

OFDMA Numerology and Structure

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Outline

- Part-I
 - Motivation and background
 - Granularity of OFDMA resource units
 - Methodology
 - The proposed OFDMA resource units

- Part-II
 - Total usable tones
 - The proposed OFDMA structure and units

Motivation and Background

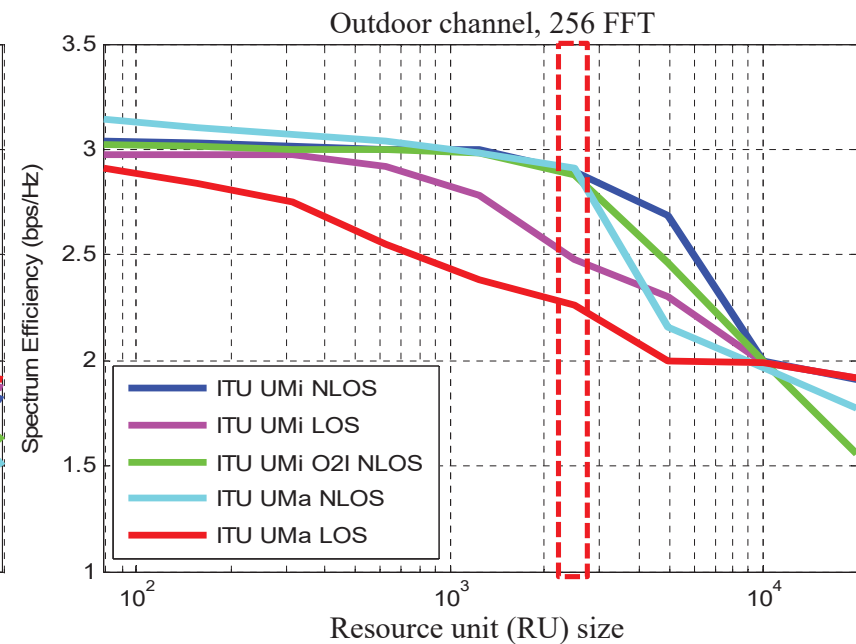
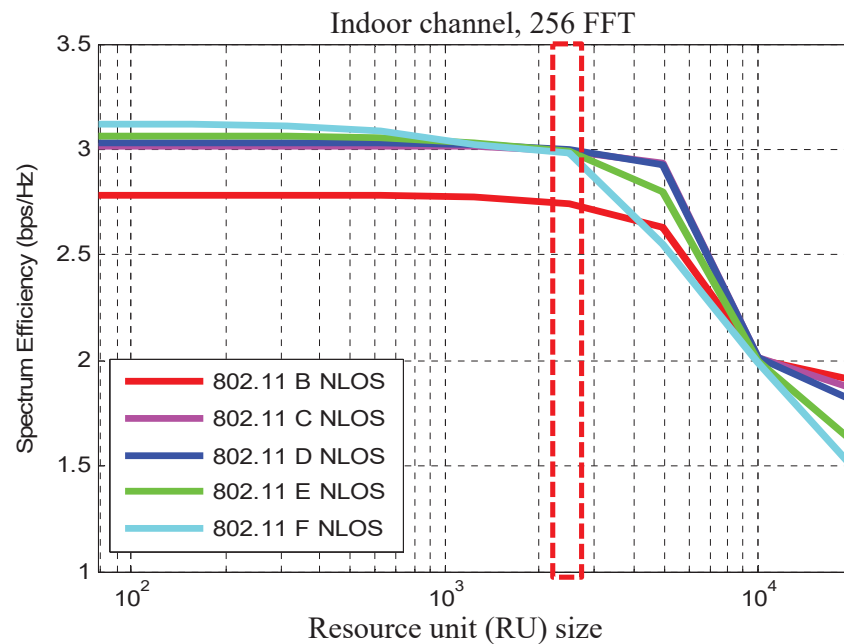
- Based on the target use cases for 802.11ax, methods to improve the PHY efficiency such as OFDMA techniques have been proposed [1-3].
 - Time and space multiplexing have already been explored, with large number of users in dense network WLAN systems need to explore multiplexing in frequency dimension
 - OFDMA can alleviate dense condition by maximizing user frequency selective multiplexing gain
 - OFDMA can extract scheduling gains/selection diversity by scheduling users not in outage
 - Scheduling is easily done at AP where channel state information is available for MU-MIMO
- Contributions to 802.11ax have demonstrated that the existence of short data frames, at a low duty cycle in the network is a major factor for capping overall system throughput because such short packets can not be aggregated, and hence system suffers from MAC inefficiency and larger preamble overhead
 - Benefits of use of OFDMA in such scenarios was shown in [4]
- The 11ax specification framework has already defined UL and DL OFDMA as one of key 11ax MU features

Discussions on the Granularity of OFDMA

- There is a tradeoff in obtaining OFDMA gain with complexity:
 - On frequency selective fading channels, smaller resource unit size provides higher gain, but at the expense of larger feedback and signaling overhead
 - The size of the smallest resource unit should be selected relative to the channel coherence BW, which is quite small especially for outdoor channels
 - The larger the number of users participating in the OFDMA scheduling the higher the gain, but this requires larger scheduling/grouping complexity
- It was agreed to use 4x OFDM symbol duration in 11ax [5,6] as follows
 - 11ax has duration 12.8 us (without CP) based on a 256 FFT in 20 MHz, 512 FFT in 40 MHz, 1024 FFT in 80 MHz/80+80 MHz and 2048 FFT in 160 MHz
 - 4x symbol duration allows better granularity for OFDMA
 - There are more number of tones in a given OFDMA bandwidth

Selection of the Smallest OFDMA Resource Unit

- Simulations are performed to evaluate the spectrum efficiency vs. selection of the smallest OFDMA resource unit
 - Evaluation assumption is provided in the Appendix-A
- It is observed that spectrum efficiency starts to go down from the point of **2.5MHz RU size**
 => The size of the smallest OFDMA resource unit needs to be smaller than 2.5MHz



Methodology (1/2)

- Simple design
 - Simple for implementation, testing, scheduling and sub-band feedback
 - Ability to create a limited number of modes and/or user assignments
- Reuse of existing design and hardware blocks of 802.11 alphabets
- Consistency
 - Consistent tone use for 2.4GHz and 5GHz bands
 - Consistent tone use for 20/40BW: easy feedback
 - And consistent with 80MHz BW
- Good packing efficiency
 - Minimize leftover tones as well as proper guard/DC tone setting depending on BWs
 - Need to resolve following problems
 - Very difficult to get 100% packing efficiency unless the resource unit is very small
 - Also inefficient to use only one small unit because number of pilots grows linearly
- Commonality between DL and UL resource unit
 - Minimize implementation, enabling a soft AP acting by a non-AP STA
 - Common design in terms of
 - Resource granularity size
 - Pilot location and portion within a resource unit
 - Pilot tone locations agnostic to BW and specific tone assignments

Methodology (2/2)

- Based on the criteria mentioned in the previous slide, the following block sizes are considered
 - Reuse 26-tone block as defined in 11ah
 - Mainly to support short/medium packets with many users
 - Reuse 52-tone or 56-tone blocks from 11a/g or 11n/ac 20MHz
 - Define a 10MHz block that would be similar to the existing 11n/ac 40MHz
 - Reuse 242-tone block as defined in 11ac
- Packing efficiency and number of leftover tones are analyzed for variety of combinations of the considered resource units on 20/40 and 80MHz bandwidth
 - The next slide proposes an OFDMA resource units that
 - maximizes reuse of existing architecture while minimizes leftover tones
 - can be extended to 40/80 and 160 MHz

