MulteFire Technical Specification Group
May 15, 2020

Title: LS on Extending current NR operation to 71 GHz
Release: Rel-17
Study Item: MFA using NR at 60 GHz (MFA RWG), NR_ext_to_71GHz (3GPP RAN1)

Source: MulteFire Alliance Technical Specification Group (TSG)
To: 3GPP RAN1

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MulteFire Alliance (MFA) is a global organization that develops and promotes technology based upon 3GPP specifications (e.g. LTE and 5G NR) for standalone operation in unlicensed and shared spectrum. The MulteFire Alliance Technical Specification Group (TSG) has extended 3GPP Release 13 and Release 14 specifications to provide standalone capability based upon LAA and eLAA. MulteFire Alliance, while supporting 3GPP EPC, has developed a neutral host capability. Additional information about MulteFire Alliance can be found from its website: http://www.multefire.org.

Realizing the importance of large swaths of bandwidth available in the mm Wave spectrum (57 GHz to 71 GHz) for high data rate applications, MFA initiated a use case study under the Industrial Working Group (IWG) for operations in mm Wave spectrum. Based on the report of the study (TR MF 101 [1]), the Radio Working Group (RWG) initiated a study in the 2nd half of 2019, to analyse waveforms for operations in the mm Wave spectrum, starting with NR FR2 waveforms with different numerologies. The intention was to see if NR FR2 operations can be extended to 71 GHz.

MulteFire Alliance is pleased that 3GPP approved the study item of Extending NR operations to 71 GHz in Release 17. Since 3GPP is starting the study item to extend NR FR2 operation to 71 GHz, so MFA decided to stop the work in RWG and defer the remaining work to 3GPP. MulteFire Alliance would like to cooperate with 3GPP by sending this LS with attached Technical Report summarizing the information and knowledge it gained over the course of its study item and hopes that this information will be useful for the 3GPP study item. MFA is looking forward to a productive collaboration with 3GPP in the future.

Best Regards,

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Technical Report

MulteFire Alliance
Radio Working Group

Study of using NR at 60 GHz (Phase 1)

(Release X)

The present document has been developed within MulteFire Alliance and may be further elaborated for the purposes of the MulteFire Alliance. The MulteFire Alliance accepts no liability for any use of this Specification.

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Foreword

This Technical Report has been produced by the MulteFire Alliance, Radio Working Group (RWG).
The contents of the present document are subject to continuing work within the RWG and may change following formal RWG approval. Should the RWG modify the contents of the present document, it will be re-released by the RWG with an identifying change of release date and an increase in version number as follows:
Version x.y.z
where:

x the first digit:

1 presented to RWG for information;

2 presented to RWG for approval;

3 or greater indicates RWG approved document under change control.

y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

This document covers regulations and waveform studies for MulteFire using NR-U at 60GHz.

1 Scope

The objective of this TR is to provide an overview of spectrum regulatory requirements and summarize the waveform studies for MulteFire support of using NR in unlicensed millimetre wave spectrum, in the 57 GHz to 71 GHz bands.

2 References

For interpretations of references, the defined rules in Section 4 of MFA TR MF.100 [1] apply.

[1] MulteFire Alliance (MFA). *Guidelines for MulteFire Specifications*. MFA TR MF.100.
[2] TR MF.101v3.3.0 (mf2019.001.12), MulteFire Alliance, IWG Report of "study on use cases of MulteFire based on NR at 60 GHz"
[3] 3GPP TR 38.807 (v16.0.0): "Study on requirements for NR beyond 52.6 GHz (Release 16)"
[4] ETSI EN 302 567 V2.1.1: European Telecommunications Standards Institute, "Multiple-Gigabit/s radio equipment operating in the 60 GHz band; HarmonisedStandard covering the essential requirements of article 3.2 of Directive 2014/53/EU." ETSI EN 302 567 V2.1.1, European Telecommunications
[5] Radio Sector of International Telecommunications Union," Multiple Gigabit Wireless Systems in frequencies around 60 GHz," Recommendation ITU-R M2003-2, Radio Sector of International Telecommunications Union, June 2018
[6] 3rd Generation Partnership Project, "Study on channel model for frequencies from 0.5 to 100 GHz (Release 15)", TR 38.901 v15.0.0, June 2018
[7] Moraitis, Nektarios, and Philip Constantinou. "Indoor channel measurements and characterization at 60 GHz for Wireless local area network applications." *IEEE Transactions on Antennas and Propagation* 52.12 (2004): 3180-3189.
[8] R1-1701823, 3GPP TSG RAN WG1 Meeting #88, Athens, Greece, 13th –17th February 2017 "Evaluation Assumptions for Phase 1 NR MIMO link level calibration"
[9] 3rd Generation Partnership Project, "Study on New Radio Access Technology Physical Layer Aspects (Release 14)," TR 38.802 v14.2.0, Sept. 2019
[10] 3rd Generation Partnership Project, "Study on new radio access technology: Radio Frequency (RF) and co-existence Aspects (Release 14)", TR 38.803 v14.2.0 (Sept. 2017)
[11] R4-163314, "Realistic power amplifier model for the New Radio evaluation", Nokia
[12] 3rd Generation Partnership Project, "NR; Physical layer proecideures for data (Release 15)," TS 38.214 v15.7.0, Sept. 2019
[13] 3rd Generation Partnership Project, "Physical channel and modulation (Release 15)", TS 38.211 v15.7.0, Sept. 2019

3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply.
An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

5G	Fifth Generation
ACIA	Alliance for Connected Industry and Automation
AP	Access Points
AR	Augmented Reality
CPE	Customer Premise Equipment
DoS	Denial of Service
DN	Distribution Network
ETSI	European Telecommunications Standards Institute
FWA	Fixed Wireless Access
IAB	Integrated Access and Backhaul
IoT	Internet of Things
LOS	Line of Sight
MF	MulteFire
MFA	MulteFire Alliance
MNO	Mobile Network Operator
mmWave	Millimeter Wave
NG	Next Generation
NR	New Radio
NR-U	New Radio in Unlicensed spectrum
QoS	Quality of Service
PoP	Point of Presence
SDO	Standard Driven Organization
SC	Small Cell
STB	Set Top Box
SUHD	Samsung Ultra High Definition
TIP	Telecom Infra Project
VR	Virtual Reality
WTTB	Wireless To The Building
WTTH	Wireless To The Home

