3GPP TSG RAN Rel-18 workshop
Electronic Meeting, June 28 - July 2, 2021
Agenda Item: 4.2

RWS-210027

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On New Waveform Studies for Rel-18 & beyond

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Background and motivations

- Rel.16 plenary study item (TR 38.807) studies requirements for 52.6~114.25 GHz
  - Decided to go with two steps with step 1 (52.6 - 71GHz) in Rel.17, and above 71GHz in future releases

Rel.16 | Rel.17 | Rel.18+

Plenary SI

Covered in Rel.17 SI/WI

Candidate for Rel.18+ SI/WI

Region	Country	Frequency (GHz)																					
		52.6-54.25	54.25-55.78	55.78-56.9	56.9-57	57-58.2	58.2-59	59-59.3	59.3-64	64-65	65-66	66-71[1)]	71-74[2)]	74-76[2)]	76-77	77-81	81-84[2)]	84-86[2)]	86-92	92-94	94-94.1	94.1-95	95-100
ITU Region 1	Europe/CEPT					U (Mobile)							L (Fixed)				L (Fixed)			L (Fixed)	L (Fixed)		
	Israel																						
	South Africa					U (Mobile)				U (Mobile)			L (Fixed)				L (Fixed)						
ITU Region 2	USA					U (Mobile)							L (Fixed /Mobile)				L (Fixed /Mobile)			L (Fixed /Mobile)		L (Fixed /Mobile)	
	Canada					U (Mobile)							L (Fixed)				L (Fixed)						
	Brazil					U (Mobile)							L (Fixed)				L (Fixed)						
	Mexico					U (Mobile)							L (Fixed)				L (Fixed)						
ITU Region 3	China							U (Mobile)															
	Japan					U (Mobile)							L (Fixed)				L (Fixed)						
	Korea					U (Mobile)							L (Fixed)				L (Fixed)						
	India																						
	Taiwan					U (Mobile)							L(Fixed)				L (Fixed)						
	Singapore					U (Mobile)							L (Fixed)				L (Fixed)						
	Australia					U (Mobile)																	

Note 1: Access regime currently under discussion in CEPT
Note 2: Candidate frequency band for IMT identification under WRC-19 AI 1.13

Identified design considerations and requirements (TR 38.807)

- Waveform
  - Power efficiency of PA
  - Dynamic range of ADC/DAC
  - EVM and OOBE
  - Complexity and performance of waveform
  - Spectrum flexibility of waveform
  - Robustness of freq offset and PN
  - Feature reusability and design commonality
- MIMO
  - Multi-antenna tech with BF
  - Max supported layers: At least two
  - Enhanced beam management
  - Enhanced path diversity
  - Multi-cell/panel for higher reliability and mobility
- Power consumption
  - Higher power consumption due to RF:
    - Large number of beams
    - Low latency and high data rate tx/rx
    - PA efficiency loss
  - Power efficiency in baseband
- Channelization and bandwidth
  - Variant regulation and coexistence requirements
  - Support configurable bandwidth
  - Channelization under coexistence and use cases
- Range, availability, and connectivity
  - Outdoor mid/long range (backhaul or relay)
  - Short/mid range (indoor or small cell)
  - Adjacent/near field (isolated area)
- Spectrum regime
  - Licensed/unlicensed, mobile/fixed,…
- Other design considerations
  - Latency
  - Mobility support
  - Standalone and non-standalone

On the need for a new waveform

- For Rel.17 52.6-71GHz WI, no waveform change is introduced, i.e, CP-OFDM DL with CP-OFDM/DFT-s-OFDM UL, other than subcarrier spacings
  - The main reason for no fundamental waveform change is limited EIRP for operation in the band
  - Also considered faster time to market due to availability of other radio access technologies

- The 71-114.25GHz band faces more design challenges

Higher EIRP	• Regulation allows higher EIRP (up to 85dBm) for operation in the band in some regions
Even higher PN	• PN increases further as center frequency increases
Lower PA efficiency	• PA efficiency reduces as frequency increases
Complexity	• Lower complexity implementation preferred
Narrower beams	• Higher EIRP allows narrower beams to be used
Wider use cases	• The band supports both fixed deployment and mobile deployment