The Proposed Resource Units in 20MHz BW

- The proposed resource units have the following sizes
 - 26-tone with 2 pilots
 - 52-tone with 4 pilots
 - 102 data tone plus 4 to 6 pilots
 - 242-tone with 8 pilots

Discussions on Choice of Resource Units

- The following lists the rationales behind the proposed resource units
 - The two smallest units of 26-tone and 52-tone have 2 pilots and 4 pilots, respectively, as in current 11ah 1MHz and 11a/g 20MHz with 24 data and 48 data for uniformity
 - Why picking 52-tone from 11a/g and not 56-tone from 11n/ac?
 - 52-tone allows 256 QAM rate 5/6 with BCC while as in 11ac, 256 QAM rate 5/6 cannot be used in 56-tone
 - 52-tone is a multiple of 26-tone that allows a nice alignment among OFDMA assignments
 - The third unit of has 102 data plus TBD 4 to 6 pilots. It is similar to legacy 11ac 40MHz, with a small change such as replacing Ncol=18 with Ncol=17
 - The fourth unit of 242-tone is as in 11ac 80MHz with 8 pilot tones
 - There is a logical increase in pilots $2 \Rightarrow 4 \Rightarrow (4-6) \Rightarrow 8$ with data tones

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Number of Nulls at DC (1/2)

- In 5GHz, 40ppm CFO spans ~3 tones on the left/right of DC
 - Mainly 80/160MHz operation, as well as 40 and 20MHz operation
- In 2.4GHz, 40ppm CFO spans 1 tone on the left/right of DC
 - Mainly 20MHz operation
- To avoid DC, ideally we need at least 7 nulls in 5GHz, and at least 3 nulls in 2.4GHz
- DL OFDMA
 - Rx LO Leakage + CFO is the major concern
- UL OFDMA
 - In UL OFDMA, the assumption is that STAs are required to synchronize the carrier frequency to the AP
 - If carrier frequency compensation is done in digital domain, then Tx carrier leakage (Tx DC) of each UL OFDMA transmission may not be at the center of the transmitted OFDMA waveform, potentially interfering with data tones.
 - In Uplink, carrier leaks from the received signals cannot be calibrated out by the AP receiver
 - Unknown frequencies, unknown magnitude
 - Impact could be more severe than Rx DC in DL OFDMA, especially for narrow bandwidth OFDMA assignments near DC

Number of Nulls at DC (2/2)

- Can we overcome the impact of DC offset if there is less than 7 nulls at DC?
 - Tone-erasure techniques can be implemented to overcome the impact of insufficient number of DC nulls.
 - It is observed through simulations that tone-erasure of 1, 2 or 4 tones causes only negligible performance degradations (see Appendix-B).
 - Assign leftover tones around DC to provide a better protection for OFDMA transmissions of small units
- The proposed number of Nulls at DC
 - For 20MHz, non-OFDMA has 3 DC nulls. OFDMA TBD
 - More DC tones for 20MHz may be possible, contingent on the exact number of pilot tones adopted for the “102 data + 4 to 6 pilot” tone RU
 - For 40MHz, 5 DC nulls
 - For 80MHz, OFDMA has 7 DC nulls and non-OFDMA has 5 DC nulls

Number of Guard Tones

- The payload design of 4x Symbol 20MHz is exactly 11ac 80 MHz down-clocked by 4, meaning (6,5) guard tones, 3 DC nulls, payload 234 data, 8 pilots (for the case where each user occupies the entire BW, DL/UL SU/MU-MIMO)
 - Spectral mask is 11ac 80MHz mask down-clocked by 4
 - More DC tones for 20MHz may be possible, contingent on the exact number of pilot tones adopted for the “102 data + 4 to 6 pilot” tone RU
- For 4x Symbol 40MHz bandwidth, the spectral mask is based on 11ac 80MHz mask down-clocked by 2, but with (12,11) guard tones
 - Note that we replaced (6,5)x2 with (12,11) for better symmetry in tone assignment
- For 4x Symbol 80MHz bandwidth, the spectral mask is based on 11ac 160MHz mask down-clocked by 2, but with (12,11) guard tones

Summary of Total Number of OFDMA Usable Tones

	2.4 GHz / 5GHz		
	20MHz	40 MHz	80 MHz
FFT size	256	512	1024
Edge	(6,5)	(12,11)	(12,11)
Usable tones	242	484	994

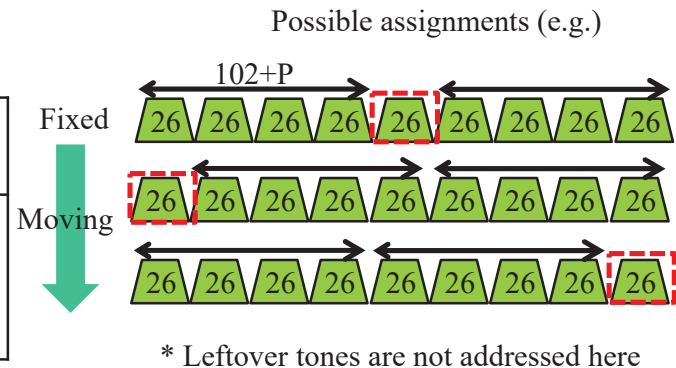
- DC Nulls
 - For 20MHz, non-OFDMA has 3 DC nulls. OFDMA TBD
 - More DC tones for 20MHz may be possible, contingent on the exact number of pilot tones adopted for the “102 data + 4 to 6 pilot” tone RU
 - For 40MHz, 5 DC nulls
 - For 80MHz, OFDMA has 7 DC nulls and non-OFDMA has 5 DC nulls
- 80MHz non-OFDMA tone plan
 - To maximize tone efficiency, non-OFDMA tone plan (SU and MU-MIMO) uses 996 with 5 DC tones
 - TBD to use 996-tone as a resource unit in 160MHz.

Analysis on location of resource units (1/3)

- We check if “moving location” for units can further improve Sub-band Selective Transmission (SST) gain by providing more available positions than “fixed position”
- Note that to help with visualizing the analysis, we have illustrated 102 data tone + TBD pilot block as 4 units of 26-tones in the pictures below

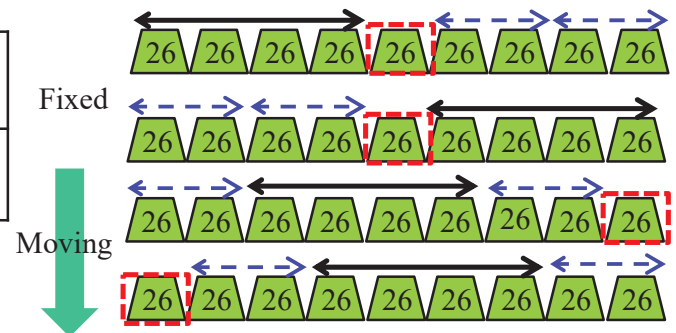
<Two 102+P (102 data + pilots) units assigned>

K (assignments)	1x26	2x26	102+P	Further improve SST gain by moving location
3	1	0	2	- Have improvement for the 1x26 unit (one position => multiple positions available) - Not much improvement for 102+P (max a 26 tone shift) units



<One 102+P unit assigned>

K	1x26	2x26	102+P	Further improve SST gain by moving location
4	1	2	1	- Have improvement for the 1x26 unit - Not much improvement for other units



