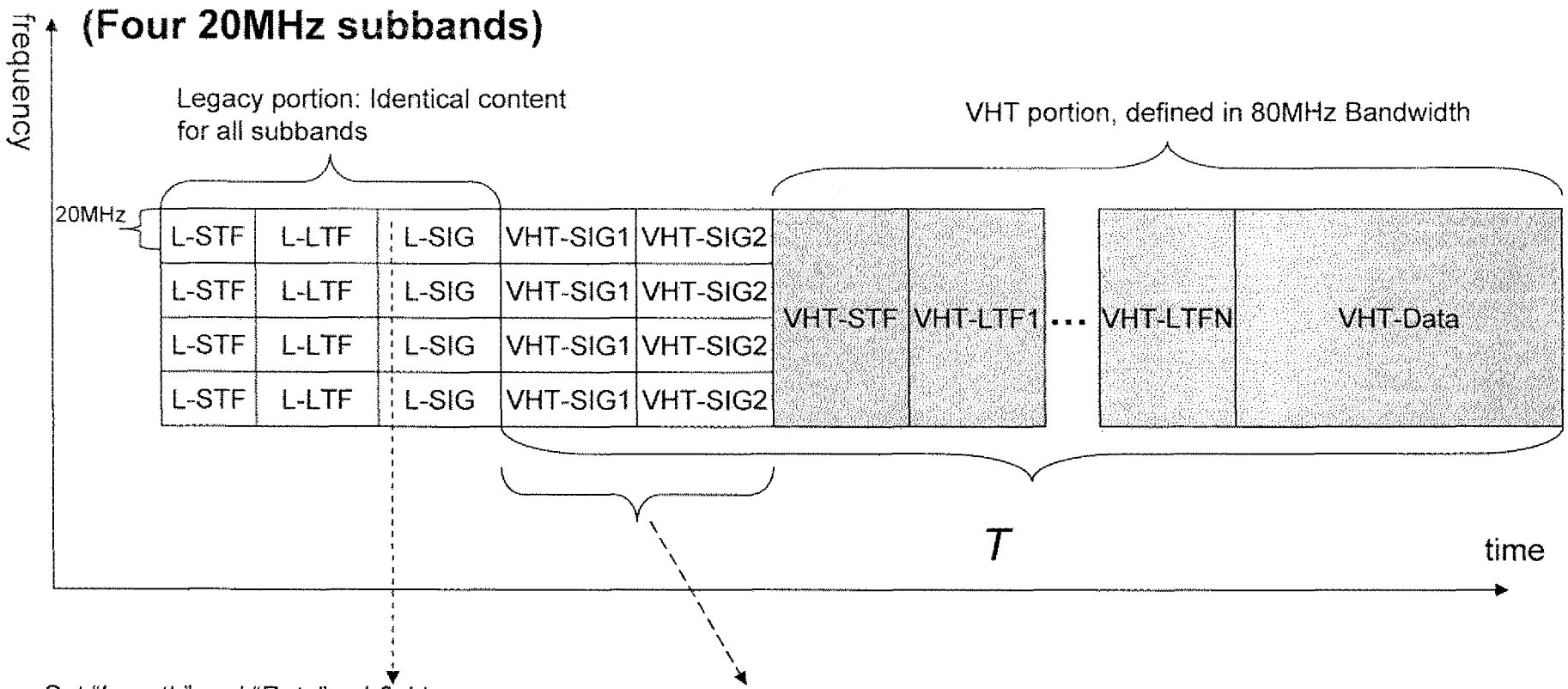
I. Mixed Mode (MM)

Mixed Mode 80MHz OFDM VHT (case 1)



Set "Length" and "Rate" subfield according to *T*, for legacy device spoofing. May set the "reserved bit" to 1 to signal 80MHz OFDM packet in VHT portion Of the pacekt.

Same format as HT-SIG of 11n [1]. May set the 11n "reserved bit" to "0", to signal 80MHZ OFDM packet (rather than in L-SIG). May apply rotated BPSK differently from 11n HT packet, to signal VHT packet.

Fig. 1

Mixed Mode 80MHz OFDM VHT (case 2)

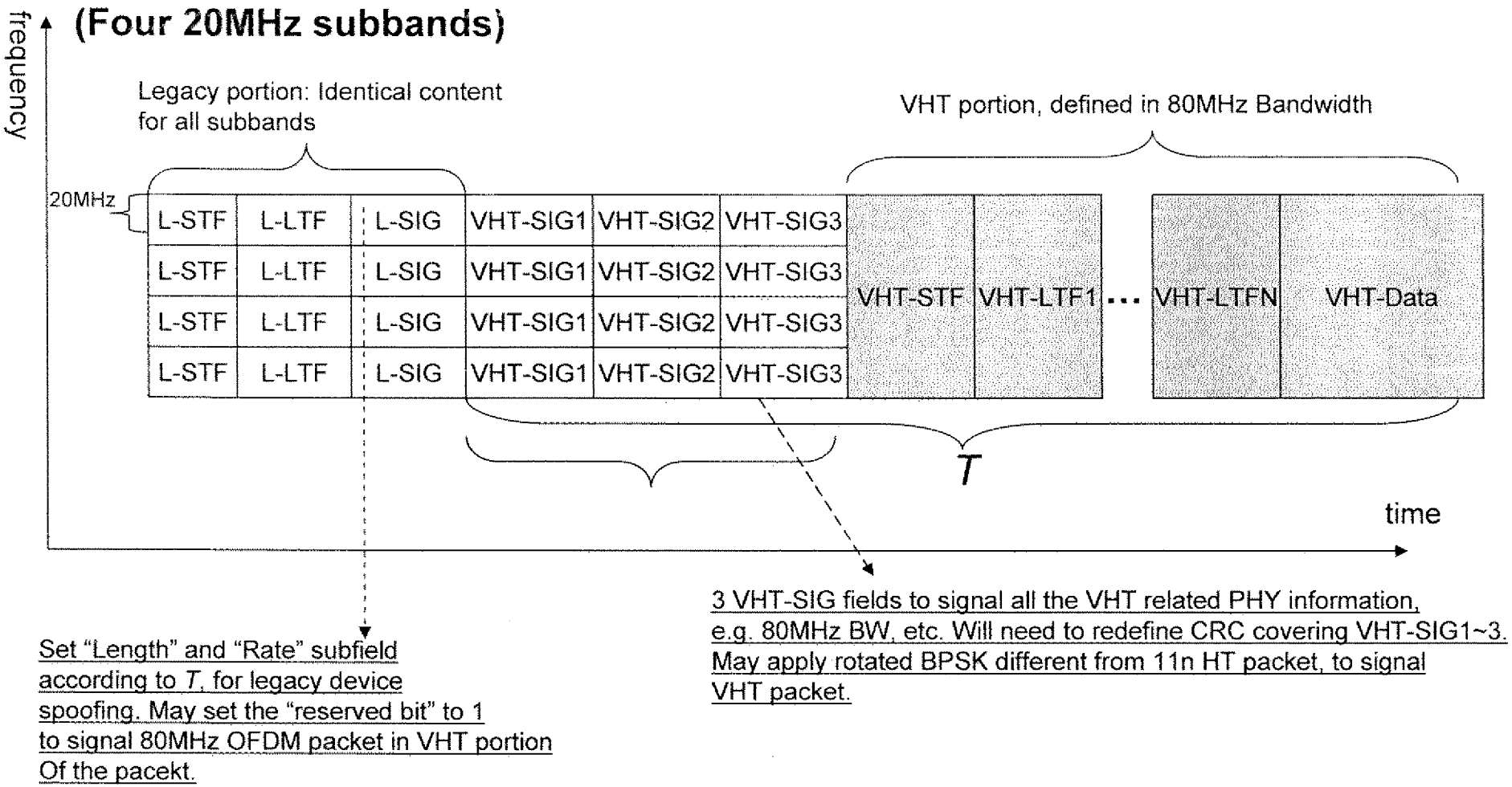


Fig. 2

Mixed Mode: Legacy Portion

- Include L-STF, L-LTF and L-SIG the same as 11a legacy preamble.

- Similar as transmitting legacy porting of MM 11n packet in 40MHz [1], here define the frequency domain symbols of the legacy portion repeated over the four 20MHz subbands of the 80MHz band, so that legacy 11a/n device with 20MHz bandwidth will 'see' a legacy 11a preamble in each of the 20Mhz subbands.
  - May rotate different 20MHz subbands signals by different angles, as in 11n [1]. For example: rotate 0-deg, 90-deg, 180-deg, -90-deg on the four subbands respectively (or 0 +-90 +-45), the order is variant and should be all included in this disclosure.

- For backward compatibility, set "rate" and "length" field in L-SIG according to the true length (*T*) of the VHT packet, so "spoofing" is possible for 11a device.
  - 11a device will see data error from "VHT-SIG1" field, according to the 11a receiver state machine [2], the 11a receiver should hold CCA until the end of the LSIG-computed packet duration.

- May set the reserved bit in L-SIG to 1 ([1][2] defines this bit to 0 by default as seen by 11a/n devices), to signal VHT device that the current packet is a VHT packet.
  - May not need this signaling, and may be combined with VHT-SIG signaling approaches as will be described in the following slides.

Mixed Mode: VHT SIG fields (1)

- In the first option (Fig 1), 2 VHT-SIG fields are defined, similar as the HT-SIG in 11n [1]. Each VHT-SIG field is carried by one OFDM symbol in 20MHz BW, and repeated/rotated over the four 20Mhz subbands as in the legacy portion in previous slide →same rotation approach as in the legacy portion.
- The subfields format may be the same as HT-SIGs in 11n [1].
  - E.g. MCS here means the same modulation and coding scheme but applied in 80MHz band.
    - **MCS32 may be disallowed for VHT packets.**
  - May set the reserved bit in VHT-SIG2 to 0 ([1] defines this bit to 1 as seen by 11n devices), to signal VHT device that the current packet is a VHT packet.
  - If only 80MHz BW is allowed for ANY VHT packet, then a "80MHz" indication as above is not needed in VHT-SIG ("VHT-SIG" is modulated differently from HT-SIG→see next slide).
- Alternatively, the subfields format may be completely different from HT-SIGs in [1], for VHT packet PHY information signaling.
  - E.g. the subfield in HT-SIG "BW20/40" may not be needed, or combined with the reserved bit to select 20/40/80; the subfield "aggregated" may not be used, etc
  - Since modulation of VHT-SIG may be different from HT-SIG (next slide), so 11n device may not correctly decode VHT-SIG as HT-SIG (CRC error), this allows completely redefinition of VHT-SIG.
  - All different arrangement of the new VHT-SIG subfields should be covered by this disclosure.