4 Overview

In MFA#17, a study item to explore the use cases for MulteFire operation in 60 GHz using NR was approved and the Industry Working Group (IWG) was asked to provide a Technical Report (TR) to the MulteFire Board.
IWG presented TR MF.101 [1] to the Board summarizing the use cases of interest and indicating the market for MulteFire products in mm Wave spectrum which spans from 57 GHz to 71 GHz. Based on this report, TSG in MFA#20 approved the study item to analyse waveforms suitable for operation in the mm Wave spectrum and defined the mm Wave spectrum of interest as 57 GHz to 71 GHz.
The study will focus on analysing the performance of waveforms in mmWave spectrum for waveforms based on

- OFDM waveforms (starting with NR based OFDM with different numerology)
- Single carrier waveforms (starting with NR based DFT-s-OFDM)

For performance analysis, common requirements will be extracted based on the regulatory requirements of different regions of the world. Before the waveform analysis, channel models will be agreed on and then calibrated across all the participating companies.
TR will just provide the waveform performance and comparison and will not select a particular waveform suitable for mm Wave frequencies as 3GPP has started a similar study item in release 17.

5 Spectrum Regulatory Requirements

The largest swath of unlicensed spectrum is available in the mm Wave spectrum in different regions of the world and can be used for high data rate applications. Regulations for using this mm Wave spectrum for different ITU regions are summarized in 3GPP TR 38.807 [3] and shown in Figure 5-1

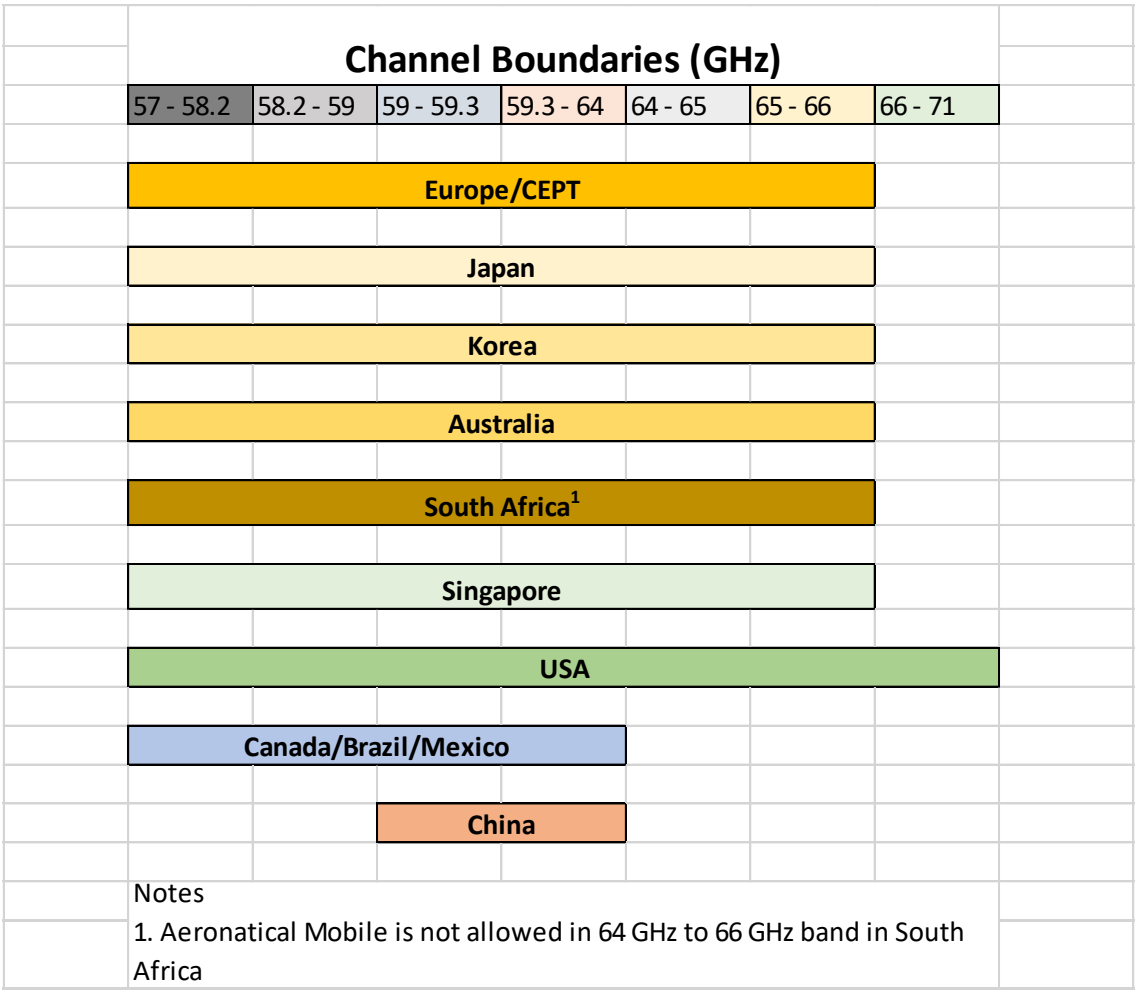


Figure 5-1 Spectrum allocation in different countries of the world [3]

Based on the regulations of different regions, waveform analysis/comparison will be performed with the following assumptions

- Max mean EIRP of 40 dBm and max EIRP spectral density of 13 dBm/MHz
- Fulfill the regulation requirement of occupied channel bandwidth of 70% to 100% of the declared nominal channel bandwidth

The transmission of unwanted emissions in the out-of-band domain shall be less than or equal to the relative limits provided in Figure 5-2 and Table 1 where $BW_{channel}$ represents the declared nominal channel BW.