Areas of study for a new waveform

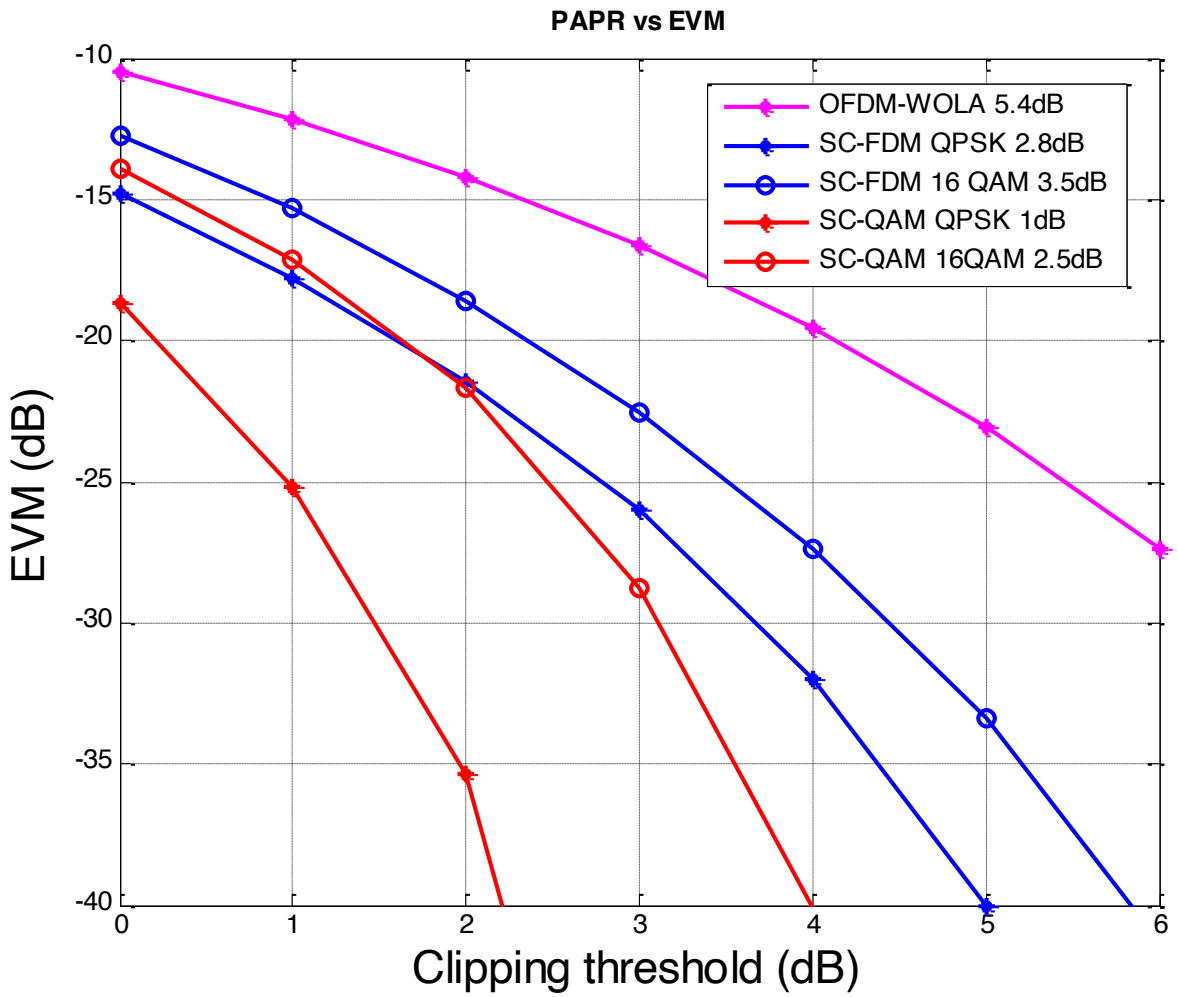
- For 71-114.25GHz band, we see stronger need for study single carrier waveform
  - Better PA efficiency and Higher achievable EIRP, with better link budget as a result
  - Possible low complexity time domain transmitter/receiver implementations
  - The waveform should be optimized for both fixed and mobile applications
  - Further consider modulation constellation choices with PAPR benefits
  - The resulting waveform can be applicable for other use cases such as NTN