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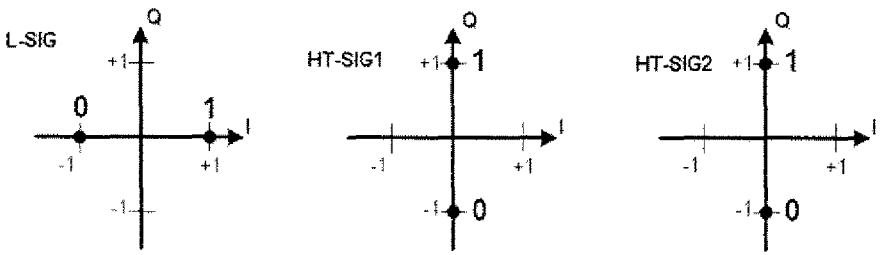
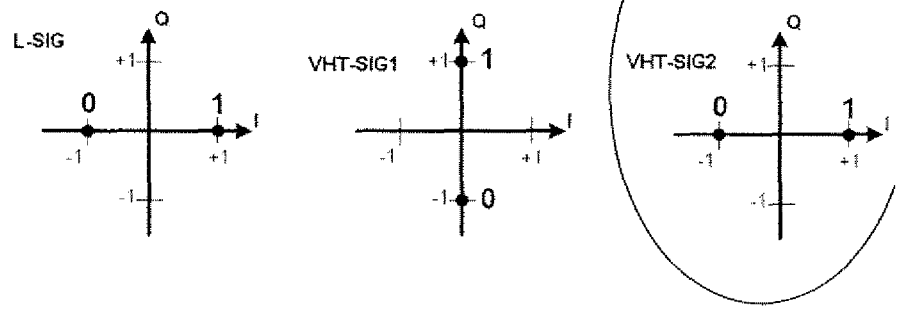
Cont'd

- To differentiate VHT-SIG from HT-SIG, the modulation of VHT-SIG may be defined differently from HT-SIG in [1].
- VHT-SIG1 is modulated using 90-deg rotated BPSK (Q-BPSK) in each data tone of the OFDM symbol, and VHT-SIG is modulated using normal BPSK in each subcarrer:
  - HT-SIG2 in 11n [1] also modulated using Q-BPSK.
  - For backward compatibility , a 11n receiver will not decode VHT-SIG2 as HT-SIG2 correctly, and the CRC check for both HT-SIG1 and 2 will fail. According to [1], the 11n receiver state machine will wait (hold CCA) until the energy of the packet drops out, before switching to CCA idle mode. On the other hand, a 11a device will see data error from "VHT-SIG1" field (as for 11n MM HT packet [1]), according to [2], the receiver should hold CCA until the end of the LSIG-computed packet duration (spoofing).

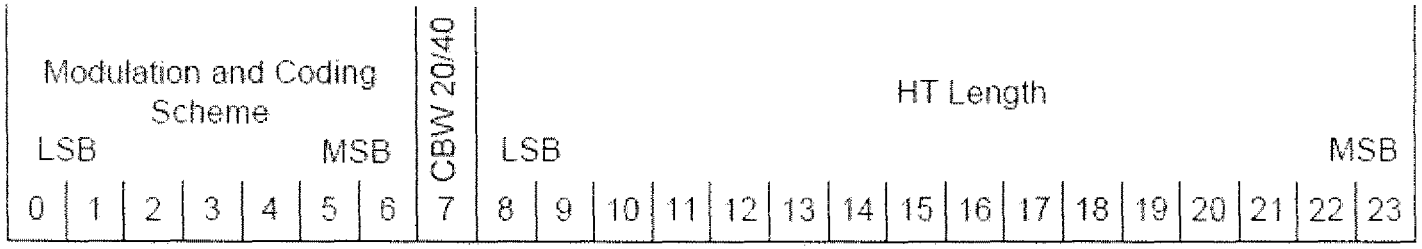
For 11n HT Packet:



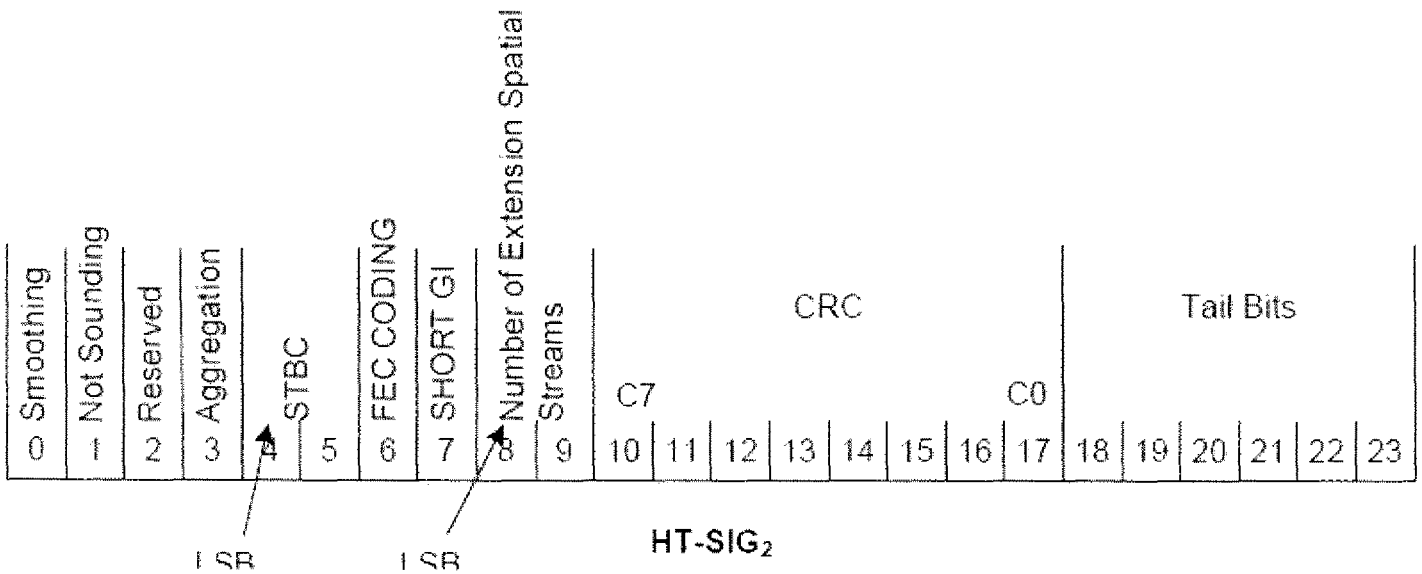
For 11ac VHT Packet:



Cont'd—HT-SIG Format as in [1]