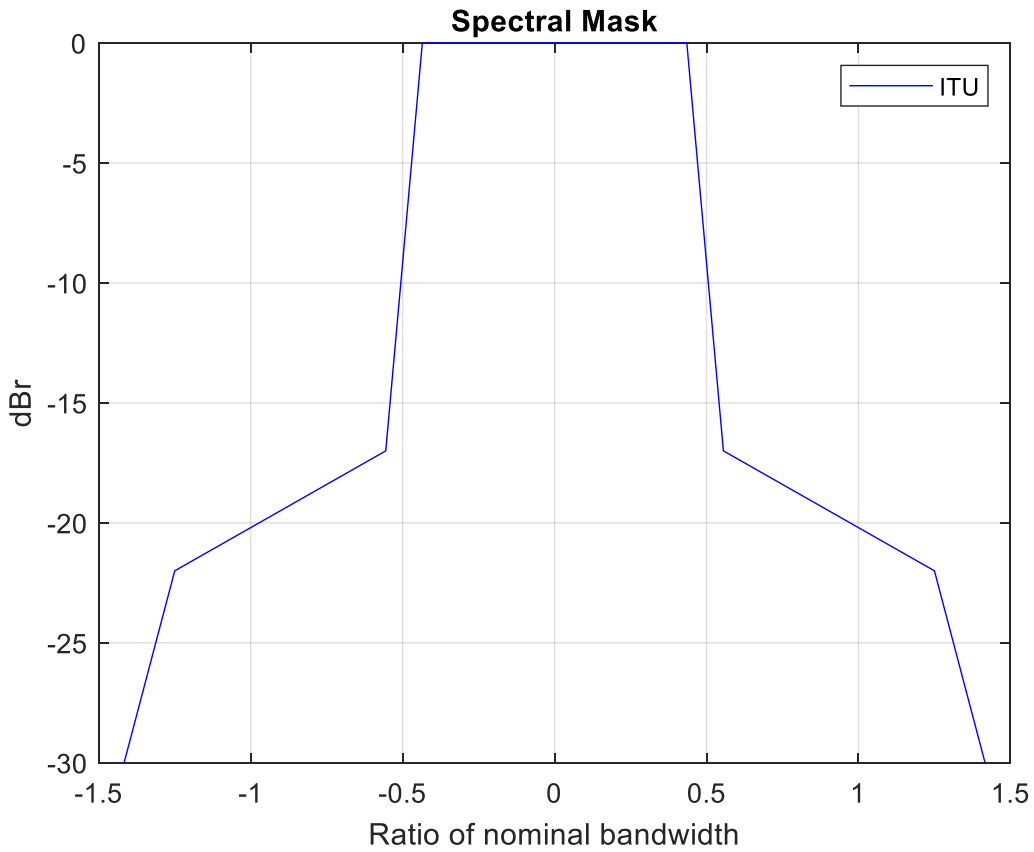


Figure 5-2 Single Channel transmission spectral mask [5]

Frequency	Relative Limit (dBr)
$-0.4752*BW_{channel} + f_c<f_c<f_c+0.4752*BW_{channel}$	0
$-0.56*BW_{channel} + f_c<f_c<f_c+0.56*BW_{channel}$	-17
$-1.25*BW_{channel} + f_c<f_c<f_c+1.25*BW_{channel}$	-22
$-1.5*BW_{channel} + f_c<f_c<f_c+1.5*BW_{channel}$	-30

Table 1 Transmit Spectral Mask Parameters

- For channelization it was decided to defer the discussion of exact channelization of 57 GHz – 71 GHz spectrum and focus first on evaluating different bandwidth options in this spectrum.

6 Bandwidth and Numerology considerations

There is 2.16 GHz of bandwidth allowed in the mm Wave spectrum (57 GHz to 71 GHz) but that makes it difficult to fulfil the regulatory requirement of 70% to 100% of occupied bandwidth especially in the uplink direction. In the RWG the agreement was made to re-use as much as possible 3GPP NR FR2 specifications. Based on these two restrictions, the following agreements were made in the RWG

- Evaluate multiple bandwidth options especially support of smaller bandwidths that will enable the fulfilment of the regulatory requirement of occupied bandwidth (which can otherwise be challenging for uplink). The following bandwidth options (in multiples of the 3GPP NR FR2 largest bandwidth) were agreed on:
    - 400 MHz, 800 MHz, 1.6 GHz and 2 GHz
- Based on the FR2 specification restriction it was decided to choose the numerologies such that maximum FFT size is limited to 4096 and the minimum FFT size is limited to 512. Based on the FFT restriction following numerologies were agreed on
    - 120 kHz, 240 kHz, 480 kHz, 960 kHz, 1.92 MHz and 3.84 MHz

Table 2 summarizes the bandwidth, numerology and FFT association for the waveform analysis.

Bandwidth	Subcarrier spacing	FFT size	Sampling Frequency GHz	Symbol Duration (without CP) (ns)	Extended CP duration (ns)	Normal CP	
						(I= 0, 7) symbol (ns)	Other Symbols (ns)
400 MHz	120 kHz	4096	0.49	8333.3	2083.3	1106.8	585.9
	240 kHz	2048	0.98	4166.7	1041.7	813.8	293.0
	480 kHz	1024	1.97	2083.3	520.8	667.3	146.5
	960 kHz	512	3.93	1041.7	260.4	594.1	73.2
800 MHz	240 kHz	4096	0.49	4166.7	1041.7	813.8	293.0
	480 kHz	2048	0.98	2083.3	520.8	667.3	146.5
	960 kHz	1024	1.97	1041.7	260.4	594.1	73.2
	1.92 MHz	512	3.93	521.8	130.2	557.5	36.6
1.6 GHz	480 kHz	4096	0.49	2083.3	520.8	667.3	146.5
	960 kHz	2048	0.98	1041.7	260.4	594.1	73.2
	1.92 MHz	1024	1.97	521.8	130.2	557.5	36.6
	3.84 MHz	512	3.93	260.4	65.1	539.1	18.3
2 GHz	960 kHz	4096	0.49	1041.7	260.4	594.1	73.2
	1.92 MHz	2048	0.98	521.8	130.2	557.5	36.6
	3.84 MHz	1024	1.97	260.4	65.1	539.1	18.3

Table 2 Bandwidth, Numerology and FFT sizes considered for waveform evaluation

- Based on Table 2 it was decided for maximum protection against ISI following CP and SCs associations to use
  - SCs = 120 kHz, 240 kHz, 480 kHz will use normal CP
  - SCs = 960 kHz, 1.92 MHz, 3.84 MHz will use Extended CP

7 Channel Model

The MFA Industrial Working Group (IWG), in its report of use cases at mm Wave spectrum, identified indoor and outdoor uses cases such as industrial IoT, mm Wave distribution networks, smart homes and V2X communications. Based on the requirements in the IWG use case report [1], the following agreements were made for channel model.

Use the channel model as defined by 3GPP TR 38.901 [3] for both link level and system level simulations. These channel models operates from 0.5 GHz to 100 GHz while the system level channel model has the support of large scale parameters like urban Micro (street canyon), indoor, backhaul and D2D/V2V that match the use cases identified by [1].