* K = 5 with [1x26, 2x26, 102+P] = [3, 1, 1]

=> better than above for the 1x26 unit(3) in the fixed location

Analysis on location of resource units (2/3)

<No 102+P unit assigned>

K	1x26	2x26	102+P	Further improve SST gain by moving location
5	1	4	0	- Have improvement for the 1x26 unit - Not much improvement for 2x26 (max a 26 tone shift for having four 2x26s) units

K	1x26	2x26	102+P	Further improve SST gain by moving location
6	3	3	0	Not much improvement because of being able to have enough number of units even with fixed location

* Similar trend with

K = 6 with [1x26, 2x26, 102+P] = [5, 0, 1]

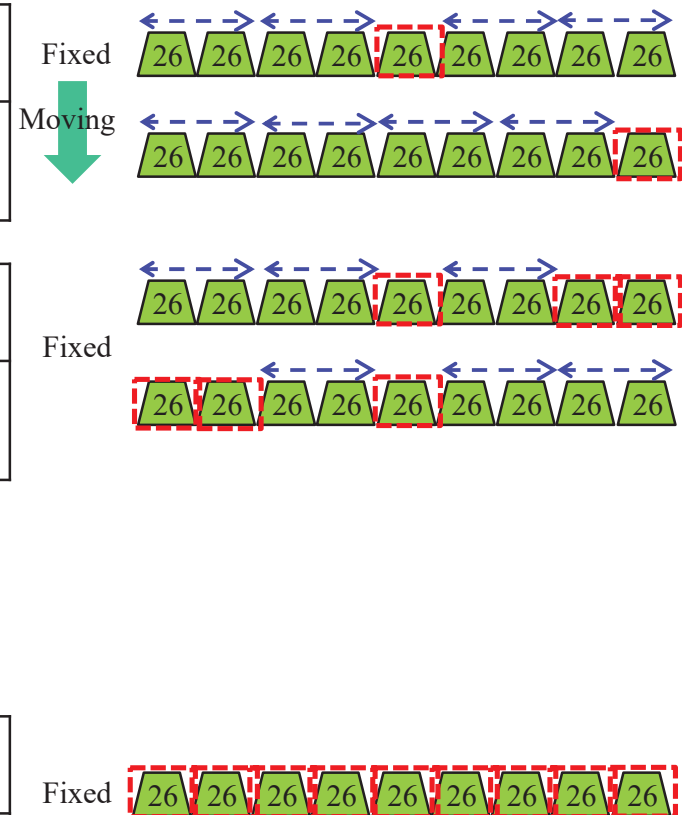
K = 7 with [1x26, 2x26, 102+P] = [5, 2, 0]

K = 8 with [1x26, 2x26, 102+P] = [7, 1, 0]

<Only 1x26 unit assigned>

K	1x26	2x26	102+P	Further improve SST gain by moving location
9	9	0	0	No gain (already able to select any 26 unit in different positions)

Possible assignments (e.g.)



Analysis on location of resource units (3/3)

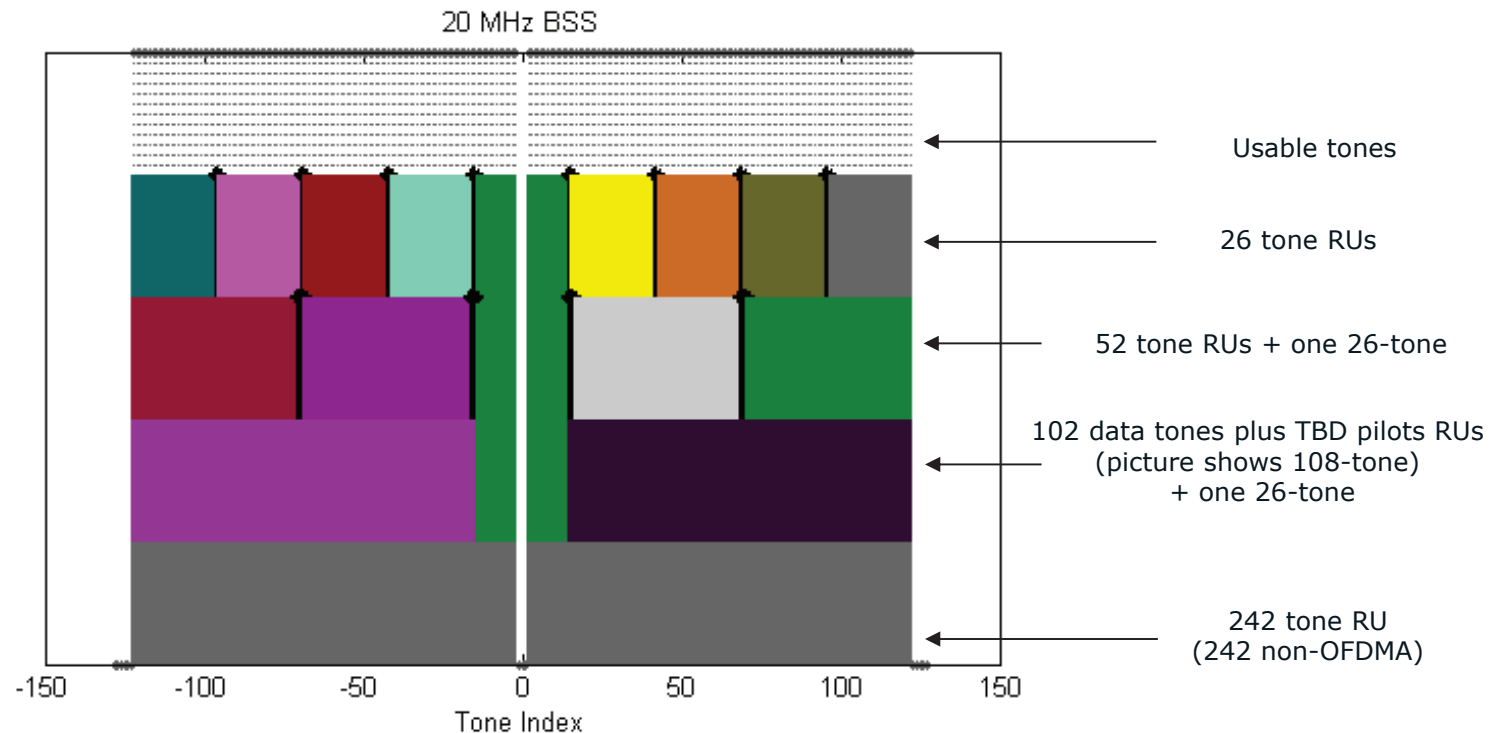
- In previous slides on checking SST gain, following is shown
 - As the number of assignments is small (requiring relatively large size of units) and a few small unit (like one 1x26) coexists with large size of units, it tends to have an opportunity to improve SST gain by moving location, otherwise the fixed location seems enough
 - But, different location of units depending on assignment would cause increase of signaling (indicate multiple combinations of position per assignment case)
- OFDMA is a technique to maximize user multiplexing gain
 - Good to multiplex as many users as possible
 - Good to multiplex traffic of similar sizes
 - For efficiency of padding, decoding time, etc.
 - The analysis showed that SST gain was limited for the case that only one 26-tone unit is assigned in the center
 - Given that target 11ax use cases have many users to schedule, the case of scheduling only one 26-tone in the center is an unlikely event.
 - SST gain also drops with multiple Tx and/or Rx antennas
 - The assumption is that the scheduler would assign units smartly to maximize OFDMA gain, and hence fixing the position of resource units is preferred
 - Reduced signaling overhead and complexity

