

Agenda Item: 7.1.4

Source: MediaTek Inc.

Title: On Numerology for New Radio Access Technology

Document for: Discussion

1 Introduction

In 3GPP RAN1#84bis, the following points are agreed and companies are encouraged to provide detailed analysis and input the views with an agreed table.

- For NR, it is necessary to support more than one values of subcarrier-spacing
 - Values of subcarrier-spacing are derived from a particular value of subcarrier-spacing multiplied by N where N is an integer
 - Alt.1: Subcarrier-spacing values include 15 kHz subcarrier-spacing (i.e., LTE based numerology)
 - Alt.2: Subcarrier-spacing values include 17.5 kHz subcarrier-spacing with uniform symbol duration including CP length
 - Alt.3: Subcarrier-spacing values include 17.06 kHz subcarrier-spacing with uniform symbol duration including CP length
 - Alt.4: Subcarrier-spacing values 21.33 kHz
 - Note: other alternatives are not precluded
 - FFS: exact value of a particular value and possible values of N
 - The values of possible subcarrier-spacing will be further narrowed-down in RAN1#85

This paper provides a comparison between Alt. 1 & Alt. 2 and numerology proposal together with analysis in Section 2 and summarizes proposals with the agreed table in Section 3.

2 Discussion

2.1 15KHz vs. 17.5KHz in Subcarrier Spacing

Table 1 compares detailed numerology for Alt. 1 & 2 based on our understanding.

Table 1. Detailed numerology of Alt. 1 and Alt. 2

	Alt. 1	Alt. 2
Subcarrier-spacing (KHz)	15	17.5
OFDM symbol length (μ s) (w/o CP)	66.67	57.14
CP Length (μ s)	4.69/5.21; 16.67	5.36
No. of symbols / Subframe	Not 2^m (e.g. 7 or 14)	2^m (e.g. 8 or 16)
CP Overhead	6.67%; 20%	8.57%

Comparing 15 KHz and 17.5 KHz subcarrier spacing, 17.5 KHz does enjoy advantages in uniform CP length and scalable TTI length from 2^m subframes to 2^m subframe with integer number of OFDM symbols. It is beneficial for the support of URLLC services which require very short transmission time to meet the latency requirement described in TS38.913 [1]. However, there are already a lot of solutions proposed in LTE R14 study on latency reduction to resolve the issue for 15 KHz. In addition, the issue only exists in smaller subcarrier spacing. On the contrary, there are several disadvantages for 17.5 KHz, compared to 15 KHz.

- 17.5 KHz has larger CP overhead (8.57%), compared to the normal CP in 15 KHz (6.67%).

- In 17.5 KHz, support of longer CP for services facing large channel delay spread (e.g. MBMS) requires decreasing subcarrier spacing and the maximal supported UE mobility may decrease at the same time when the subcarrier spacing decreases for longer CP. Furthermore, it also requires larger FFT size to support the same channel bandwidth. In 15 KHz, extended CP can be applied without changing the maximal supported UE mobility and FFT size to support the same channel bandwidth though it may suffer larger CP overhead (20%).
- For in-band coexistence between NR and LTE/NB-IoT, 17.5 KHz requires guard band (~10%) while 15 KHz doesn't require one if NR and LTE/NB-IoT are synchronized. Considering site sharing between NR and LTE/NB-IoT within one operator, synchronous NR and LTE/NB-IoT should be the most common case.
- Compared to 15 KHz, additional hardware complexity may be needed for 17.5 KHz to generate a sampling rate which is not an integer multiple of UTRA/LTE one by single local oscillator in NR.

Based on the above comparison, the numerology series including 15 KHz subcarrier spacing is preferred.

Proposal #1: Narrow-down numerology alternatives to the numerology series including 15 KHz subcarrier spacing.

2.2 Proposed Numerology Sets

According to **Error! Reference source not found.**, the new RAT will consider frequency range up to 100 GHz. Considering Doppler spread, phase noise and channel delay spread, it's impossible to support such large frequency range with optimized system efficiency by single numerology. Table 2 shows the candidate numerology sets for further discussion.