- For link level simulations use Clustered Delay Line (CDL) as the model is defined for large antenna arrays using beamforming which will be needed in the mm Wave spectrum.
- While most prevalent use cases with the use of fine beamforming and large antenna arrays will have the line of sight communications, non-line of sight communications cannot be ruled out. It was agreed to use CDL-B (non-line of sight) and CDL-D (line of sight) channel models in the link level simulations.
- 3GPP TR 38.901 [3] summarize RMS delay spread estimates for various channels. Table 3 below summarizes the delay spread for frequency and use cases that match the use cases identified in [1]. Based on the values shown in Table 3, **delay spreads of 40 ns and 100 ns will be used in link level simulations to evaluate waveforms in the 60 GHz spectrum bands**. These delay spreads represent worst case indoor and above average for urban micro cases.

Proposed Scaling Factor in $DS_{desired}$ [ns]		Frequency 60 GHz
Indoor office	Short delay profile	16
	Normal delay profile	16
	Long delay profile	38
UMi Street canyon	Short delay profile	27
	Normal delay profile	55
	Long delay profile	293

Table 3 RMS delay spread estimates for various channels [6]

8 RF Impairments

The following RF impairments will be included in the waveform analysis study item.

8.1 Phase Noise

Phase noise is a very important parameter to consider in relation to mm wave frequencies. Since different subcarrier spacings are being considered in this study item, it is important to consider the performance effect caused by phase noise. Phase noise is caused by the Local Oscillator (LO) and different antenna array transceivers can assume different architectures that may have different phase noise effects.

1. Centralized LO generation with a single PLL for all transceivers

2. Distributed LO generation with one PLL per transceiver

Centralized LO generation will give rise to more correlated phase noise and hence will cause lower performance than the distributed LO generation method. Centralized LO generation will need wider subcarrier spacings for mitigation while distributed LO generation might increase the complexity. Both these architectures and their effect are explained in 3GPP TR 38.803.
For phase noise it was decided to use the phase noise model described in example 2, section 6.1.11 in 3GPP TR 38.803. This model is reproduced below with all the parameters from 3GPP TR 38.803 [10].

$$S_{Total}(f) = \begin{cases} S_{Ref}(f) + S_{PLL}(f), & \text{when } f \leq loop\ BW \\ S_{VCO_v2}(f) + S_{VCO_v3}(f), & \text{when } f > loop\ BW \end{cases}$$

Where

$$S_{Ref/PLL/VCO_v2/VCO_v3} = PSD0 \cdot \left[\frac{1+(f/f_z)^k}{1+f^k}\right] \text{ (dB)}$$

$$PSD0 = FOM + 20\log f_c - 10\log\left(\frac{P}{1\ mW}\right) \text{ (dB)}$$

	Model 1, UE, Loop BW = 187kHz				Model 2, BS, Loop BW = 112kHz			
	REF clk	PLL	VCO V2	VCO V3	REF clk	PLL	VCO V2	VCO V3
FOM	-215	-240	-175	-130	-240	-245	-187	-130
f_z	Inf	1.00E+04	50.30E+06	Inf	Inf	1.00E+04	8.00E+06	Inf
P (mW)	10	20	20		10	20	50	
k	2	1	2	3	2	1	2	3

Table 4 Parameters for phase noise models [10]

8.2 Power Amplifier

A high amplification stage is needed to transmit large amounts of data modulated in complex waveform. At higher frequencies the efficiency of the power amplifier decreases while the output power is limited by the semi-conductor technologies. Power amplifiers need more power to transmit the signal than at lower frequencies. Power amplifiers also have nonlinear regions which cause problems that become more evident with larger bandwidths and higher order modulation schemes.
In the waveform analysis study item, it was agreed to use a simple Rapp model to study the effect of power amplifiers on the performance of waveforms in mm wave spectrum. The Rapp model that will be used is described in Appendix A of 3GPP TR 38.803 [10]. The basic equations described in [10] and values of parameters are specified in [11] are reproduced below.

1. Rapp AM-AM

$$F_{AM-AM} = \frac{Gx}{\left(1 + \left|\frac{Gx}{V_{sat}}\right|^{2P}\right)^{\frac{1}{2P}}}$$

   Where
   G = small gain in signal = 4.65 (for CMOS)
   Vsat = 0.58
   P = 0.81

2. Rapp AM-PM

$$F_{AM-PM} = \frac{Ax^q}{1 + \left(\frac{x}{B}\right)^q}$$

   Where
   A = 2560
   B = 0.114

q = 2.4

"x" is the envelope of the complex input signal. If signal measurements are available for the input/output relationship, the parameters of the model may be readily modified for a particular amplifier by for example regression techniques.

9 Simulation Work

9.1 Channel Calibration

Just like in 3GPP, a channel calibration effort was carried out in RWG to reduce the variance of results between different companies. The simulation assumptions for channel calibration are shown in Annex A. 3GPP did not perform calibration of the line of sight channel during its channel calibration effort in Release-14; the LOS channel was calibrated for the first time in the MFA RWG work item.

A new metric of **post beamforming RMS delay spread** was added to measure the actual delay spread observed after the beamforming. This metric is very useful with large antenna arrays and beamforming. Depending on the observed post beamforming delay spread the performance results of different companies with wider subcarrier spacings will vary. Companies observing larger delay spreads after beamforming will see effect of ISI with larger subcarrier spacings. As a result, the RWG group agreed to add this metric for the channel calibration efforts, to better understand the results of different companies. Annex A1 summarizes the simulation assumptions for channel calibration, as well as the channel calibration simulation results.

9.2 Waveform Analysis at 60 GHz

Annex B shows the simulation assumptions used for the waveform analysis. To save time it was decided to evaluate the waveforms with different numerologies in smallest bandwidth agreed (400 MHz) and largest bandwidth agreed (2 GHz). While the simulation study is still on-going, several observations can be made, as summarized in the following sections.

9.2.1 Cyclic Prefix (CP)

Wider subcarrier spacing will be helpful to mitigate the effect of phase noise in mm wave spectrum, but wider subcarrier spacings means the symbol durations and hence the CP durations will be reduced. Table 5shows the CP durations for each subcarrier spacing based on the CP duration definitions in 3GPP FR2 specifications. With regular CP durations, the protection against ISI will diminish as we increase the subcarrier spacings. The study of channels with larger delay spreads may result in performance issues if currently defined CPs in the 3GPP TS 38.211 [7] are used. It was decided by the RWG group to use extended CP durations (based on the current definitions in the 3GPP TS 38.211 [7]) for the widest sub-carrier spacings to provide extra protection against large delay spread channels. It is very evident from Table 5that if subcarrier spacings of 3.84 MHz is considered then delay spreads greater than 65 ns will require new definitions of CP durations in the 3GPP TS 38.211 [7] specification to protect against ISI.