Simple approach	• Introduce DFT-s-OFDM waveform for DL, similar to the DFT-s-OFDM waveform already available in UL
Complex approach	• Introduce (filtered) singe carrier waveform for both DL and UL • The filtering allows different trade-off between bandwidth growth and PAPR • SC waveform can also support low complexity transmitter/receiver implementation
Other?	• New waveform for both DL and UL

On the urgency of a study for a new waveform

- FR1 & FR2 defined during 3GPP Rel-15
- FR2 extending up to 52.6GHz
  - Spectrum still being allocated & deployed in several regions. Still room to grow!
- Performance and importance of FR2 are bound to increase
  - Deployments are just getting started and use cases and still being experimented upon
- FR2x (52.5-71GHz defined in Rel-17)
  - Further “upward” extension of the FR2 framework, which unlocks a large amount of spectrum
- Is >71GHz “important” at this stage?
  - Important that **eventually** 3GPP addresses even high spectrum ranges & it does so considering new waveform approaches
  - It is definitely **not the highest priority** task for Rel-18 for the industry
  - This project could either be postponed further or maybe commenced with a “slow start”
    - For example, start mid-release with a low time allocation
    - This would potentially remove pressure from completing any study in the Rel-18 timeframe, thus ensuring a more thorough exploration is performed

Link Budget : PAPR and EVM comparison



- Clipping threshold (PAPR) for EVM of -25dB captured in the figure legend
- SC-QAM w/ QPSK has **4.4dB** PAPR gain over OFDM
  - SC-QAM w/ 16QAM still has **2.9dB** PAPR gain
- SC-FDM w/ QPSK has **2.6dB** PAPR gain over OFDM
  - SC-FDM w/ 16QAM still has **1.9dB** PAPR gain
- Single carrier waveform helpful for providing better coverage, critical in coverage limited mmW use case
- Between SC-QAM and SC-FDM (as in LTE UL), SC-QAM has even better PAPR gain and worth considering
  - 1.8dB w/ QPSK
  - 1dB w/ 16QAM