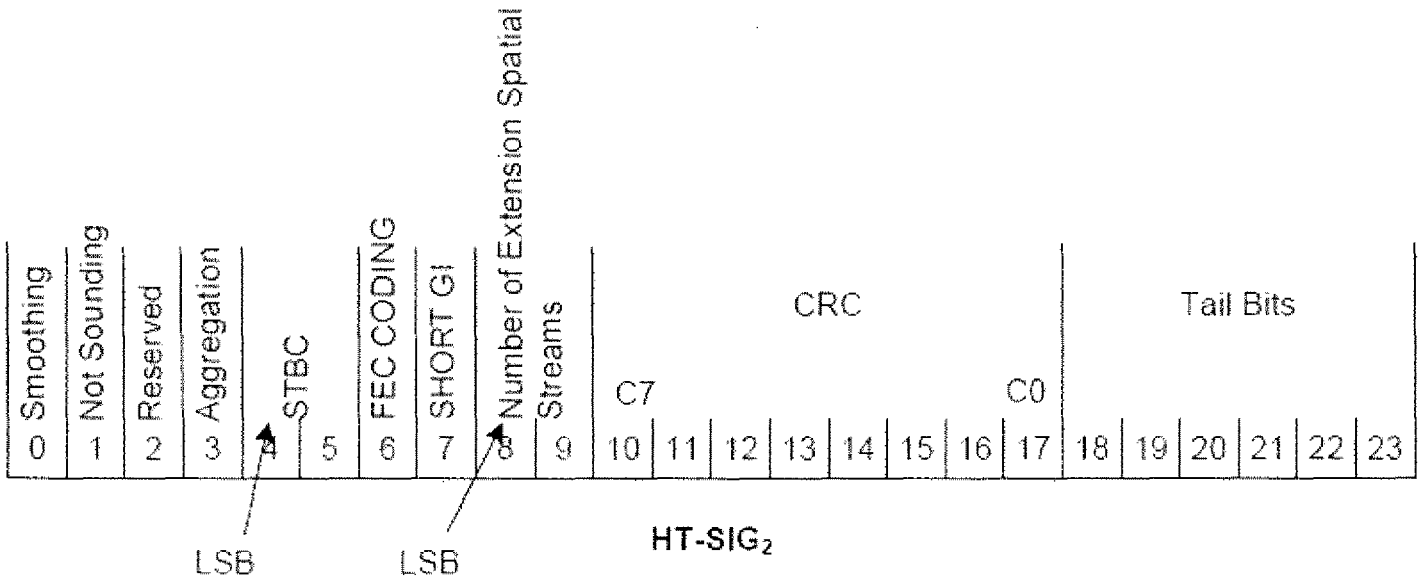
HT-SIG$_1$



HT-SIG$_2$

Cont'd—example of VHT-SIG Format

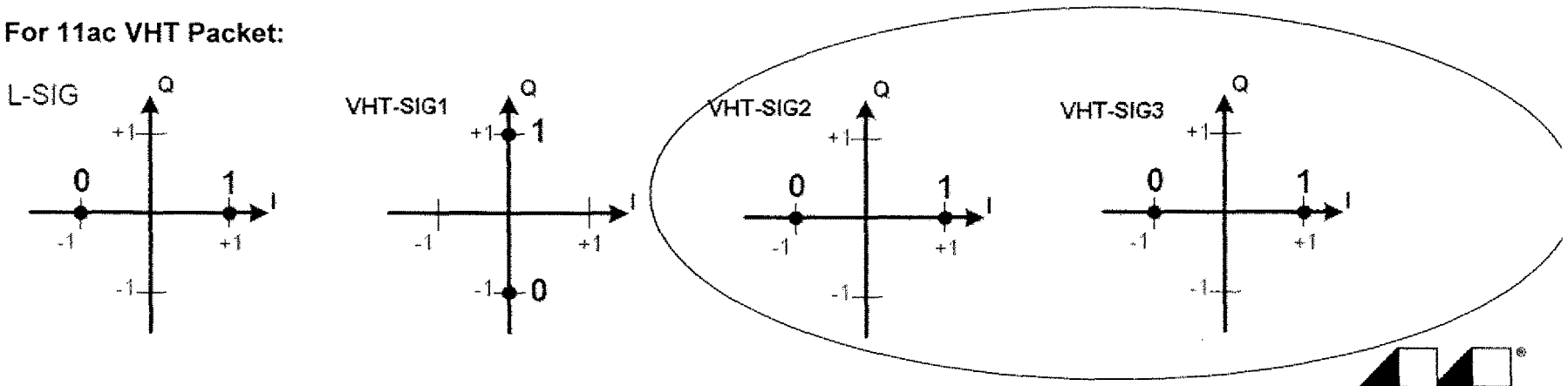
Example when only 80MHz OFDM is allowed for VHT packet (Should not be constraint to this example)



Mixed Mode: VHT SIG fields (2)

- In the second option (Fig 2), 3 VHT-SIG fields may be defined to signal all the VHT packet related PHY information, since the overall content of PHY information signaling could be larger than the PHY information for 11n HT packets, so we may need 3 VHT-SIG fields here.
  - Each VHT-SIG is modulated by one OFDM symbol.
  - May redesign all the 3 VHT-SIG subfield formats, which is different from HT-SIG fields in 11n [1]. (e.g. use 2 bits to signal 20/40/80 MHz bandwidth, or no indication of 20/40/80MHz in the case thay only 80MHz is allowed for VHT packets)
  - The same CRC check as HT-SIG[1] is moved to VHT-SIG3, that checks the correctness of the data in all the 3 VHT-SIG fields.
  - To signal the presence of the current VHT packet, VHT-SIG1 modulated using Q-BPSK, and VHT-SIG2 and VHT-SIG3 may modulate using BPSK.

For 11ac VHT Packet:



Mixed Mode: VHT Portion

- VHT-STF, VHT-LTFs, and VHT-Data OFDM symbols are defined similar to HT-STF, HT-LTFs and HT-Data as in 11n [1], except that each OFDM symbol is defined over 80MHz bandwidth.
  - Need 256 point IFFT/FFT, with the same OFDM duration (3.6us for short GI, 4 us for long GI).
  - If the constraint on the max number of space-time streams is the same as 11n [1], then the spatial mapping, P matrix in VHT-S(L)TFs, Frequency CSD, etc definitions will be the same as 11n [1], except extending to 80MHz bands.
  - For 80MHz OFDM signal, the symbols in the tones of VHT-STF and VHT-LTFs, the assignment of data tone numbers/positions, guard tones around edge bands and DC tones, number/position/content of pilot tones, and the frequency interleaver, are designed differently from 20MHz and 40MHz legacy signals in [1][2].
    - **Pilots will not be present for VHT-STF and VHT-LTFs as in [1][2].**
    - **The detailed designs of these factors may be variant, but we may claim the following basic tone structure for 80MHz OFDM signal (Data portion)**

Tone idx: -128, -127, ...,-1, 0, -1 ... .,128

Zero tones	Data/Pilot tones	zero tones	Data/Pilot tones	Zero tones

Cont'd

- In VHT-STF and VHT-LTF, the tone symbol definition may repeat the symbols defined for 20MHz band as in [1][2] over the four 20MHz subbands. i.e. similar as transmitting HT-STF and HT-LTF in 11n 40MHz mode [1], here define the frequency domain symbols of 20MHz STF and LTFs as in [1][2] repeated over the four 20MHz subbands of the 80MHz band,
  - May rotate different 20MHz subbands signals by different angles, as in 11n [1]. For example: rotate 0-deg, 90-deg, 180-deg, -90-deg on the four subbands respectively (or 0 +-90 +-45), the order is variant and all included in this disclosure.

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II. Green Field (GF)

Overview

- Same format as MM, except the preamble part.
- Not designed for backward compatibility with legacy 11a; but may be compatible with 11n.

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Greenfield 80MHz OFDM VHT (case 1)

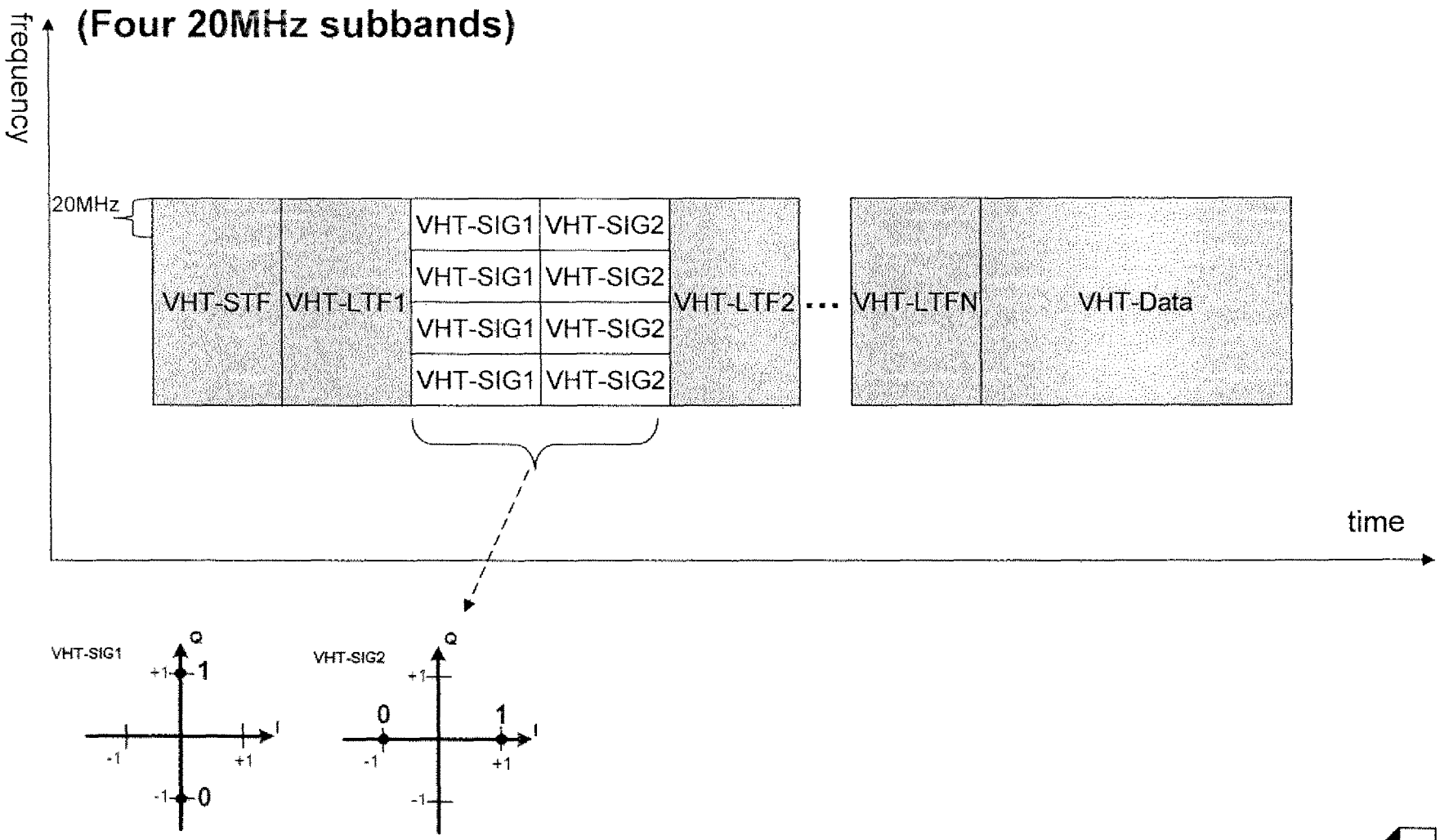


Fig. 3

Greenfield 80MHz OFDM VHT (case 2)