Table 2. Candidate numerology sets

Subcarrier-spacing	15 KHz	60 KHz	75 KHz	120 KHz	240 KHz	375 KHz
OFDM symbol length (μs) (w/o CP)	66.67	16.67	13.33	8.33	4.17	2.67
CP Length (ns)	4687	1172	938	586	293	188

Table 3. 50% coherent time of different UE mobility for 2GHz, 6GHz, 39GHz and 70GHz

Carrier Frequency UE Mobility	2 GHz	6 GHz	39 GHz	70 GHz
3 km/hr	76196 μs	25399 μs	3907 μs	2177 μs
30 km/hr	7620 μs	2540 μs	391 μs	218 μs
60 km/hr	3810 μs	1270 μs	195 μs	109 μs
120 km/hr	1905 μs	635 μs	98 μs	54 μs
350 km/hr	653 μs	218 μs	33 μs	19 μs

Table 3 shows 50% coherent time for 2GHz, 6GHz, 39GHz and 70GHz spectrums based on the Clarke's model with the

equation of $\sqrt{\frac{9}{16\pi}} \frac{C}{V \cdot f_c}$, where V is the UE mobility, C is the light speed and f_c is the carrier frequency for

different UE mobility. Since OFDM subcarrier orthogonality can be kept only if the channel within the OFDM symbol is constant, it's expected that the degree of OFDM subcarrier orthogonality in NR can be kept the same as that in LTE if the ratio of 50% coherent time over OFDM symbol length in NR is equal to or larger than that in LTE. According to the calculation, the minimal ratio in LTE is around 10, considering 350km/hr in 2GHz spectrum. In addition to Doppler spread, phase noise is another important factor to be considered, especially for mmWave spectrums [3]. To support high modulation order (e.g. 256QAM) and MIMO (e.g. 4x4 MIMO), maximal achievable SNR = 32 dB is preferred. Based on the above considerations on Doppler spread and phase noise, observations can be drawn as follows. Since 120 KHz and 375 KHz subcarrier spacing provide similar scenarios, compared to 60 KHz & 240 KHz subcarrier spacing, it's not preferable to support these two numerology sets in NR.

Observation #1: 15 KHz subcarrier spacing can support 3/30/60/120/350 km/hr in 2GHz spectrum and 3/30/60 km/hr in 6GHz spectrum, considering Doppler spread & phase noise.

Observation #2: 60 & 75 KHz subcarrier spacing can support 3/30/60/120/350 km/hr in 2/6GHz spectrum and 3/30/60 km/hr in 39GHz spectrum, considering Doppler spread & phase noise.

Observation #3: 120 KHz subcarrier spacing can support 3/30/60/120/350 km/hr in 2/6GHz spectrum and 3/30/60/120 km/hr in 39GHz spectrum, considering Doppler spread & phase noise.

Observation #4: 240 KHz subcarrier spacing can support 3/30/60/120/350 km/hr in 2/6GHz spectrum and 3/30/60/120 km/hr in 39/70GHz spectrum, considering Doppler spread & phase noise.

Observation #5: 375 KHz subcarrier spacing can support 3/30/60/120/350 km/hr in 2/6/39GHz spectrum and 3/30/60/120 km/hr in 70GHz spectrum, considering Doppler spread & phase noise.

Table 4. CDL-A RMS channel delay spread for 2/6/39/70GHz in indoor office, UMi and UMa deployments

Carrier Frequency Channel Type		2 GHz	6 GHz	39 GHz	70 GHz
Indoor Office	Nominal delay spread	38.8 ns	59.0 ns	32.1 ns	26.2 ns
	Long delay spread	66.9 ns	85.1 ns	57.8 ns	50.9 ns
UMi	Nominal delay spread	136.5 ns	117.2 ns	81.4 ns	72.1 ns
	Long delay spread	376.0 ns	410.6 ns	406.8 ns	405.6 ns
UMa	Nominal delay spread	508.5 ns	487.2 ns	332.7 ns	295.2 ns
	Long delay spread	1546.9 ns	1538.1 ns	1049.9 ns	931.8 ns

According to [4], CDL-A has the largest normalized channel RMS delay spread so it is used to verify the applicable deployment scenarios for each numerology. Table 4 shows the calculated CDL-A RMS delay spread for 2GHz, 6GHz, 39GHz and 70GHz spectrums in indoor office, UMi and UMa deployments. According to [5], optimal CP length is highly correlated to RMS channel delay spread, instead of maximal channel delay spread, and is roughly 3 times RMS channel delay spread. According to [6], RMS channel delay spread can be further reduced by half after MIMO beamforming. Based on the considerations of channel delay spread and MIMO beamforming, observations can be drawn as follows. Since 60 & 75 KHz subcarrier share similar robustness to Doppler spread and phase noise and 60 KHz subcarrier can support more channel cases, it's preferable to keep only 60 KHz subcarrier spacing for minimized number of supported numerology sets.