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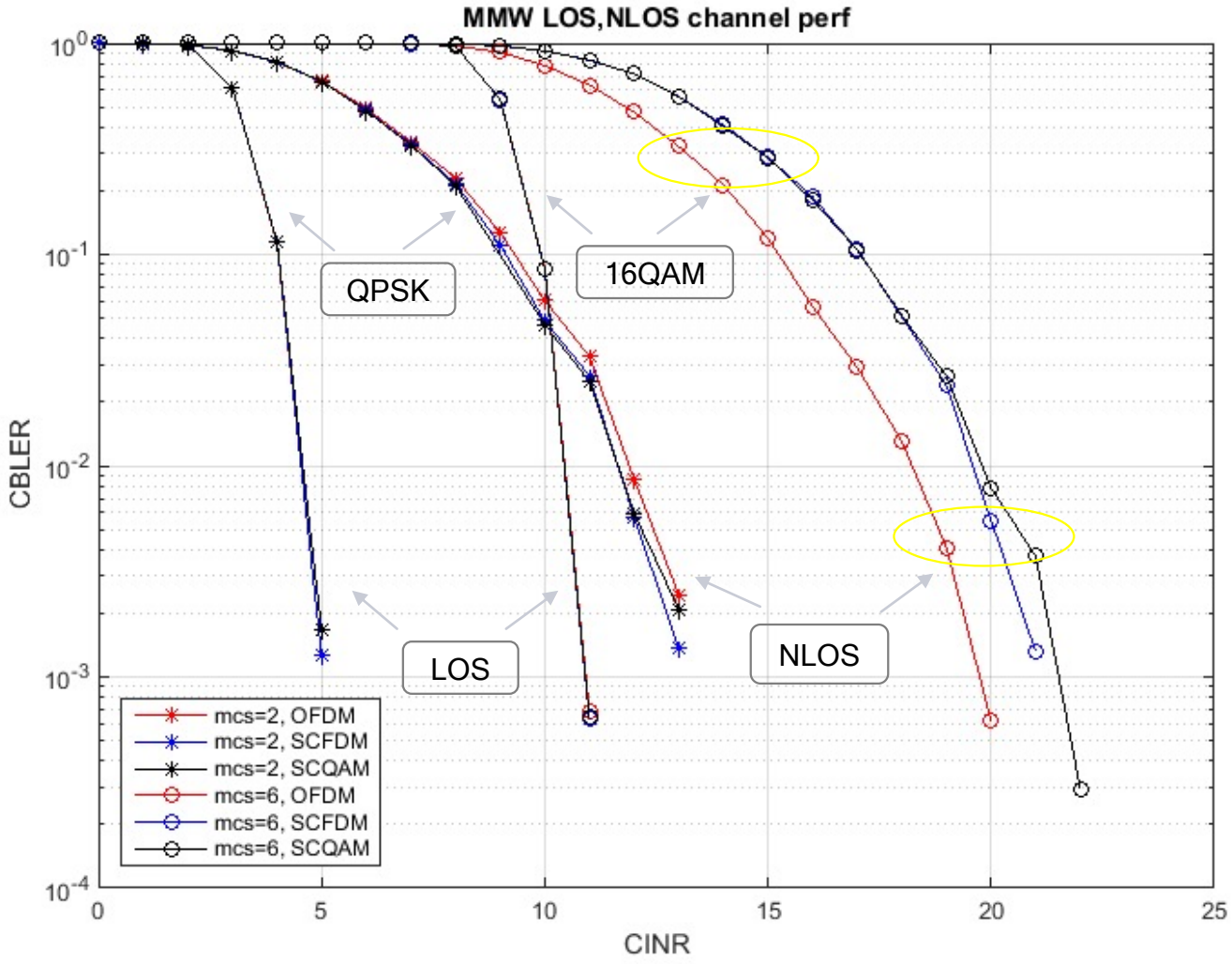
Link Budget : PDSCH Performance Comparison

Channel Models
- NLOS channel = CDL-B
- LOS Channel = CDL-D
- RMS delay = 10ns, bandwidth = 2 GHz

LOS
- All 3 waveforms on top of each other for QPSK and 16QAM

NLOS
- About 2 dB loss for 16QAM rate ¾ for SC-FDM/SC-QAM over OFDM
- All 3 waveforms on top of each other for QPSK

Conclusion for 16 QAM
- SC-QAM has between 1-3dB overall gain over OFDM for 16QAM as well.
- For SC-FDM PAPR gains are washed out for NLOS in some cases. Overall gains vary between 0-2dB