The Proposed OFDMA Structure

- OFDMA resource units are
 - (1,2)x26-tone with 2 pilots
 - 102 data tone plus 4 to 6 pilots (exact number is TBD)
 - (1,2)x242-tone with 8 pilots
 - 996-tone
- The 20 MHz OFDMA structure uses the 26-tone, 52-tone and 102 data+ TBD pilots at fixed positions, and the non-OFDMA 242-tone
- The 40 MHz OFDMA structure is two replicas of 20MHz structure, and has the addition of non-OFDMA 2x242-tone
 - Reuse of 11ac 160MHz
- The 80MHz OFDMA structure is two replicas of 40MHz plus one central 26-tone, and has the addition of non-OFDMA 996-tone

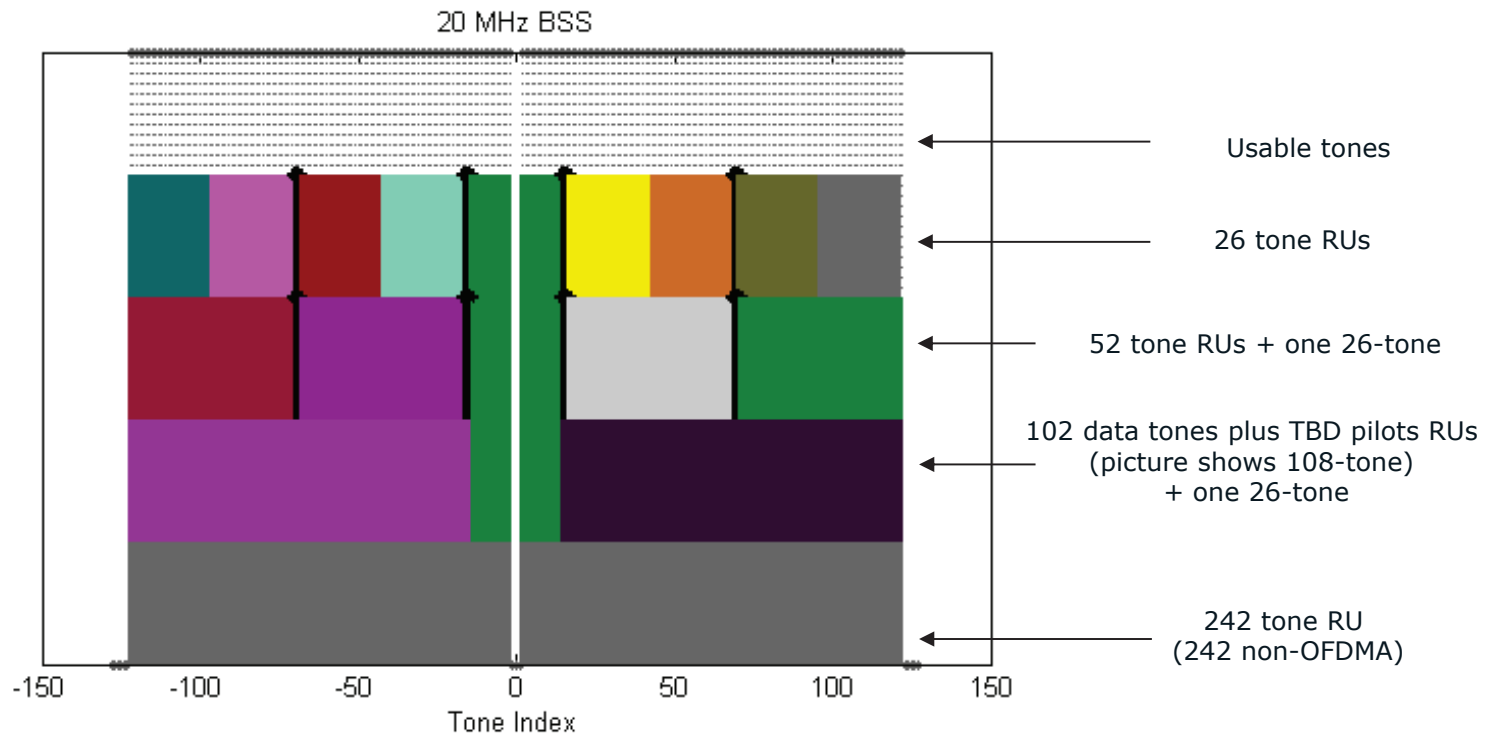
20 MHz BSS: Example 1

- Eight interlaced null subcarriers are illustrated by black arrows:
 - Exact location of leftover tones is open for discussions



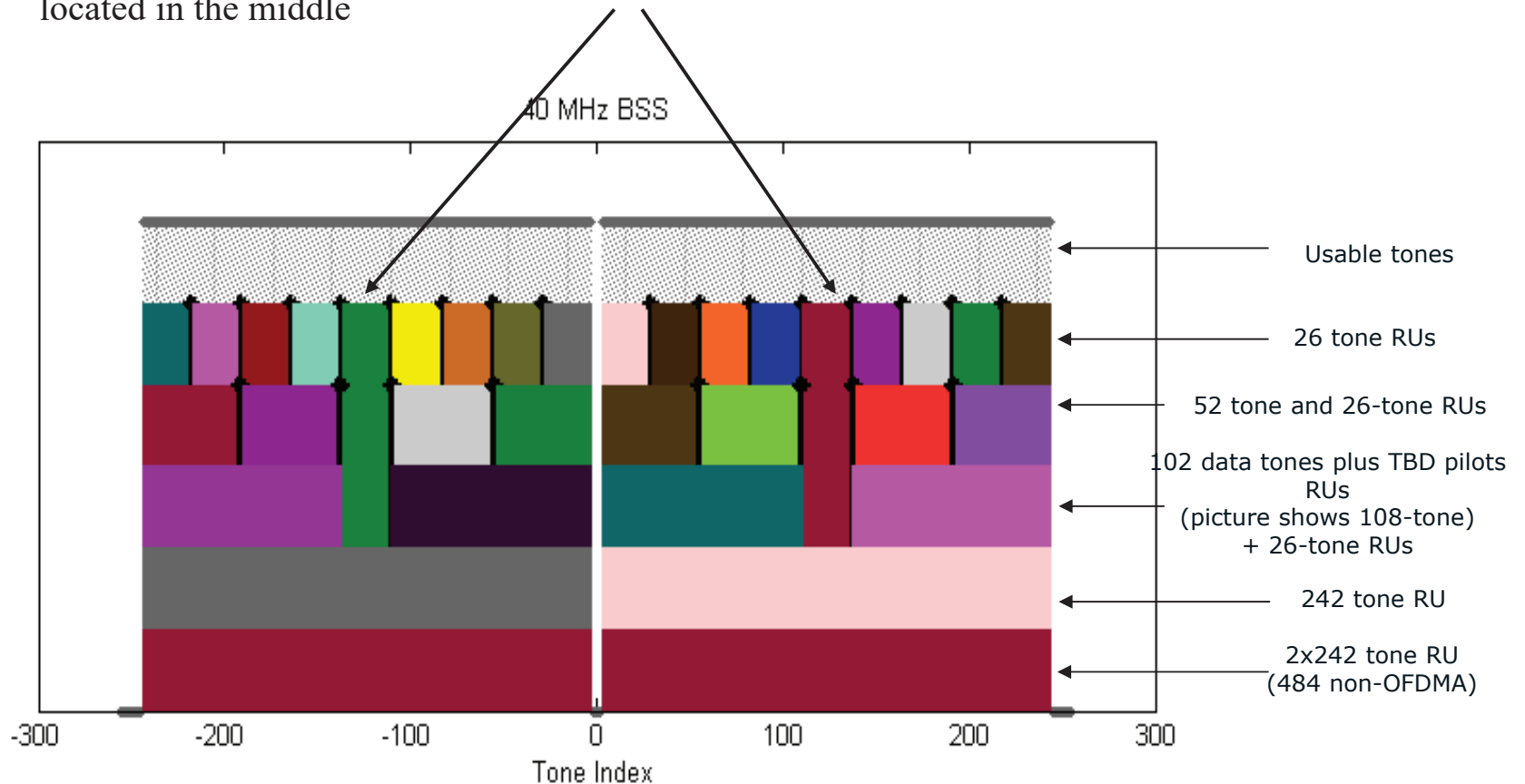
20 MHz BSS: Example 2

- Two null subcarriers are located in between pair of 26-tone units:
 - Exact location of leftover tones is open for discussions