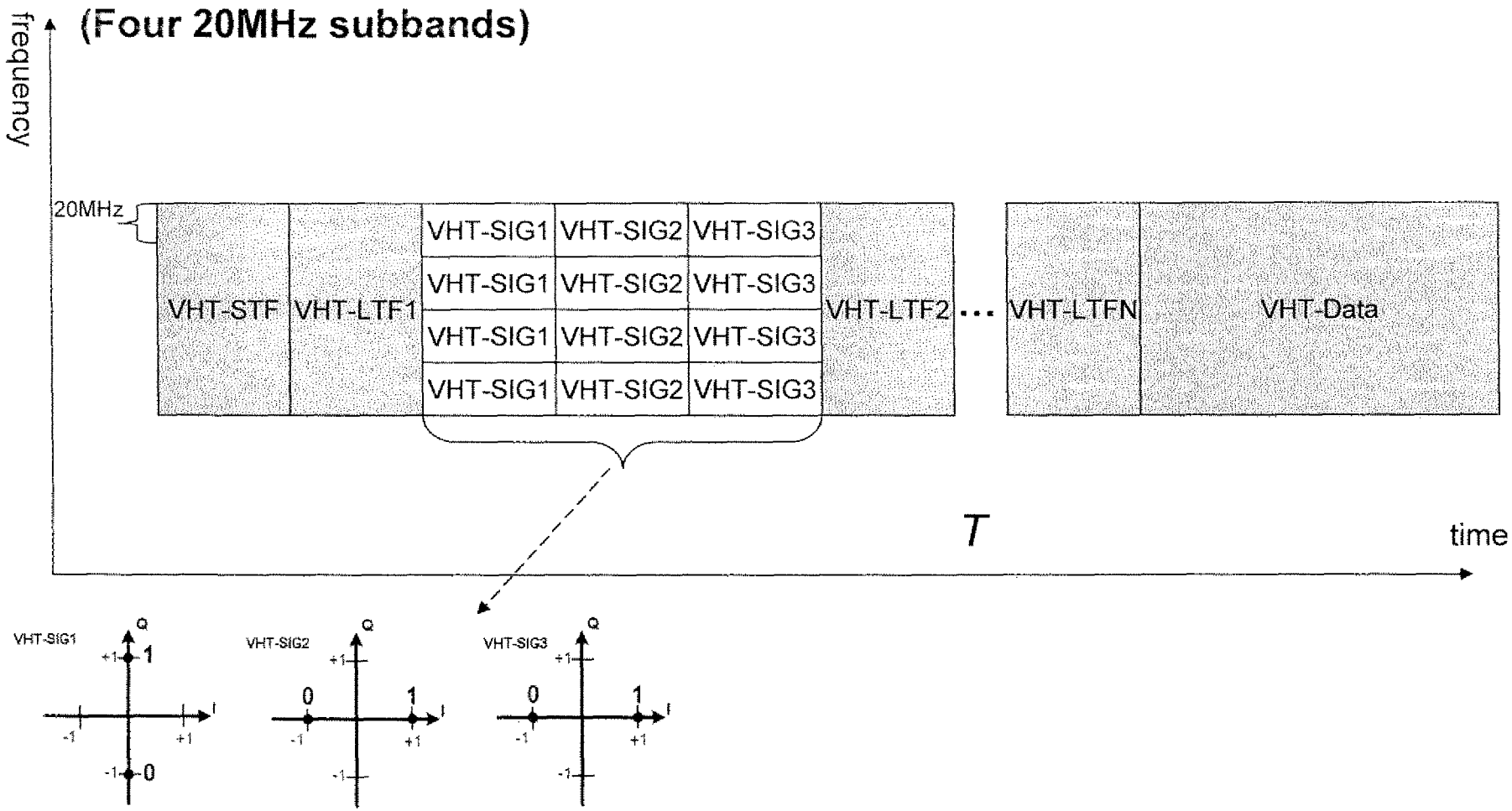


Fig. 4

For VHT-STF, VHT-LTF1, and VHT-SIG

- As in MM, VHT-STF and VHT-LTF may be defined as the frequency domain symbols of 20MHz legacy STF and LTFs as in [1][2] repeated over the four 20MHz subbands of the 80MHz band (for VHT-LTF, it is with non-zero values inserted at the "DC" and "Guanrd" tones in the original 20MHz subband LTFs), and rotate differently in each of these 20MHz subbands.

- <u>11n device will 'see' a legacy 11n preamble and HT-SIG1 in each of the 20MHz subbands.</u>

- VHT-SIG fields in GF are defined/modulated the same way as in MM.
  - So 11ac receiver will be able to decode VHT-SIG fields in each of the 20MHz subbands.
  - In Fig 3,4, the different rotation BPSK modulation in VHT-SIG2(3), compared with HT-SIG2 [1], will make 11n receiver not able to decode HT-SIG correctly (CRC error). So according to 11n receiver state machine [1], 11n receiver will hold CCA until the energy of the packet drops out.

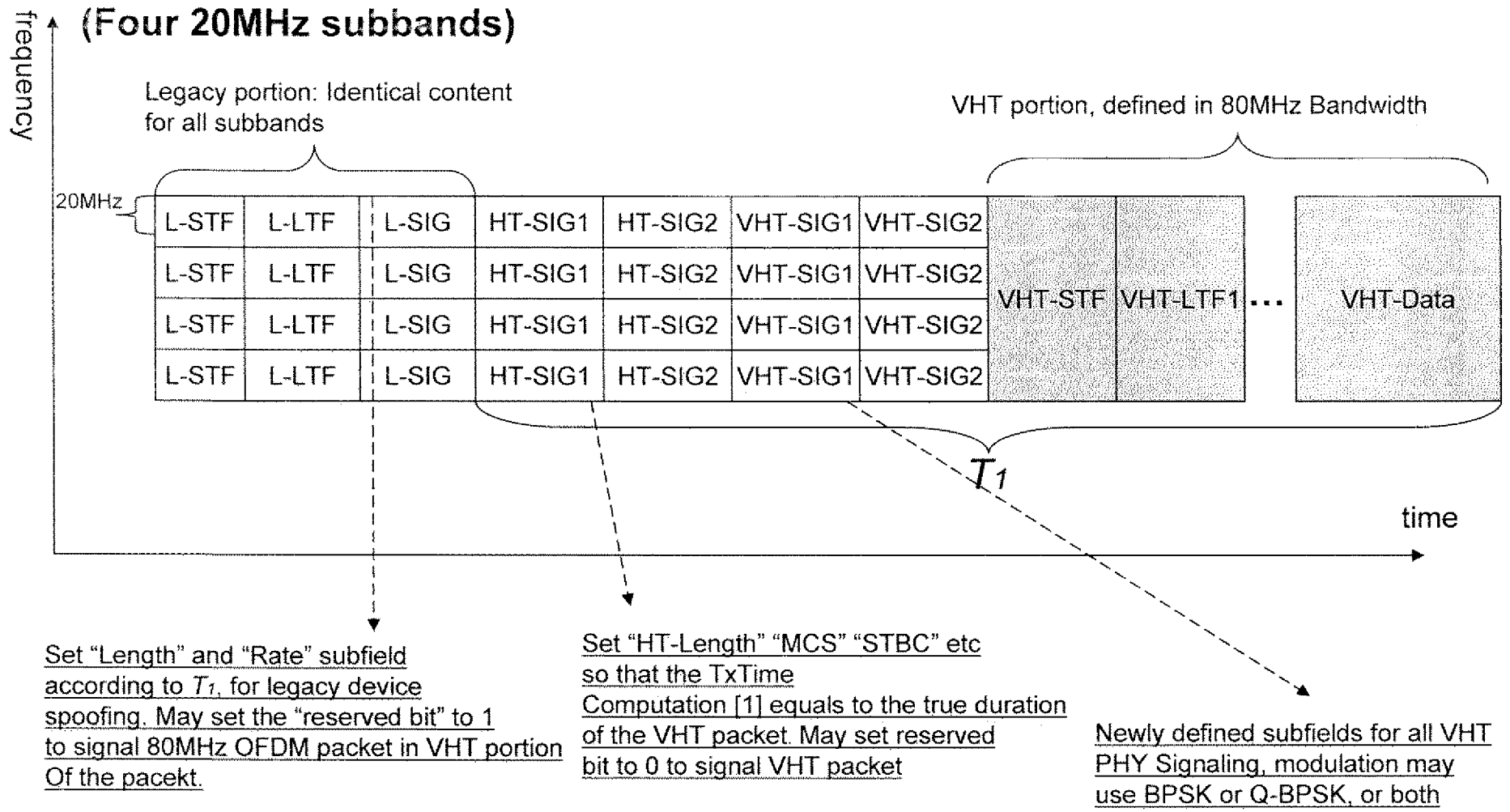
III. HT Spoofing Mode

Overview

- This mode allows 11n HT device to "spoof" for the CCA time, according to HT-SIG field, when receiving a VHT packet.

- May define three submodes (or apply some of them):
  - MM HT Spoof: allow spoofing of 11a and 11n devices
  - 11n GF HT Spoof: allow spoofing of 11n device only
  - VHT GF: pure VHT packet not allowing any spoofing for 11a/n receiver

MM HT Spoofing 80MHz OFDM VHT



Set "Length" and "Rate" subfield according to T_1, for legacy device spoofing. May set the "reserved bit" to 1 to signal 80MHz OFDM packet in VHT portion Of the pacekt.

Set "HT-Length" "MCS" "STBC" etc so that the TxTime Computation [1] equals to the true duration of the VHT packet. May set reserved bit to 0 to signal VHT packet

Newly defined subfields for all VHT PHY Signaling, modulation may use BPSK or Q-BPSK, or both