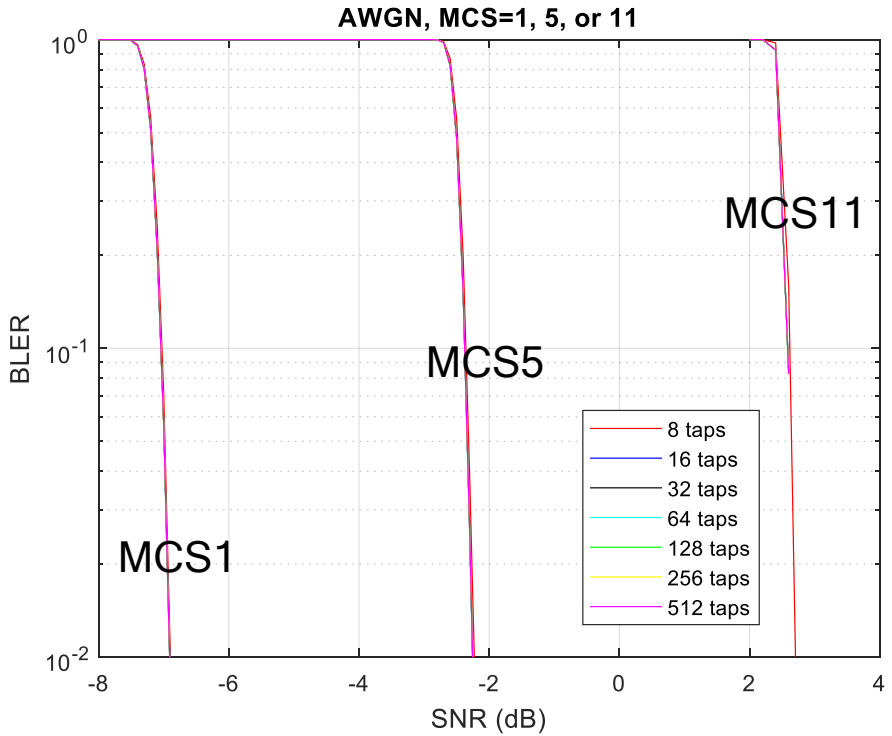
Complexity Comparison

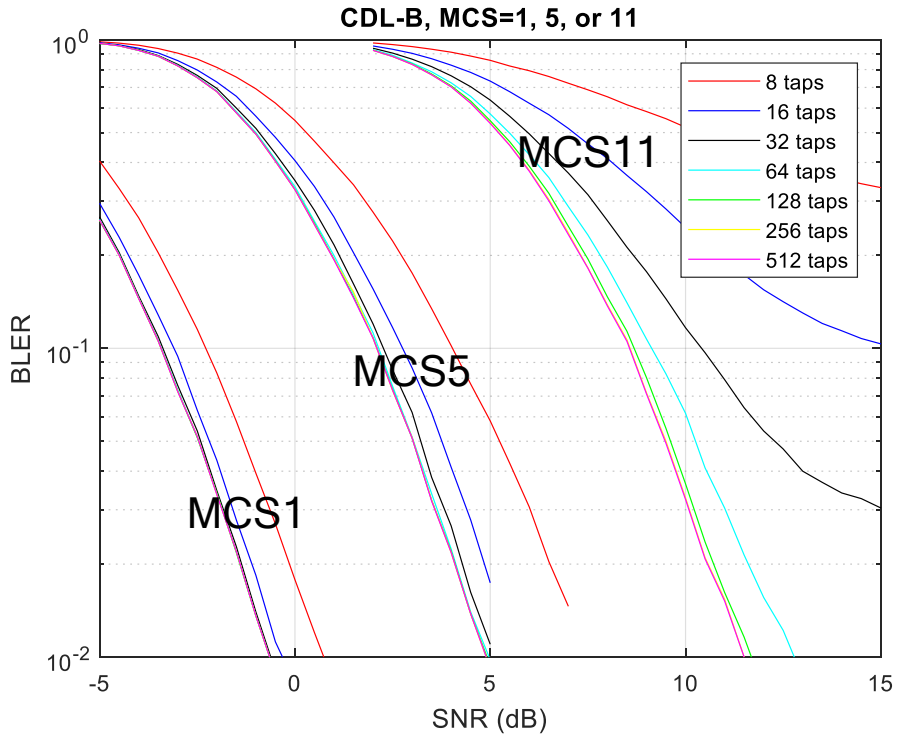
	Computation breakdown
OFDM	For K modulation symbols: • FFT of size N → $O(N \times \log_2 N)$ • Freq domain equalization over K allocated tones → $O(K)$
SC-FDM	For K modulation symbols: • FFT of size N → $O(N \times \log_2 N)$ • Freq domain equalization over K allocated tones → $O(K)$ • IDFT of size K → $O(K \times \log_2 K)$
SC-QAM	For K modulation symbols and M taps : • TDE → $O(K \times M)$
Note 1. N is up to 4096 for current NR, K depends on the allocation, M depends on the delay profile of the channel and performance loss acceptable	

- Due to the FFT/IDFT operation, the computation complexity of SC-FDM is approximately twice that of OFDM waveform (depending on the size of allocation K and IDFT implementation)
- When TDE is used and the number of taps is small, the complexity can be reduced to a similar or lower level than OFDM waveform

SC-QAM performance with TDE with different taps

AWGN vs. CDL-B channel, RRC filter 0.22, TDE w/ different # of taps





- Observations:
  - Performance improves with more taps
  - For low SNR or low MCS, the performance loss from smaller number of taps is acceptable
  - For channel with shorter delay profile, the performance loss from smaller number of taps is acceptable

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Thank you!

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