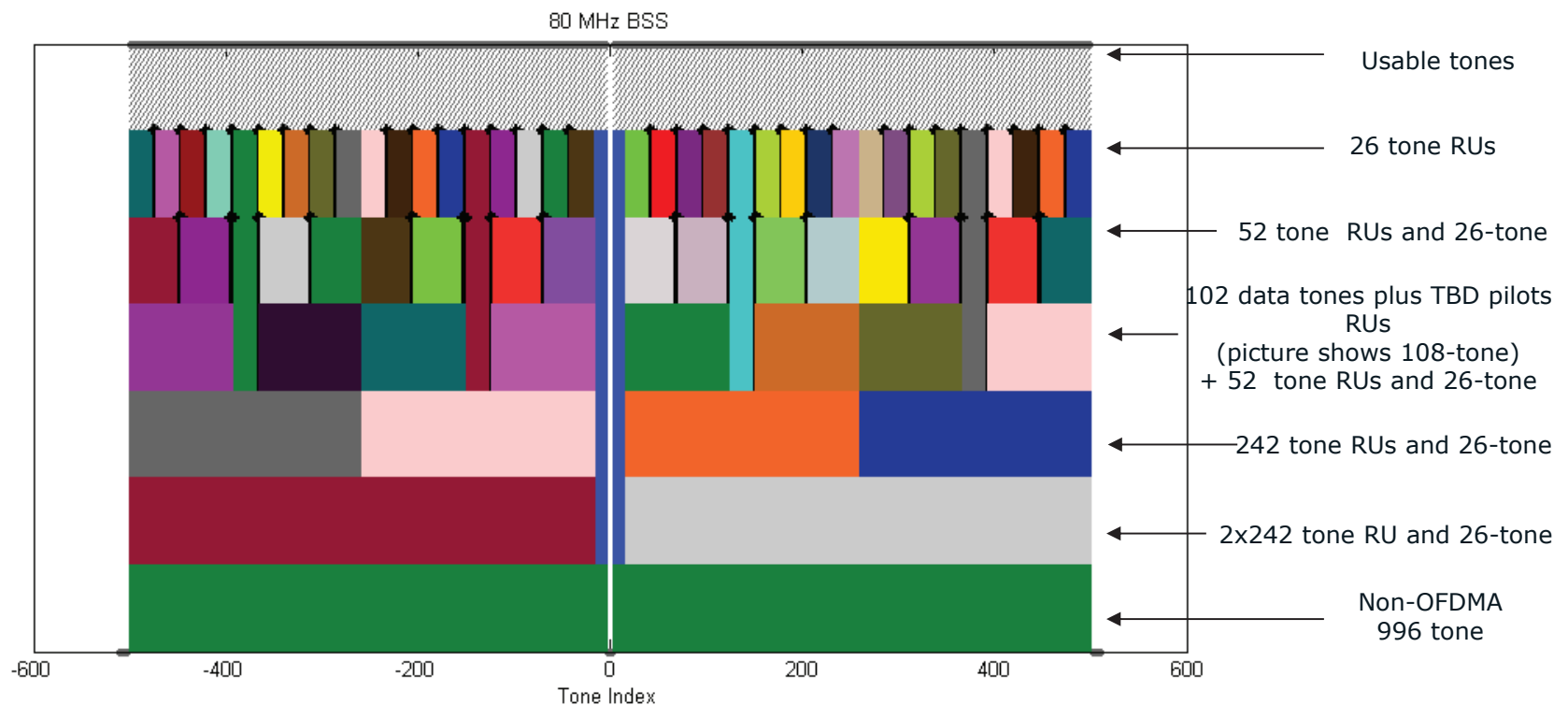
40 MHz BSS

- Duplicated 20MHz assignment
- In case of 52-tone and 108-tone resource units, there are additional 26-tone units that each is located in the middle



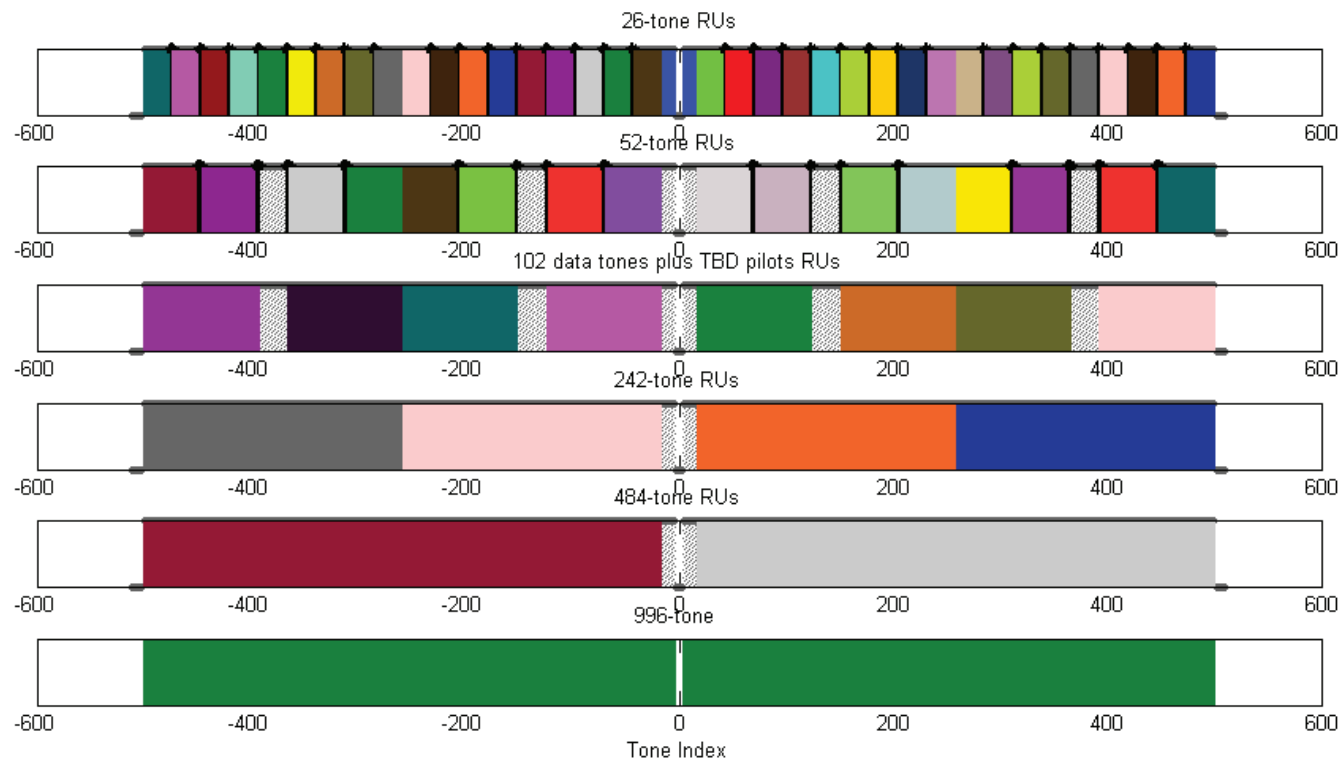
80 MHz BSS

- Duplication of 40MHz + one 26 central
- The OFDMA assignment of resource units to different users are completely aligned with 242-boundary