Subcarrier Spacing (SCS)	Symbol Duration (ns)	Regular CP Duration [I=0,7] (ns)	Regular CP Duration (ns)	Extended CP Duration (ns)
120 kHz	8333.3	1106.8	585.9	2083.3
240 kHz	4166.7	813.8	293.0	1041.7
480 kHz	2083.3	667.3	146.5	520.8
960 kHz	1041.7	594.1	73.2	260.4
1.92 MHz	520.8	557.5	36.6	130.2
3.84 MHz	260.4	539.1	18.3	65.1

Table 5 Cyclic prefix (CP) duration per numerology

9.2.2 PTRS

For the waveform analysis study item a 2% overhead is assumed for PTRS to compensate for the phase noise. Annex B shows the agreement on the placement of PTRS for waveform analysis.

General observation is that PTRS as currently specified in Rel-16 may be good enough to compensate the phase noise, but some companies have shown results with a rearranged PTRS, which have resulted in the performance improvement for smaller subcarrier spacings. This was not considered by the RWG group as the MFA study item was trying to minimize the changes to 3GPP FR2 specifications.

9.2.3 DMRS

Annex B shows the agreement on the placement of DMRS for waveform analysis.

DMRS definitions need to be evaluated with realistic implementation (Channel and Noise Estimates). For very wide subcarrier spacings (3.84 MHz), the current density of DMRS (e.g. every other RE) may not be sufficient for a good interpolation result. There were mixed simulation results provided by companies, some companies claim poor performance with realistic implementation in wide sub-carrier spacings while others showing no performance loss. There is a need to closely evaluate DMRS with wider subcarrier spacings for realistic implementation with results provided by more companies.

9.2.4 SC-FDMA

Some companies have provided SC-FDMA results showing that performance even with smaller subcarrier spacings with phase noise is comparable to wider subcarrier spacings. SC-FDMA simulations were not fully evaluated, as the UL study was deferred to 3GPP.

10 Conclusions

Following are the conclusions of MFA RWG study of evaluating the performance of NR FR2 waveforms in mm wave spectrum

- Expanded numerologies with larger SCS for Rel-16 waveforms can help mitigate the phase noise impact. Results from one source indicate that phase noise impact can also be mitigated without increasing SCS by modifying reference signal design or by using SC-FDMA
- There is a need to evaluate practical implementation with the use of very wide subcarrier spacings of 1.92 MHz and above

Since 3GPP is starting the study item to extend NR FR2 operation to 71 GHz, so MFA decided to stop the work in RWG and defer the remaining work to 3GPP.

Annex A:

Simulation assumptions for link level channel model calibration

This subclause describes the link level simulation assumptions used for evaluating the channel model for calibration.

Carrier frequency	60 GHz			
Bandwidth	400 MHz		2 GHz	
Subcarrier Spacing	120 kHz	960 kHz	960 kHz	1920 kHz
Channel Model[5]	CDL-B, CDL-D (Rician K-factor = 10 dB) UE speed = 3 km/hr			
Delay spread	40 ns, 100 ns			
TXRU Mapping to Antenna Elements	One TXRU per panel per polarization			
TXRU Mapping Weights[3,4]	2D TXRU virtualization weights for each panel is the Kronecker product between vertical and horizontal weight vectors taken from DFT i.e., 2D sub-array partition model defined in TR36.897			
Criterial for Beam Selection	Select the beam pair by maximizing received signal power per beam pair. The Tx beam selection is done independently per panel Method 1: The DFT beam directly is pointing to the strongest cluster			
BS Antenna Configurations	(M,N,P,Mg,Ng)=(4,8,2,2,2); (dv,dH)=(0.5,0.5)□□□(dgv,dgH) = (2.0,4.0)□□			
BS Antenna Element Radiation Pattern	See Table A.2.1-6 in TR 38.802			
BS Array Orientation	Azimuth angle 0º, down tilt angle 110º			
UE Antenna Configurations	(M,N,P,Mg,Ng)=(2,4,2,1,2); (dv,dH)=(0.5,0.5)□□□(dgv,dgH) = (0.0,0.0)□□			
UE Array Orientation	Uniformly distributed Azimuth angle [0º, 360º]; UE panels are exactly 180º rotated in azimuth			
UE Antenna Element Radiation pattern	See Table A.2.1-8 in TR 38.802			
Metrics	Adopt the metric of CDF of receive SNR w/beamforming at SNR=0dB (element to element e.g. like SISO channel) for calibration[1,2] Adopt the metric of post beamforming RMS delay spread			
Note 1: The panel with the best receive SNR is chosen for output metric i.e. no combining is done between panels (ref. R1-1701823) Note 2: SNR reported is SNR/RE Note 3: Transmission rank of 1 is assumed				

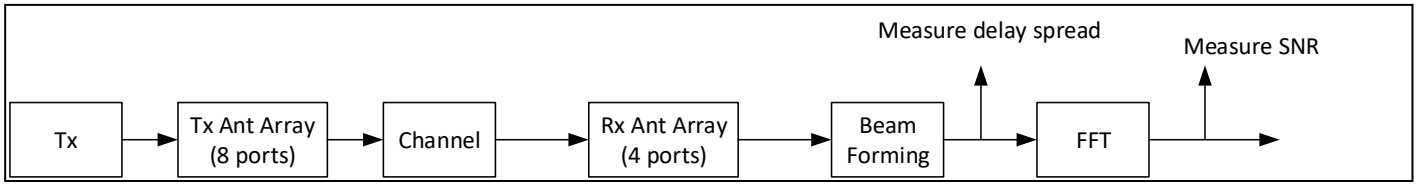
Note 4: No codebook is used

Note 5: **For NLoS channels** (i.e. CDL-A/B/C), the angles of BS, i.e., AoD, ZoD, are uniformly distributed within [-60, 60] degrees in azimuth domain and [90, 135] degrees in zenith domain, and those of UE, i.e., AoA, ZoA, are uniformly distributed within [-180, 180] degrees in azimuth domain and [45, 90] in zenith domain, via applying uniform-distribution desired mean angle in Section 7.7.5.1 in TR 38.900 accordingly.