Observation #6: 15 KHz subcarrier spacing can support the following, considering the channel delay spread

- $\geq 90\%$ cases for indoor office, UMi and UMa in 2/6GHz spectrums with/without beamforming
- $\geq 90\%$ cases for indoor office, UMi and UMa in 39/70GHz spectrums with/without beamforming

Observation #7: 60 KHz subcarrier spacing can support the following, considering the channel delay spread

- $\geq 90\%$ cases for indoor office and $\geq 90\%$ cases for UMi in 2/6GHz spectrums without beamforming
- $\geq 90\%$ cases for indoor office, $\geq 90\%$ cases for UMi and $\geq 50\%$ cases for UMa in 2/6GHz spectrums with beamforming
- $\geq 90\%$ cases for indoor office, $\geq 90\%$ cases for UMi and $\geq 50\%$ cases for UMa in 39/70GHz spectrums with/without beamforming

Observation #8: 75 KHz subcarrier spacing can support the following, considering the channel delay spread

- $\geq 90\%$ cases for indoor office and $\geq 50\%$ cases for UMi in 2/6GHz spectrums without beamforming
- $\geq 90\%$ cases for indoor office, $\geq 90\%$ cases for UMi and $\geq 50\%$ cases for UMa in 2/6GHz spectrums with beamforming
- $\geq 90\%$ cases for indoor office, $\geq 50\%$ cases for UMi and $\geq 50\%$ cases for UMa in 39/70GHz spectrums without beamforming
- $\geq 90\%$ cases for indoor office, $\geq 90\%$ cases for UMi and $\geq 50\%$ cases for UMa in 39/70GHz spectrums with beamforming

Observation #9: 240 KHz subcarrier spacing can support the following, considering the channel delay spread

- $\geq 90\%$ cases for indoor office in 2/6GHz spectrums without beamforming
- $\geq 90\%$ cases for indoor office and $\geq 50\%$ cases for UMi in 2/6GHz spectrums with beamforming
- $\geq 90\%$ cases for indoor office and $\geq 50\%$ cases for UMi in 39/70GHz spectrums with/without beamforming

Proposal #2: The numerology sets with 15 KHz, 60 KHz and 240 KHz subcarrier spacing should be considered as potential options for further study in NR.

3 Conclusion

Proposal #1: Narrow-down numerology alternatives to the numerology series including 15 KHz subcarrier spacing.

Proposal #2: The numerology sets with 15 KHz, 60 KHz and 240 KHz subcarrier spacing should be considered potential options for further study in NR

Proposal #3: Include the numerology sets shown in the following table as potential options for further study.

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	Set 1	Set 2	Set 3
Subcarrier-spacing (KHz)	15	60	240
Component carrier bandwidth (MHz)	5/10/20/40	20/40/80/160	80/160/320/640
OFDM symbol length (μ s) (w/o CP)	66.67	16.67	4.17
CP Length (μ s)	4.69/5.21; 16.67	1.17/1.30; 4.17	0.293/0.326; 1.04
No. of symbols / Subframe	7; 6	7; 6	7; 6
Subframe length (ms)	0.5	0.125	0.03125
Frame length (ms)	10	10	10
NOTE	The system bandwidth is flexible to be any value but the supported carrier bandwidths for a UE are limited to the above values.		

4 References

- [1] TR38.913, “Study on scenarios and requirements for next generation access technologies”, 3GPP RAN.
- [2] NTT Docomo, “New SID proposal: study on new radio access technology”, RP-160671, 3GPP RAN Meeting #71, Gothenbourg, Sweden, 7-10 March 2016.
- [3] Choi, C. S., et. al., RF Impairment Models for 60GHz-Band SYS/PHY Simulation, IEEE Document 802.15-06-0477-01-003c, Nov. 2006.
- [4] TR38.900, “Study on channel model for frequency spectrum above 6GHz”, 3GPP RAN1.
- [5] Kostanic, “Effect of variable cyclic prefix length on OFDM system performance over different wireless channel models”, Universal Journal of Communications and Network 3(1): 7-14, 2015.
- [6] Theodore S. Rappaport, “Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design”, IEEE Transactions on Communications, Vol. 63, No. 9, September 2015.