Fig. 5

11n GF HT Spoofing 80MHz OFDM VHT

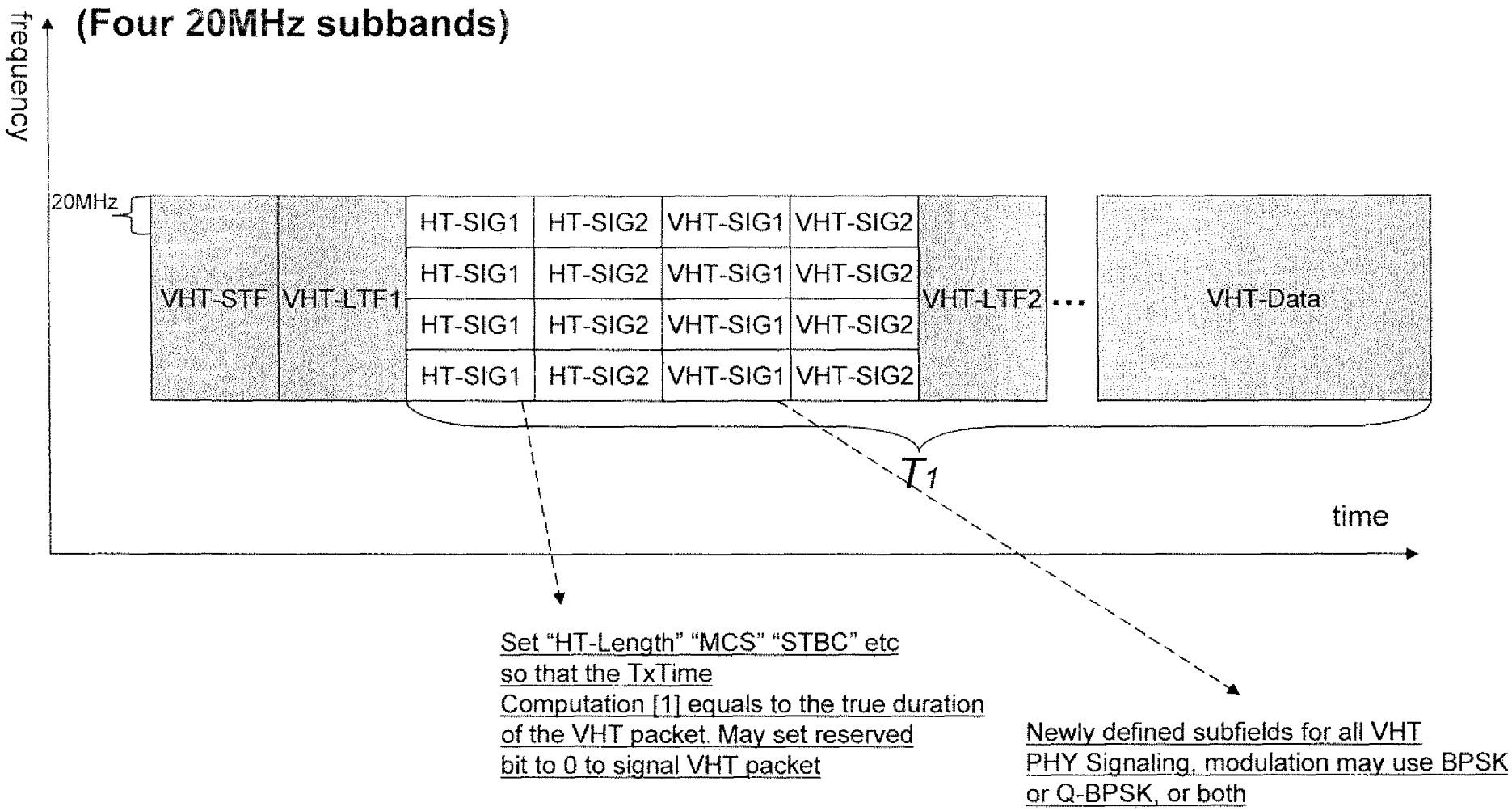


Fig. 6

VHT GF 80MHz OFDM

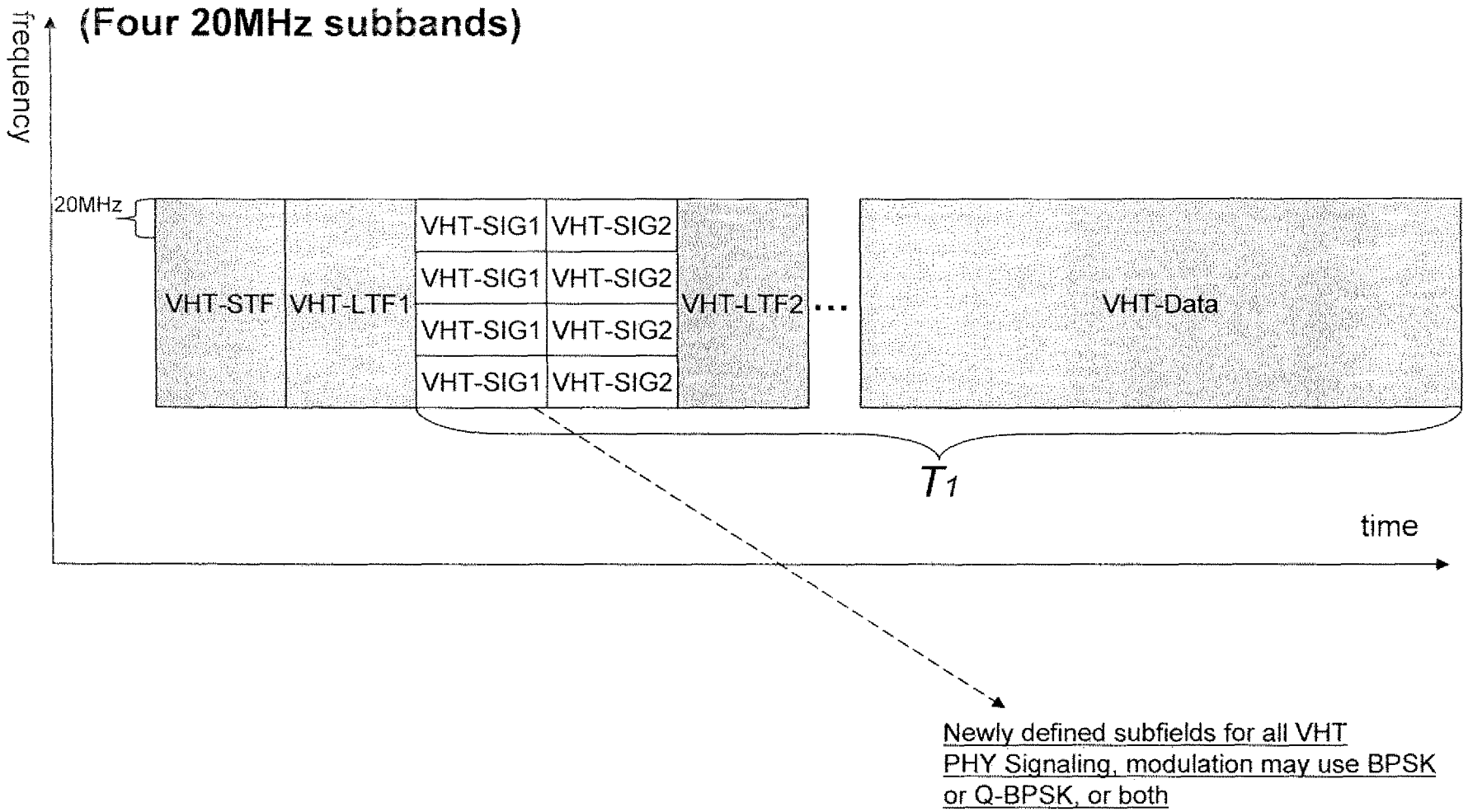
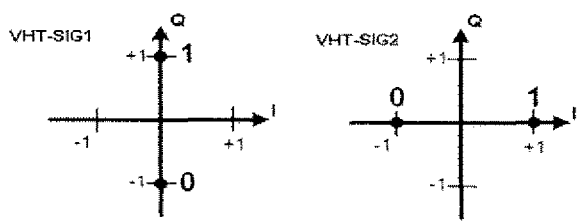


Fig. 7

Discussions

- L-SIG in Fig 5 may set the reserved bit to "1" to signal 11ac receiver the presence of VHT packet (i.e. VHT-SIG1,2 will follow HT-SIG2).
- HT-SIG Fields in Fig 5,6, are formatted/modulated the same way as in 11n [1].
- "HT-LENGTH", "MCS", "STBC" subfields in HT-SIG fields should be set such that the TXTIME computation for a 11n receiver equals to the true packet duration of the VHT packet.
  - See 20.4.3 of [1] for the detailed way of computing TXTIME.
  - So 11n Spoofing is achieved: 11n receiver will see "carrier lost" after decoding HT-SIG2, so according to its state machine in [1], it will hold CCA until the end of TXTIME.

- The GF packet in Fig6 only can spoof in 11n receiver, cannot spoof 11a receiver. The VHT GF packet in Fig 7 (the same as Fig3) cannot spoof any legacy 11a/n receiver (but 11n receiver will see HT-SIG CRC error, so it will hold CCA until energy of the packet drops out).
- May use the reserved bit in HT-SIG2 setting to 0, to signal the VHT packet presence (VHT-SIG following HT-SIG).
  - May not set this bit for a MM packet in Fig5, if L-SIG uses reserved bit setting to "1" to signal VHT packet.
- Subfield allocation and CRC in VHT-SIG1 and VHT-SIG2 may be newly defined to signal all the VHT related PHY information: e.g MCS, Length, etc.
- Apply QBPSK, or BPSK in VHT-SIG fields.
  - E.g. QBPSK in VHT-SIG1, and BPSK in VHT-SIG2, so in VHT GF frame of Fig7, the 11ac receiver may differentiate VHT GF packet (Fig 7), from GF HT Spoofing packet (Fig 6).



IV. Extensions

Extension-1

- **The mentioned frame formats and signaling approaches (i.e. L-SIG subfield (reserved bit) changes from 11a/n, VHT-SIG subfield changes and modulation changes from HT-SIG in 11n) across this disclosure, may be used to signal other VHT packet other than 80MHz OFDM modulation, depending on the final PHY layer technologies that applied for VHT packet.**
  - **i.e. these mentioned signaling approaches may be applied to signal the presence of a "VHT packet" or "11ac packet", which is not necessarily only with 80Mhz OFDM signal. Or it means the presence of VHT-SIG fields.**
    - E.g. a 40MHz/20MHz 11ac packet may use the same preamble.
    - 40MHz 11ac may have the upper and lower duplications structure similar as or the same as in 11n [1].
  - **E.g. SDMA signal, OFDMA signal, dual-radio signal, etc. May or may not with 80MHz bandwidth.**
  - **Therefore Figs1~7 may be redrawn for 40MHz, or 20MHz BW VHT signals. But the VHT-SIG signaling schemes mentioned in this dislcosure may still be used for signal the presence of the current "VHT" packet.**

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Extension-2

- In the above mentioned VHT signaling approaches that change the constellation points of VHT_SIG fields, the disclosure may extend to the cases where ANY changes on the VHT-SIG fields modulation that is different from HT-SIG fields in 802.11n[2].