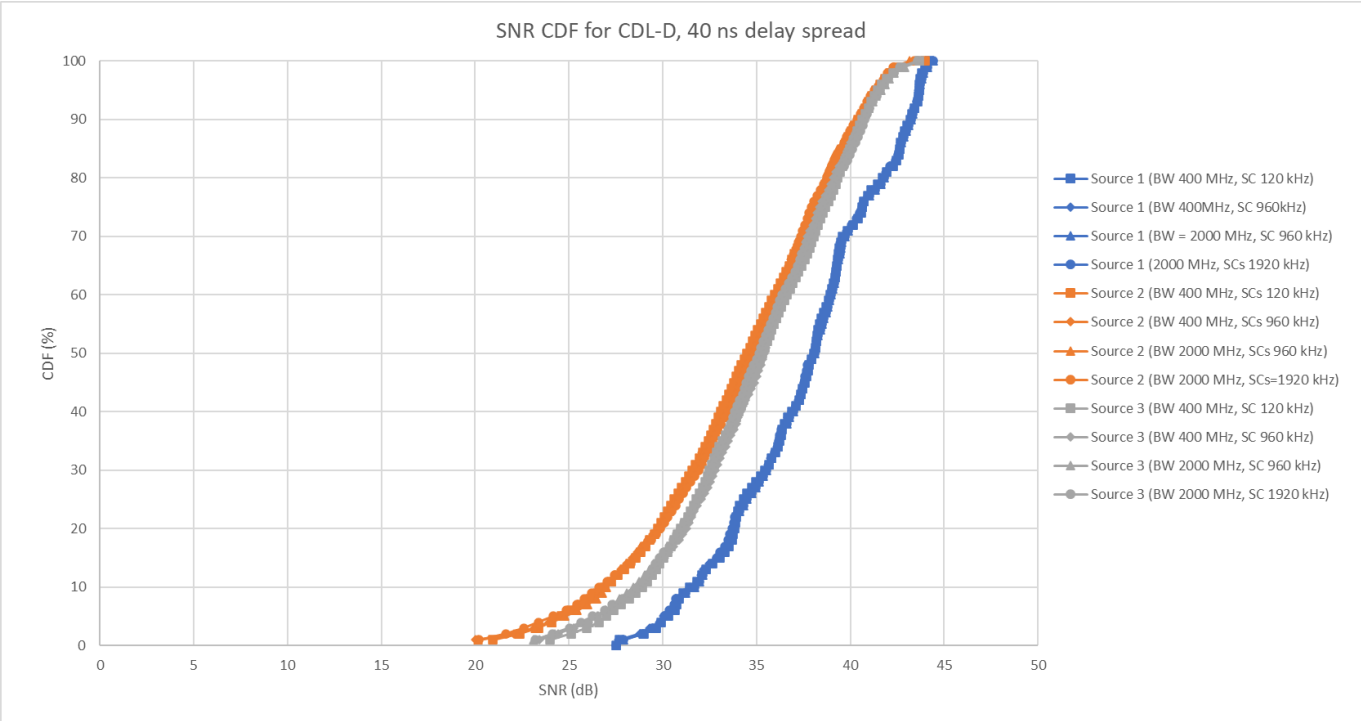
Note 6: **For LoS channel** (i.e. CDL-D and CDL-E), angles of BS i.e. AoD and ZoD, are uniformly distributed within [-60, 60] degrees in azimuth domain and [90, 135] degrees in zenith domain, and those of UE, i.e., AoA and ZoA, will be translated as negative of the offset for AoD and ZoD.

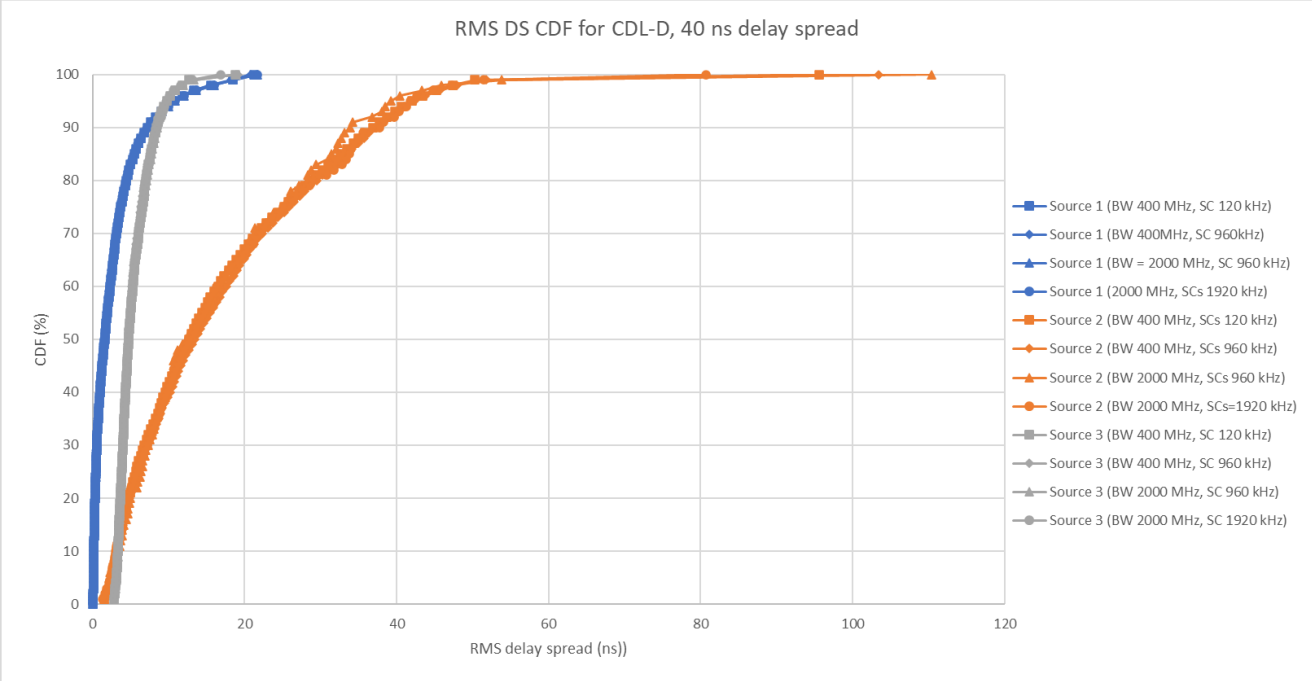
Note 7: For all NLoS and LoS channels, scaling of angular spread is not performed and is equal to 1.