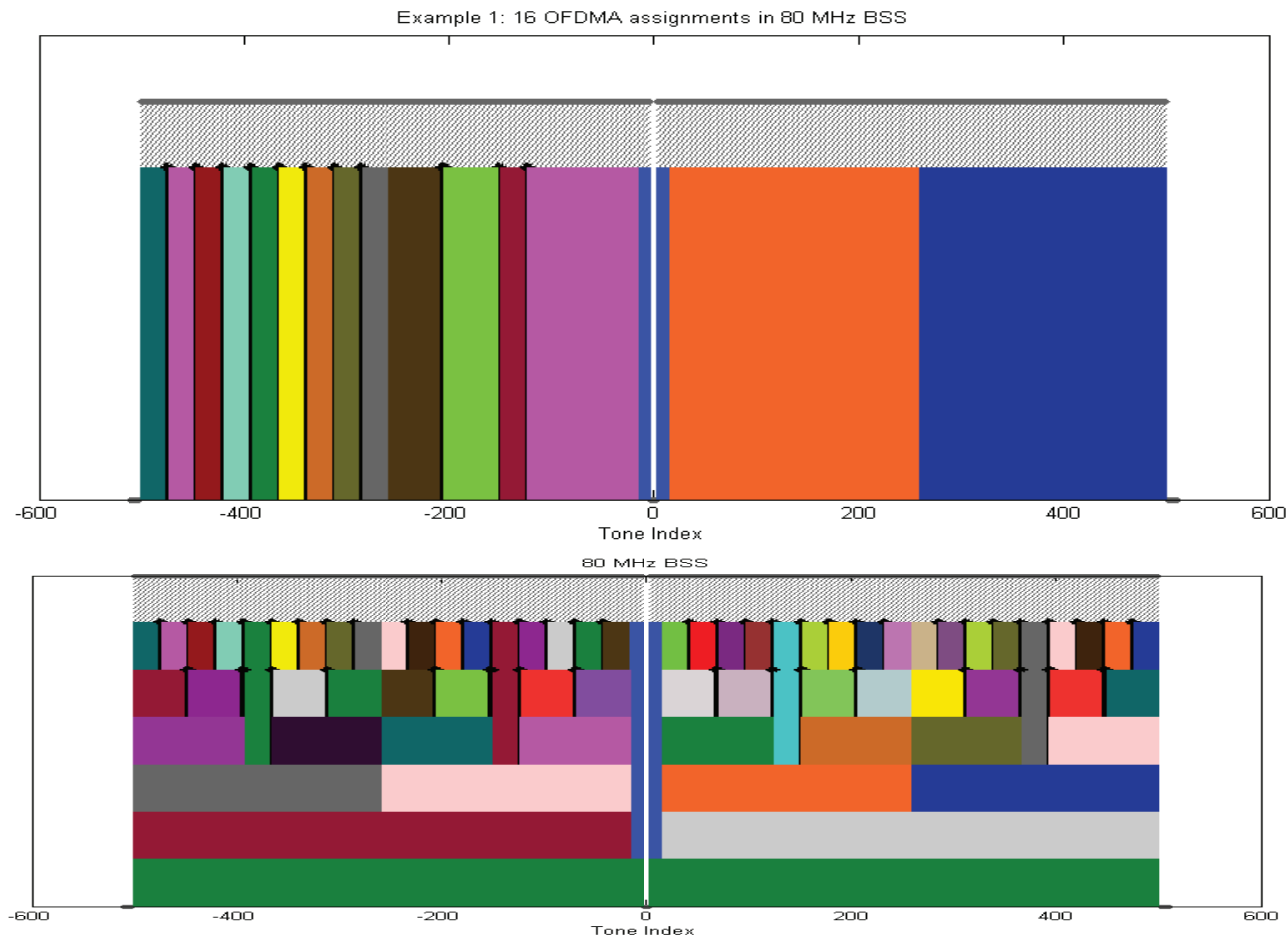
Fixed Position of Building Blocks

- The proposed resource units are at fixed positions (as shown below)
 - RUs are building blocks for the scheduler to assign them to different users



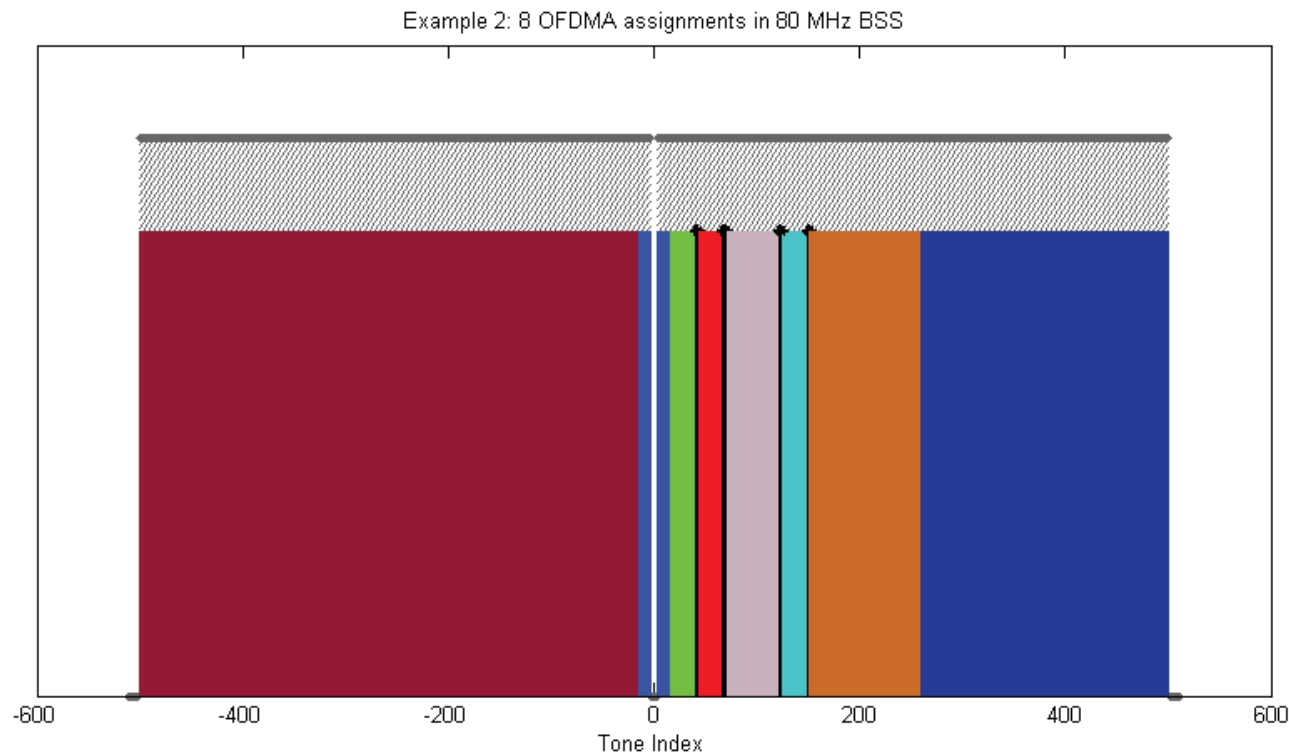
Example 1: 16 OFDMA assignments in 80MHz BSS

- The proposed resource units at fixed positions are used as building blocks for the scheduler to assign them to different users



Example 2: 8 OFDMA assignments in 80MHz BSS

- The proposed resource units at fixed positions are used as building blocks for the scheduler to assign them to different users



Straw Poll #1

Do you agree to add the following in 11ax SFD?