- Example (other than the mentioned cases earlier),
  - ALL the VHT-SIG symbols are modulated using BPSK
  - The first VHT-SIG symbol is BPSK, the remaining symbols are modulated using Q-BPSK.

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Example of Ext 2: Mixed Mode 1

(Four 20MHz subbands)

Legacy portion: Identical content for all subbands

VHT portion, defined in 80MHz Bandwidth

20MHz

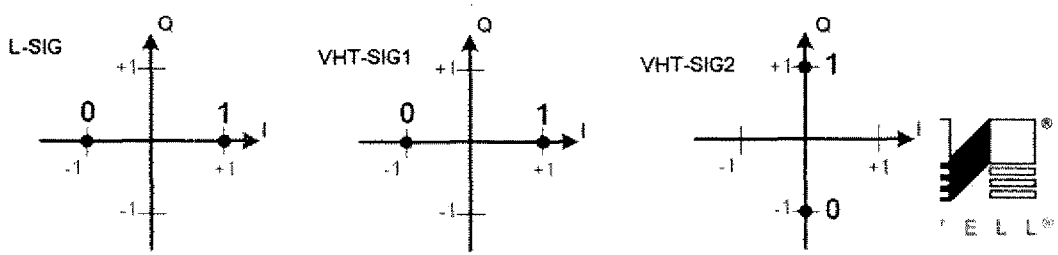
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2	VHT-STF	VHT-LTF1	... VHT-LTFN	VHT-Data
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2				
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2				
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2				

T

time

Set "Rate" subfield to "1101" to indicate 6Mbps, and set "Length" subfield according to *T*, for legacy device spoofing. May set the "reserved bit" to 1 to signal 11ac packet.

Subfield defintion may be completely different from 11n, to signal the 11ac Specific PHY parameters. Modulation as below:



Cont'd

- L-SIG has to set Rate to 6Mbps (same as 11n).
- 11a receiver will set CCA duration according to LSIG field.
- 11n receiver (compatible with 11a) will think the 11ac packet is a 11a packet, and set CCA duration according to LSIG field.
- 11ac device (compatible with 11a/n) will detect 11ac (11ac auto-detection) at the VHT-SIG2 by looking at its modulation.
  - Since VHT-SIG1 is using BPSK, receiver will discard 11n mode → the current packet could be either 11a or 11ac.
  - The OFDM symbol at the position of VHT-SIG1 could be either a 11a Data or 11ac VHT-SIG1, but both are modulated using 6Mbps 11a mode (as set by LSIG).
  - After detecting 11ac at VHT-SIG2, the receiver combines VHT-SIG1 and VHT-SIG2 decoded bits to check CRC and get PHY parameters.
- In the previous slide, if the reserved bit in L-SIG is used for signaling 11ac (11ac autodetection), then the modulation of VHT-SIG2 is not important, could be either BPSK or QBPSK, and 11ac receiver doesn't need to autodetect 11ac by looking at constellation of VHT-SIG2.

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Example of Ext 2: Mixed Mode 2

(Four 20MHz subbands)

frequency

Legacy portion: Identical content for all subbands

VHT portion, defined in 80MHz Bandwidth

20MHz

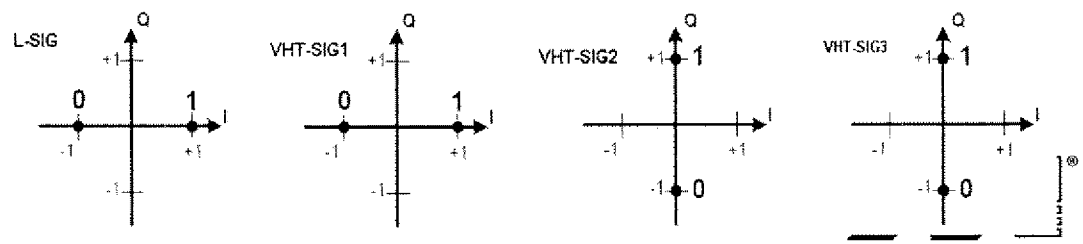
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2	VHT-SIG3	VHT-STF	VHT-LTF1	...	VHT-LTFN	VHT-Data
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2	VHT-SIG3					
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2	VHT-SIG3					
L-STF	L-LTF	L-SIG	VHT-SIG1	VHT-SIG2	VHT-SIG3					

T

time

Set "Rate" subfield to "1101" to indicate 6Mbps, and set "Length" subfield according to *T*, for legacy device spoofing. May set the "reserved bit" to 1 to signal 11ac packet.

Subfield defintion may be specific for 11ac PHY parameters. Modulation as below:

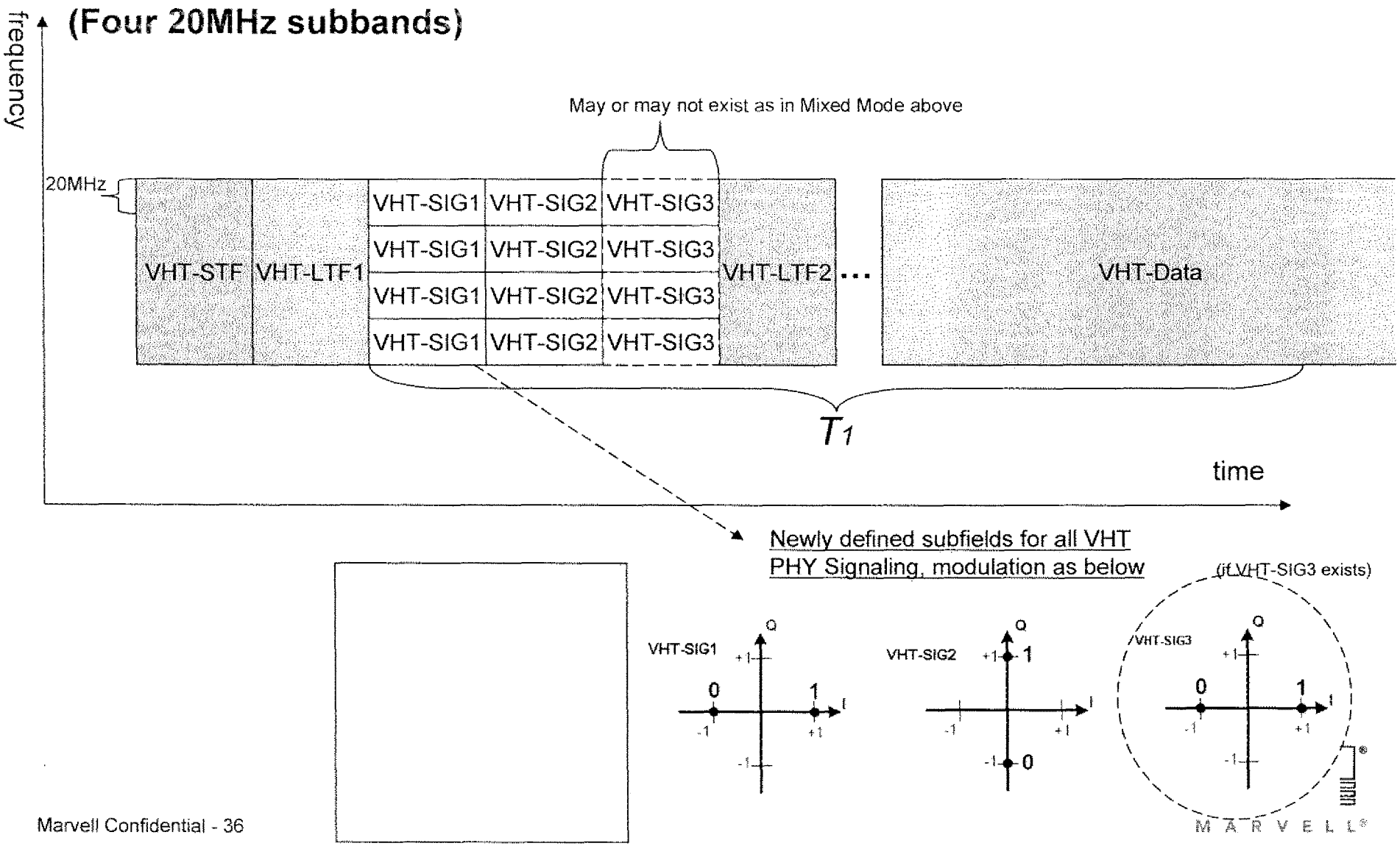


Cont'd

- VHT-SIG3 may also be modulated using BPSK→ we claim both cases.
- 11a/n/ac decoding process similar as the previous example.

- In the previous slide, if the reserved bit in L-SIG is used for signaling 11ac (11ac autodetection), then the modulation of VHT-SIG2 is not important, could be either BPSK or QBPSK, and 11ac receiver doesn't need to autodetect 11ac by looking at constellation of VHT-SIG2.

Example of Ext 2: Green Field

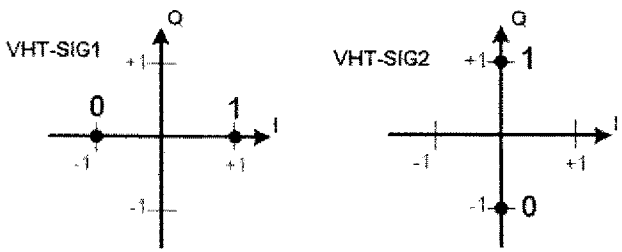


Cont'd

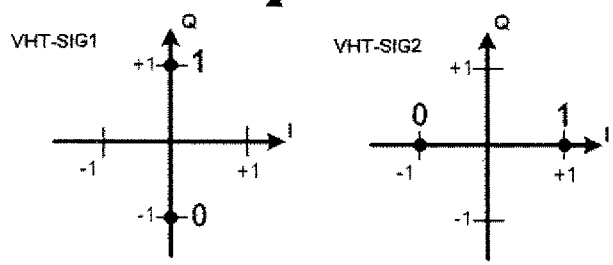
- Need MAC protection of GF transmission within a BSS.
- If there is two OFDM symbols in VHT-SIG, 11ac receiver can only differentiate a 11ac green field packet from 11n mixed mode packet, by checking the CRC jointly on VHT-SIG1 and VHT-SIG2.
- If there is three OFDM symbols in VHT-SIG, then the VHT-SIG3 may be modulated using BPSK, so 11ac receiver can differentiate 11ac green field packet from 11n mixed mode packet by checking the modulation constellation of VHT-SIG3.