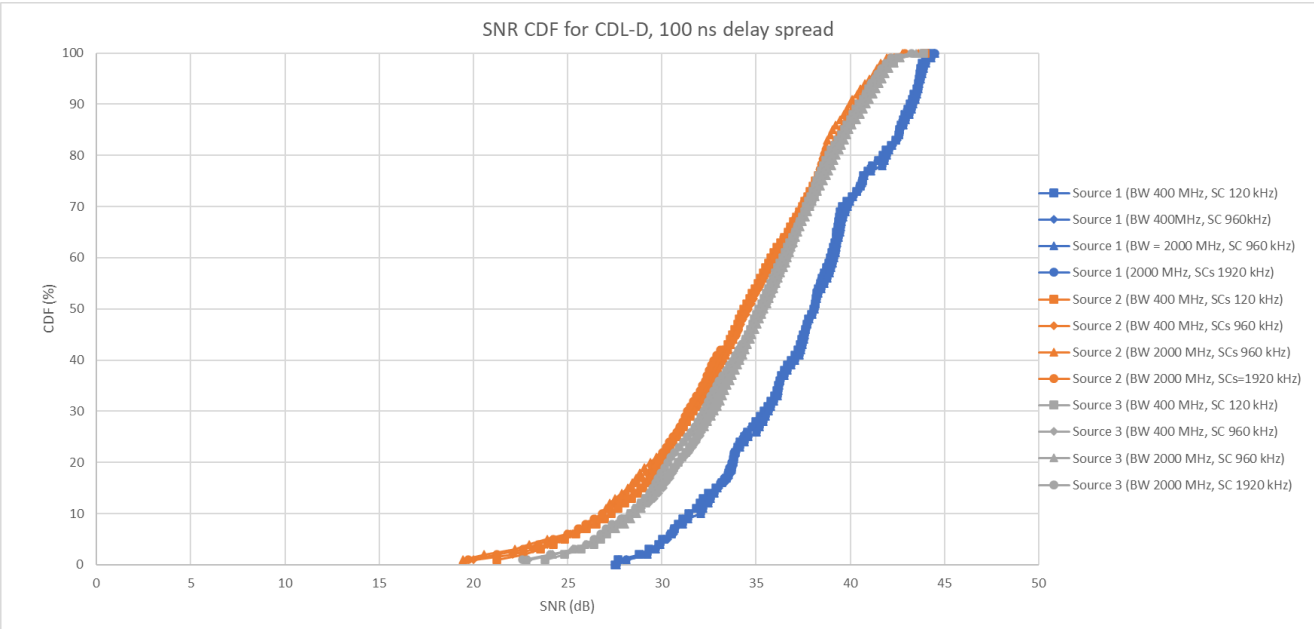
The following figure illustrates where in the transmitter and receiver chains the measurements for channel calibration are performed

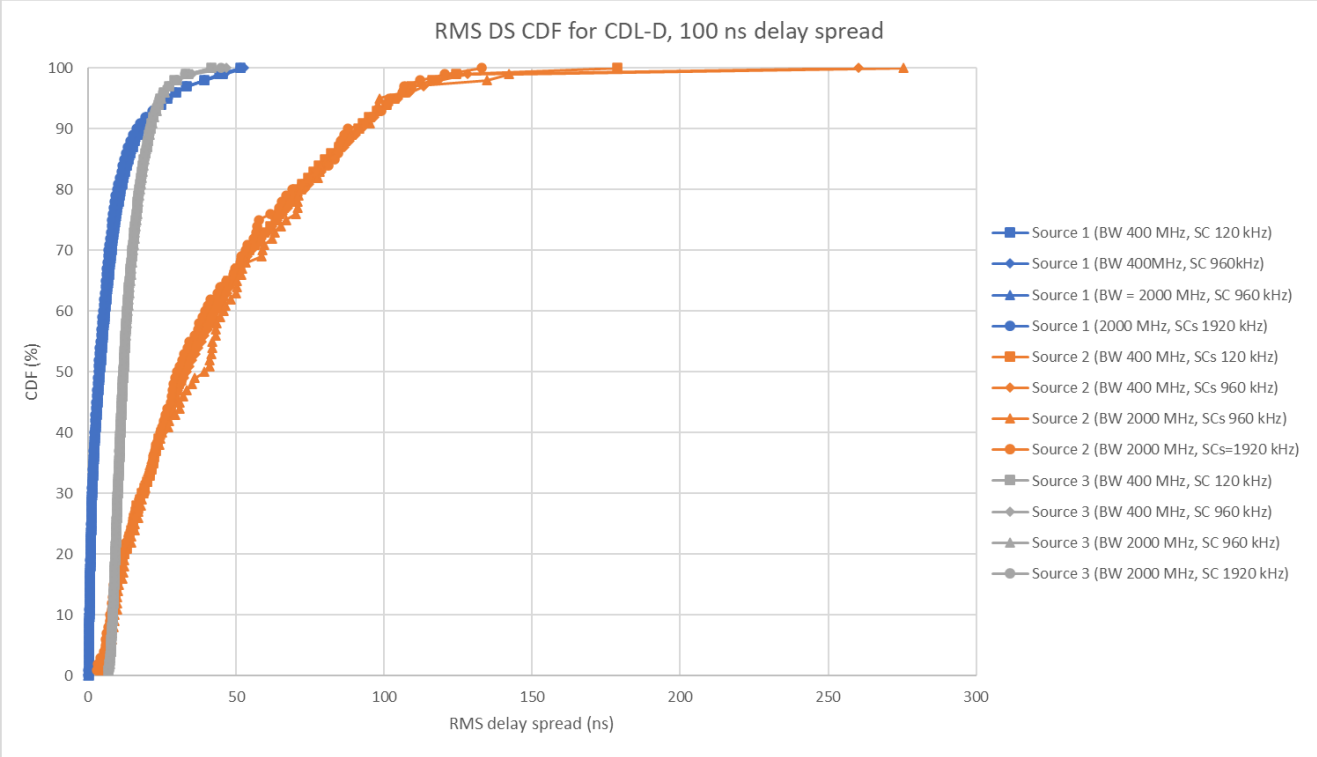


The Following CDF graphs show the contributions of different companies using CDL-D LoS channel. Only CDF graphs for CDL-D channel are shown, as the Line of Sight channel is calibrated first time in MFA RWG.