The tone structure of the Data field of the HE PPDU is as follows:

1. (6,5) guard tones and 3 DC tones for a 20MHz non-OFDMA PPDU
2. (6,5) guard tones and at-least 3 DC tones for 20MHz OFDMA PPDU
 - a) More DC tones may be possible, contingent on the exact number of pilot tones adopted for the “102 data + 4 to 6 pilot” tone RU
3. (12,11) guard tones and 5 DC tones for a 40MHz non-OFDMA PPDU
4. (12,11) guard tones and 5 DC tones for a 40MHz OFDMA PPDU
5. (12,11) guard tones and 5 DC tones for an 80MHz non-OFDMA PPDU
 - a) This means a total of 996 non-zero tones for 80MHz SU or MU-MIMO PPDUs
6. (12,11) guard tones and 7 DC tones for an 80MHz OFDMA PPDU
 - a) This means a total of $994 = (484+26+484)$ usable tones for an 80 MHz OFDMA PPDU

Note: The term “OFDMA PPDU” also includes the “potential” case where MU-MIMO is being done on part of the PPDU BW.

- Yes
- No
- Abstain

Straw Poll #2

Do you agree to define 20MHz, 40 MHz, and 80MHz OFDMA building blocks as follows

1. 26-tone, 52-tone and 102 data tones plus 4-6 pilot tones as defined in slide 6, and at fixed positions as shown in slides #24 (or 25), #26 and #27
 - An OFDMA PPDU can carry a mix of different tone unit sizes within each 242 tone unit boundary
2. 242-tone at fixed positions as shown in slides #26 and #27
3. 484-tone at fixed positions as shown in slide #27

Note that 40MHz OFDMA is two replicas of 20MHz, and 80MHz OFDMA is two replicas of 40MHz plus one central 26-tone. The following is TBD:

- Exact location of leftover tones within a 242 unit
- Yes
- No
- Abstain

References

- [1] 11-14-0858-01-00ax-analysis-on-frequency-sensitive-multiplexing-in-wlan-systems.pptx
- [2] 11-14-1227-02-00ax-ofdma-performance-analysis.pptx
- [3] 11-14-1452-00-00ax-frequency-selective-scheduling-in-ofdma.pptx
- [4] 11-14-0855-00-00ax-techniques-for-short-downlink-frames.pptx
- [5] 11-15-0099-03-00ax-payload-symbol-size-for-11ax.pptx
- [6] 11-15-0132-02-00ax-spec-framework.docx

Appendix-A: Evaluation assumptions (1/2)

- Evaluation setting
 - Average spectrum efficiency(SE) is used
 - 100 STAs with same large scale fading (10dB SNR)
 - 256 subcarriers for 20MHz system BW
 - Did not consider guard and pilot subcarrier for simplicity
 - Resource Unit (RU) sizes of 1/2/4/8/16/32/64/128/256 subcarriers are compared
 - DL Scheduler to maximize SE for each RU (refer the Appendix)

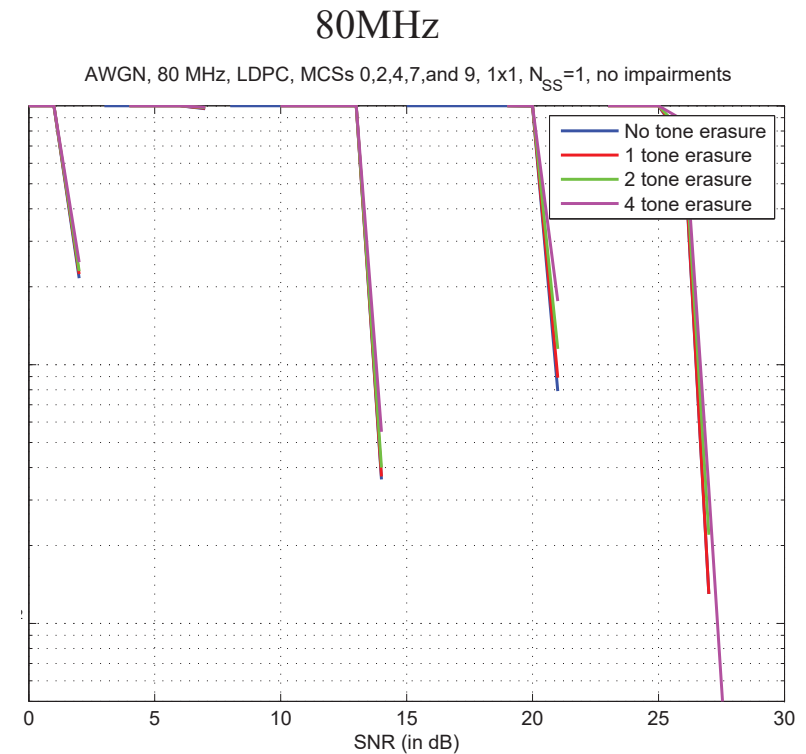
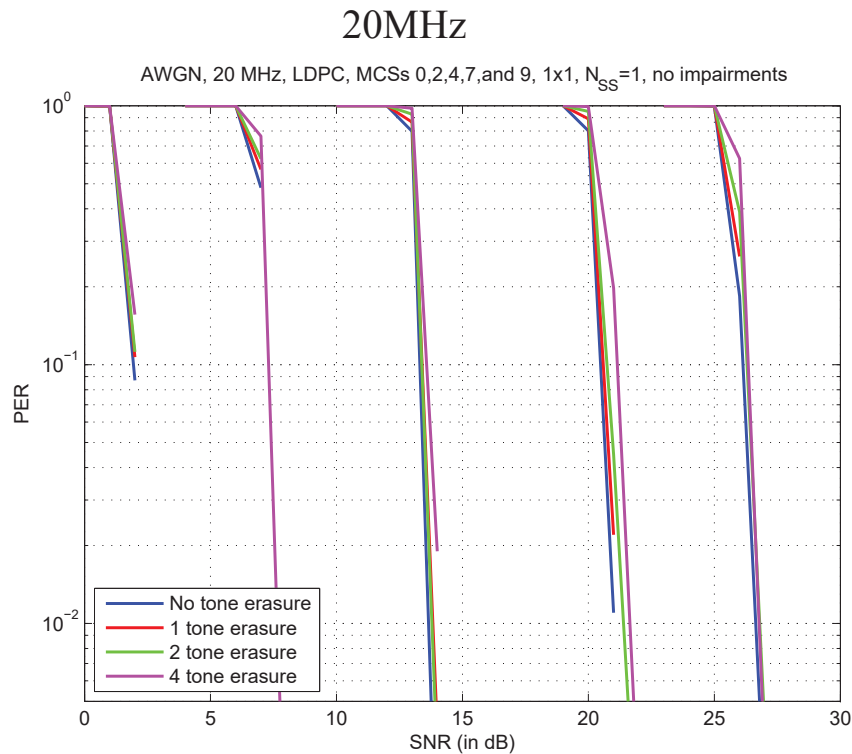
Appendix-A: Evaluation assumptions (2/2)