- <u>It is possible that VHTSIG modulation in Mixed mode and Greenfield are different: e.g. Mixed mode using BPSK and QBPSK in VHT-SIG1 and VHT-SIG2; and Green field using QBPSK and BPSK respectively (like Fig3 of slide 20).</u>

MM:



GF:



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Extension-3

- In the above mentioned VHT signaling approaches in the non HT-spoofing modes, the disclosure may extend to the cases where the modulations of VHT_SIG is exactly the same as the HT_SIG fields in 802.11n[2]; but the content of VHT_SIG fields will be different from HT-SIG of 11n, so that it will invalidate the CRC checking of 11n receiver on receiving the HT-SIG field.

- Examples,
  - Use more than 2 VHT-SIG symbols, so the CRC is redesigned to cover all the (longer) VHT-SIG fields.
  - Re-place the position/length/coding method (e.g. the initial states of the CRC logic) of the CRC bits in VHT-SIG1 and 2; and then we may completely redefine the content of the VHT-SIG fields which are different from HT-SIG.

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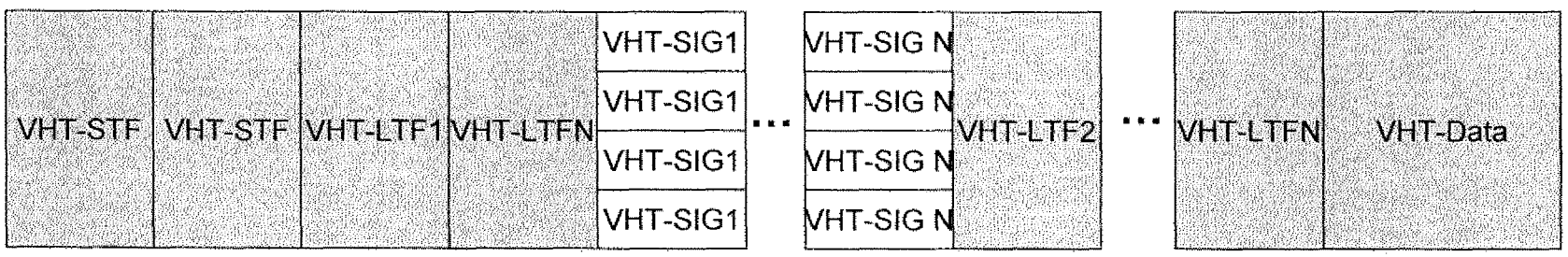
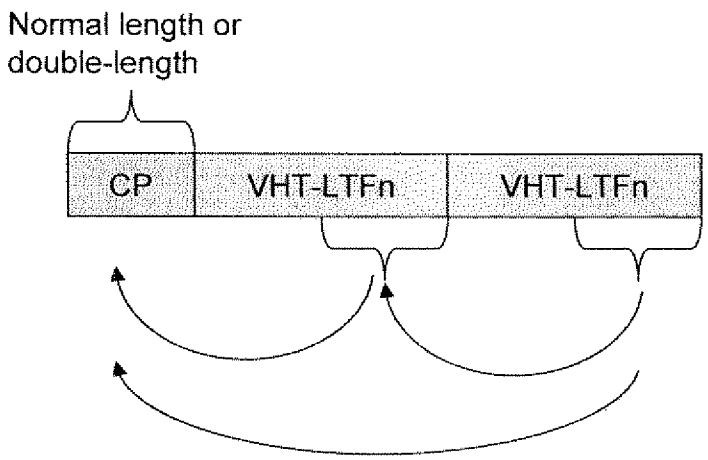
Extension-4

- In all the previously mentioned preamble formats (Mixed Mode, Greenfield Mode and Spoofing Mode), the disclosure may also extend to cases where the VHT-STF and/or one or more VHT-LTF symbols may be repeated two or more times (for the purpose of more reliable channel estimation, frequency synchronization, and AGC refinements).
- For example, in Greenfield Mode, the VHT-STF and the first VHT-LTF symbol may be repeated two times each as shown in the following figure:



Cont'd

- **The repetition may be similar as the L-LTF in 11n [1], i.e. a single cyclic prefix (e.g. 0.8 us) or double-length cyclic prefix (1.6 us) is followed by two repetitions of OFDM symbol of VHT-(S)LTF.**



Extension-5 P Matrix

- This disclosure applies equally well to cases where the training sequences used for the VHT-STF and the VHT-LTF are defined differently from those in 11n [1].
- For example, consider the following VHT-(S)LTF : a pilot $P_{s,n}^{(k)}$ is transmitted on the k-th subcarrier for the nth training symbol at the sth spatial stream. The VHT-(S)LTF can be expressed as (expression before spatial mapping): $\mathbf{P}^{(k)}s(k)$

  where *s(k)* is the training (S)LTF symbol at the k-th subcarrier.
- The matrix $\mathbf{P}^{(k)}$ used for the kth subcarrier may be any invertible matrix that is known at both the AP and the STA.
- As one example of P matrix: the disclosure also applies to the scenario where the P vectors for different streams are interleaved in the same VHT-LTF.
- In another example of P matrix: in the case repeated VHT(S)LTF as in Ext4, columns of P matrix is repeated x times if x-time repetetion is applied.

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Extension-6 VHT-SIG Fields (Contd.)

- Downlink SDMA/OFDMA [3][4][5] are concepts that may find acceptance in the VHT (802.11ac) standard.
- The disclosure also covers cases where the VHT-SIG field contains subfield(s) that indicate whether the packet is part of an SDMA/OFDMA transmission (i.e. in one subspace of SDMA [3][4], or in one subband of OFDMA[5]).
- In the case of SDMA/OFDMA transmission, all of the intended receivers should hold their respective CCAs till the end of transmission, and should not send ACK packets till then. Since the packets to the different receivers may have different lengths, the CCA should be held high till the end of the longest packet.
  - The transmitter may indicate the duration of the longest in the LENGTH field of the L-SIG in MM, or in the VHT-SIG in Greenfield Mode.
  - The mentioned subfield in VHT-SIG indicates the receiver that the current packet is part of SDMA or OFDMA, so the receiver should hold CCA for appropriate amount of time (e.g. according to the duration as indicated in L-SIG mode of MM, or MAC protection is applied to signal the receiver the true length of the SDMA/OFDMA packet.)

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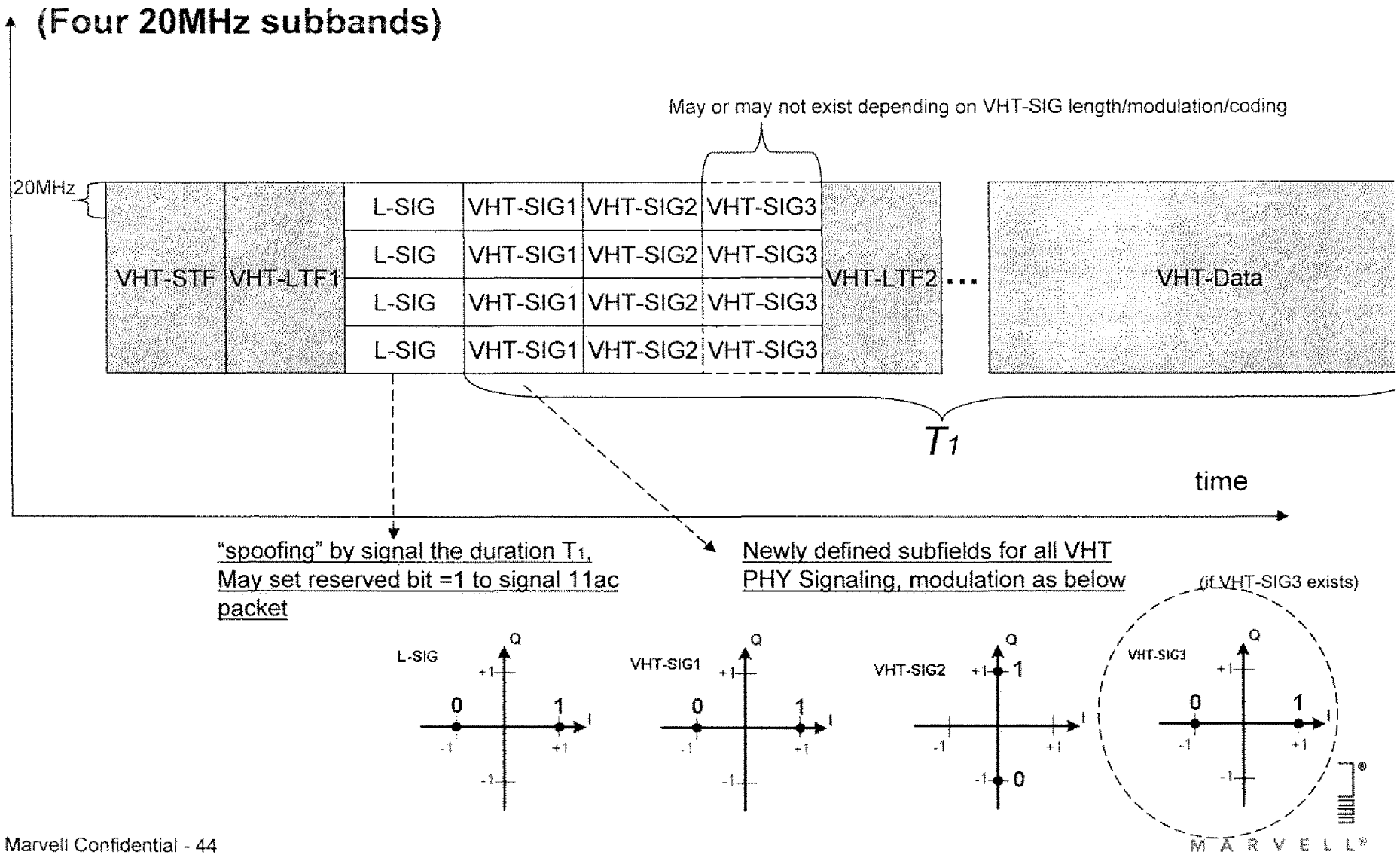
Extension-7 Backward Compatible Short Preamble Design (short-MM)