RMS DS CDF for CDL-D, 40 ns delay spread
CDF (%)
RMS delay spread (ns))
Source 1 (BW 400 MHz, SC 120 kHz)
Source 1 (BW 400MHz, SC 960kHz)
Source 1 (BW = 2000 MHz, SC 960 kHz)
Source 1 (2000 MHz, SCs 1920 kHz)
Source 2 (BW 400 MHz, SCs 120 kHz)
Source 2 (BW 400 MHz, SCs 960 kHz)
Source 2 (BW 2000 MHz, SCs 960 kHz)
Source 2 (BW 2000 MHz, SCs=1920 kHz)
Source 3 (BW 400 MHz, SC 120 kHz)
Source 3 (BW 400 MHz, SC 960 kHz)
Source 3 (BW 2000 MHz, SC 960 kHz)
Source 3 (BW 2000 MHz, SC 1920 kHz)


SNR CDF for CDL-D, 100 ns delay spread
CDF (%)
SNR (dB)
Source 1 (BW 400 MHz, SC 120 kHz)
Source 1 (BW 400MHz, SC 960kHz)
Source 1 (BW = 2000 MHz, SC 960 kHz)
Source 1 (2000 MHz, SCs 1920 kHz)
Source 2 (BW 400 MHz, SCs 120 kHz)
Source 2 (BW 400 MHz, SCs 960 kHz)
Source 2 (BW 2000 MHz, SCs 960 kHz)
Source 2 (BW 2000 MHz, SCs=1920 kHz)
Source 3 (BW 400 MHz, SC 120 kHz)
Source 3 (BW 400 MHz, SC 960 kHz)
Source 3 (BW 2000 MHz, SC 960 kHz)
Source 3 (BW 2000 MHz, SC 1920 kHz)


RMS DS CDF for CDL-D, 100 ns delay spread
CDF (%)
RMS delay spread (ns)
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
Source 1 (BW 400 MHz, SC 120 kHz)
Source 1 (BW 400MHz, SC 960kHz)
Source 1 (BW = 2000 MHz, SC 960 kHz)
Source 1 (2000 MHz, SCs 1920 kHz)
Source 2 (BW 400 MHz, SCs 120 kHz)
Source 2 (BW 400 MHz, SCs 960 kHz)
Source 2 (BW 2000 MHz, SCs 960 kHz)
Source 2 (BW 2000 MHz, SCs=1920 kHz)
Source 3 (BW 400 MHz, SC 120 kHz)
Source 3 (BW 400 MHz, SC 960 kHz)
Source 3 (BW 2000 MHz, SC 960 kHz)
Source 3 (BW 2000 MHz, SC 1920 kHz)

Annex B:

Link level simulation assumptions

This subclause describes the link level simulation assumptions used for evaluating waveform candidates.

Carrier frequency	60 GHz						
Duplexing	FDD (for simplicity)/or TDD						
Bandwidth	400 MHz				2 GHz		
Subcarrier Spacing (kHz)	120	240	480	960	960	1920	3840
CP Type	Regular	Regular	Regular	Extended	Extended	Extended	Extended
Data bandwidth	DL: 90% of system bandwidth UL: 70% of system bandwidth (according to ETSI regulations)						
BS Antenna Configurations	(M,N,P,Mg,Ng)=(4,8,2,2,2).(dv,dH)=(0.5,0.5)λ.(dgv,dgH) = (2.0,4.0)λ One TXRU per panel per polarization. DFT vector is used to map TXRU to antenna elements. Per antenna element pattern is in TR36.873_v210 table 7.1.1						
UE Antenna Configurations	(M,N,P,Mg,Ng)=(2,4,2,1,2); (dv,dH)=(0.5,0.5)λ; (dgv,dgH) = (0.0,0.0) λ. UE panels are exactly 180° rotated in azimuth						
Channel Model	CDL-B, CDL-D (Rician K-factor = 10 dB), Delay spread = 40ns, 100ns, (optional 800 ns) UE speed = 3 km/hr The angles of BS, i.e., AoD, ZoD, are uniformly distributed within [-60, 60] degrees in azimuth domain and [90, 135] degrees in zenith domain, and those of UE, i.e., AoA, ZoA, are uniformly distributed Select the beam pair by maximizing received signal power per beam pair. Method 1: The DFT beam directly is pointing to the strongest cluster						
RF impairments	Phase Noise:Example 2 as specified in TR38.803 (sec. 6.1.11.2) PA nonlinearity: Rapp model No Frequency offset modeling						
Rank per UE	1						
Channel/Noise Estimation	Ideal, Realistic						
PTRS	2% overhead (for CPE compensation) – For CP-OFDM as baseline use every 4th PRB in frequency and every OFDM symbol in time, if companies use anything else then elaborate, for SC waveforms elaborate the placement of PTRS						

DMRS	Release 15 based				
MSC (PDSCH)	Table 1 (38.214)			Table 2 (38.214) (optional)	
	QPSK	16QAM	64QAM	256QAM (optinal)	
	7	16	22	23	27
Metrics	As per agreement (BLER vs. SNR, PAPR/Cubic Metric, OOBE/ACLR, UE Complexity, Transmitter EVM, if different than agreements then report receiver waveform design and power spectral density)				

Note 1: The panel with the best receive SNR is chosen for output metric i.e. no combining is done between panels (ref. R1-1701823)

Note 2: SNR reported is SNR/RE

Note 3: Transmission rank of 1 is assumed

Note 4: No codebook is used

Note 5: **For NLoS channels** (i.e. CDL-A/B/C), the angles of BS, i.e., AoD, ZoD, are uniformly distributed within [-60, 60] degrees in azimuth domain and [90, 135] degrees in zenith domain, and those of UE, i.e., AoA, ZoA, are uniformly distributed within [-180, 180] degrees in azimuth domain and [45, 90] in zenith domain, via applying uniform-distribution desired mean angle in Section 7.7.5.1 in TR 38.900 accordingly.

Note 6: **For LoS channel** (i.e. CDL-D and CDL-E), angles of BS i.e. AoD and ZoD, are uniformly distributed within [-60, 60] degrees in azimuth domain and [90, 135] degrees in zenith domain, and those of UE, i.e., AoA and ZoA, will be translated as negative of the offset for AoD and ZoD.

Note 7: For all NLoS and LoS channels, scaling of angular spread is not performed and is equal to 1.

Annex C:

Change history

	Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**Old version**	**New version**
2019-06	MFA#21	MFA TR xxx				Skeleton for MFA TR xxx ("Study of using NR at 60 GHz (Phase1)")	-	0.0.0
2020-02	MFA#22	MFA TR.xxx				Added details of different sections based on the study item	0.0.0	0.1.0
2020-05	MFA#22.1	MFA TR.160				Added details of observations during the course of the waveform study and added conclusions	0.1.0	0.2.0