- Formulation on DL scheduler
 - Calculate the post-detection SINR γ_j on each OFDM subcarrier (j) considering the receiver algorithm.
 - Calculate the effective SINR (γ_{eff}), using the following equation (RBIR-based)

$$\gamma_{eff} = \alpha_1 \phi^{-1} \left(\frac{1}{J} \sum_{j=0}^{J-1} \phi \left(\frac{\gamma_j}{\alpha_2} \right) \right)$$

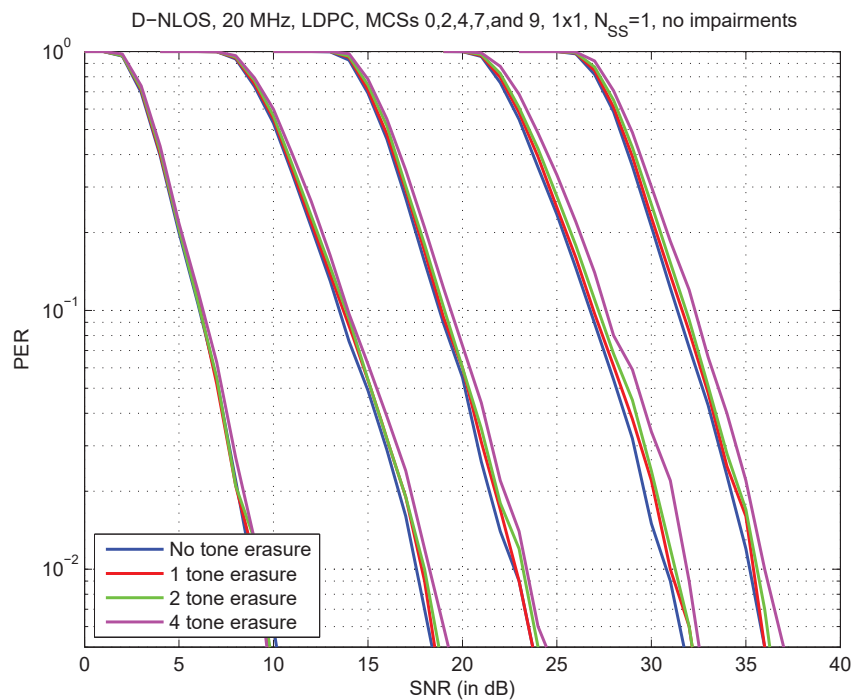
- Reference the AWGN link performance curves of different MCSs to obtain the mapping between effective SINR and PER
- Obtain each STA's max rate $rate_per_sta_{sta_idx} = \max_{mcs_idx} \left((1 - PER_{mcs_idx}) * siso_rate_{mcs_idx} \right)$
- Obtain each RU's max rate $rate_per_RU = \max_{sta_idx} (rate_per_RU_{sta_idx})$
- Obtain SE for different RU $SE = \frac{\sum rate_per_RU}{BW}$

Appendix-B: PER, Tone Erasure, AWGN

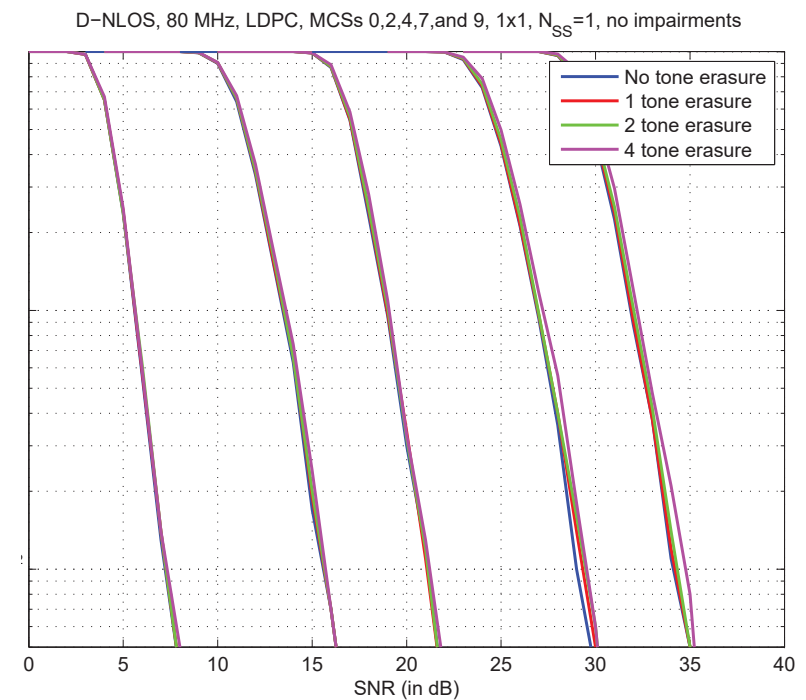


Appendix-B: PER, Tone Erasure, D-NLOS

20MHz

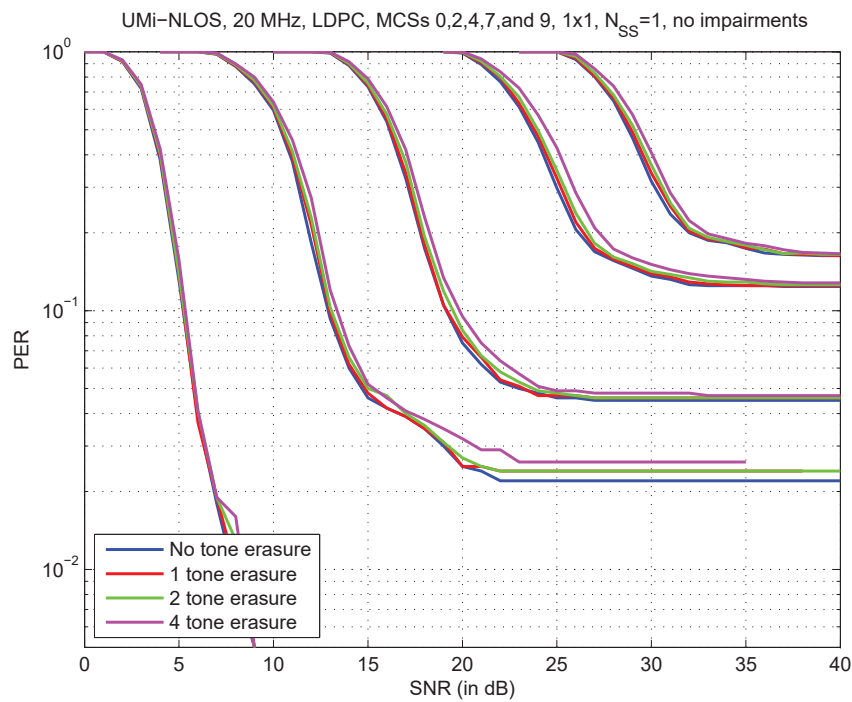


80MHz



Appendix-B: PER, Tone Erasure, UMi-NLOS

20MHz



80MHz