- Compared with MM preamble in [1], the 11ac preamble may be made shorter, but still backward compatible with 11a/n.
  - The idea is to implement a GF-like preamble as above, but with L-SIG field inserted before VHT-SIG fields.
  - The spatial mapping approach of L-SIG here is in the same way as VHT-SIG field (e.g. the single stream L-SIG is mapped to the N_{TX} Tx antennas by the matrix QP_1, where Q is the spatial mapping matrix applied in VHT data, and P_1 is the first column of the P matrix as introduced above or as in [1]), and the modulation/coding of L-SIG is the same as the SIG field of 802.11a—so the receiver can use VHT-LTF1 as the channel estimation to demodulate the L-SIG field, as it does on demodulating VHT-SIG field for the GF preamble above.
  - 11ac may discard GF preamble, and only apply this type of short-MM preamble.
  - Example see next slides, the modulation and number of OFDM symbols of VHT-SIG fields, and the format/length of VHT(S)LTF field may not be constrained to this example, could be replaced by any variation that listed above in this disclosure.

example of short-MM



Cont'd

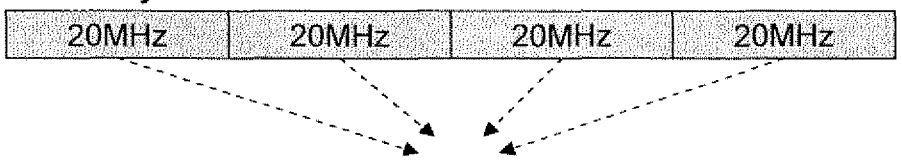
- In the previous slide, if the reserved bit in L-SIG is used for signaling 11ac (11ac autodetection), then the modulation of VHT-SIG2 is not important, could be either BPSK or QBPSK, and 11ac receiver doesn't need to autodetect 11ac by looking at constellation of VHT-SIG2.

Cont'd—changes on the VHT-LTS

- In this type of preamble, if the LTS symbol setting in 80MHz/40MHz follows the same rule as in 11n [1], i.e. duplicate 20MHz L-LTS symbols in each 20MHz subband and fill in non-zero values in the original legacy "DC/Guard tones" in each subband of L-LTS, then the receiver, when decoding L-SIG and VHT-SIG in one or more 20MHz subbands as receiving a 11a legacy signal of rate 6Mbps (the way the SIG fields are defined), will see worse channel estimation quality at tones around "DC" and "Guard band" in each subband, due to the non-zero values in "DC/Guard tones" at VHT-LTF1, in particular the non-zero "DC" may be more problematic.

- To improve the detection of SIG fields, we may keep zero values at the "DC" tones and/or "Guard" tones in each of the subbands of the LTS symbols in each of the VHT-LTF fields, and also not to transmit data in these tones in the Data field (VHT portion).
  - Doing this SIG field decoding quality may be improved, and the penalty is lower data rate, but we can still get the benefit of short Mixed mode preamble compared with the other options.

80MHz VHT-LTFs or Data OFDM Symbols:



Zeros at the four "DC" tones in the four 20MHz subbands

Extension 8: VHT-SIG Placements

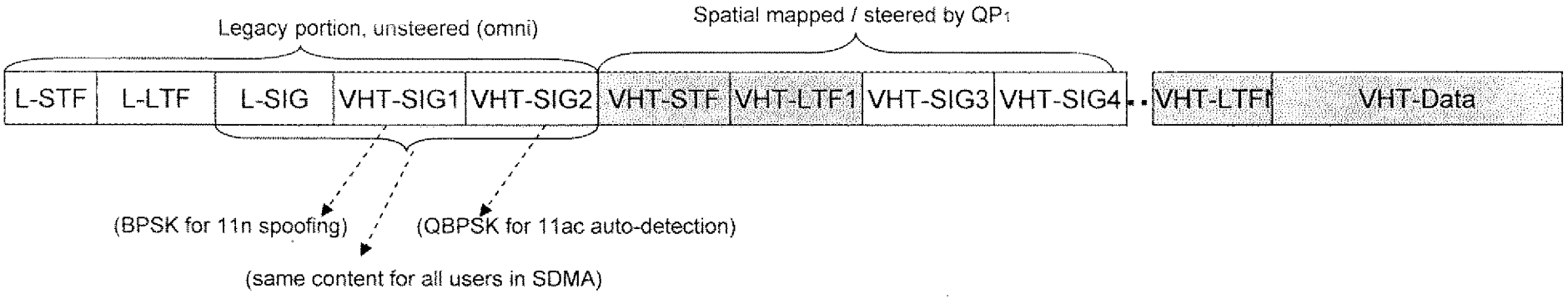
- Conforming to all the above mentioned preamble structures, one or more VHT-SIG symbols may be placed after any VHT-LTF. (VHT-LTF1, or VHT-LTF2, ...VHT-LTFN.
  - Need Signaling VHT-LTF length by other VHT-SIG field(s) that is placed after L-SIG in MM, or after VHT-LTF1 in GF. Or these VHT-SIG symbols may be defined as to be always after VHT-LTF1
  - If it is after VHT-LTFn, then it should be spatially mapped the same way as VHT-LTFn (e.g. by vector QP_n) so it may use the channel estimation from VHT-LTFn to decode.

- Either in MM or GF formats.

- The benefit is that this case allows SDMA downlink transmission to differentiate VHT-SIG fields for different users by beam-steering [3][4], while keep the legacy portion of MM packet unsteered (so "omni-directional").

Example (1)

- In DL-SDMA example [3][4], the frame format of a MM packet for one user:

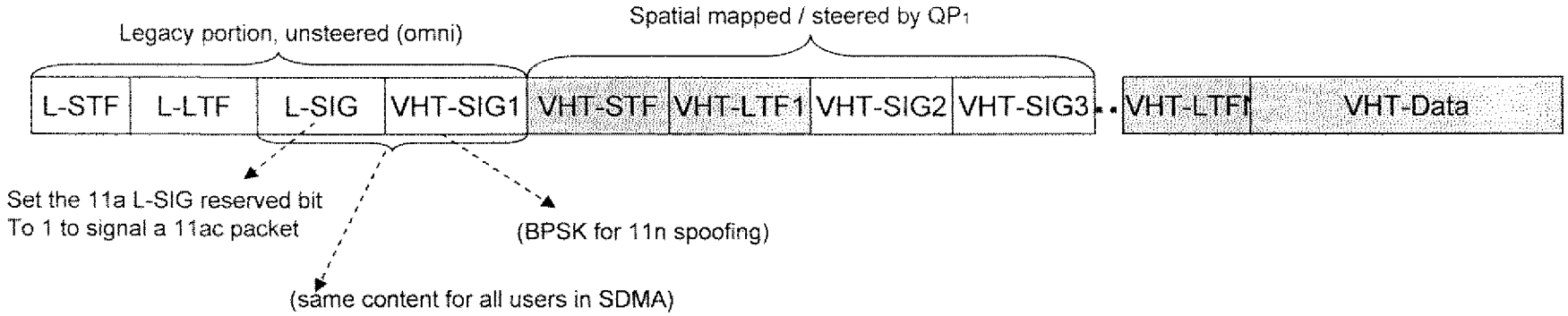


- The legacy portion (including VHT-SIG1 and 2) may have the same content for different users, so do not need to be steered.
  - The VHT-SIG1 and VHT-SIG2 may be used to jointly signal the number of VHT-LTFs or the number of VHT-LTFs before the next block of VHT-SIG for all the SDMA users.
  - Content of VHT-SIG1,2 here may be repetition of L-SIG, or any other value.
  - Or VHT-SIG1 and VHT-SIG2 may be any symbol that delivers any common information to all the users (e.g. common MAC information delivered from AP to all the users).
  - VHT-SIG1 and VHT-SIG may be modulated using BPSK or QBPSK, with r=1/2 BCC code, which is the same as L-SIG or HT-SIG of [1], so they serves the purpose of legacy device spoofing or 11ac packet type auto-detection (the same way as mentioned in all the previous designs).

- The content of the second VHT-SIG block (VHT-SIG3,4 in this example) could be different for different users, but may be multiplexed by the steering matrix Q for different users.

Example (2)

- In DL-SDMA example [3][4], the frame format of a MM packet for one user may also be:



- Similar as example 1, except one symbol shorter before VHT-STF.
  - 11n spoofing is again achieved by BPSK modulation in VHT-SIG1.
  - Content of VHT-SIG1 here may be repetition of L-SIG, or any other value.
  - 11ac auto-detection is achieved by setting the reserved bit in L-SIG to 1 (11ac), or 0 (legacy 11a/n)

- Note: in these two examples, the VHT-SIG field(s) before VHT-STF may be also named as "part of VHT-STF", or "HT Spoof", or any other name.

References

[1] 802.11n Draft Standard

[2] 802.11a Standard

[3] US Patent Application No. 60/950,429, filed July 18, 2007 entitled: "Increasing WLAN Multi-User Throughout Through Simultaneous Downlink Transmission (SDT)" R. Nabar, H. Zhang, H. Lou.

[4] US Patent Application No. 61/165,249, filed March 31, 2009 entitled: "SDMA Sounding and Steering Protocol for WLAN", H. Zhang, H. Lou, R. Nabar, Y. Liu

[5] US Patent Application No. 61/162,780, filed March 24, 2009 entitled: "Simple OFDMA with Block Tone Assignment for WLAN" H. Zhang, R. Nabar, H. Lou