Channel Model Implementation and Application for New Radio (NR) 3GPP REL-15

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3GPP Channel Model

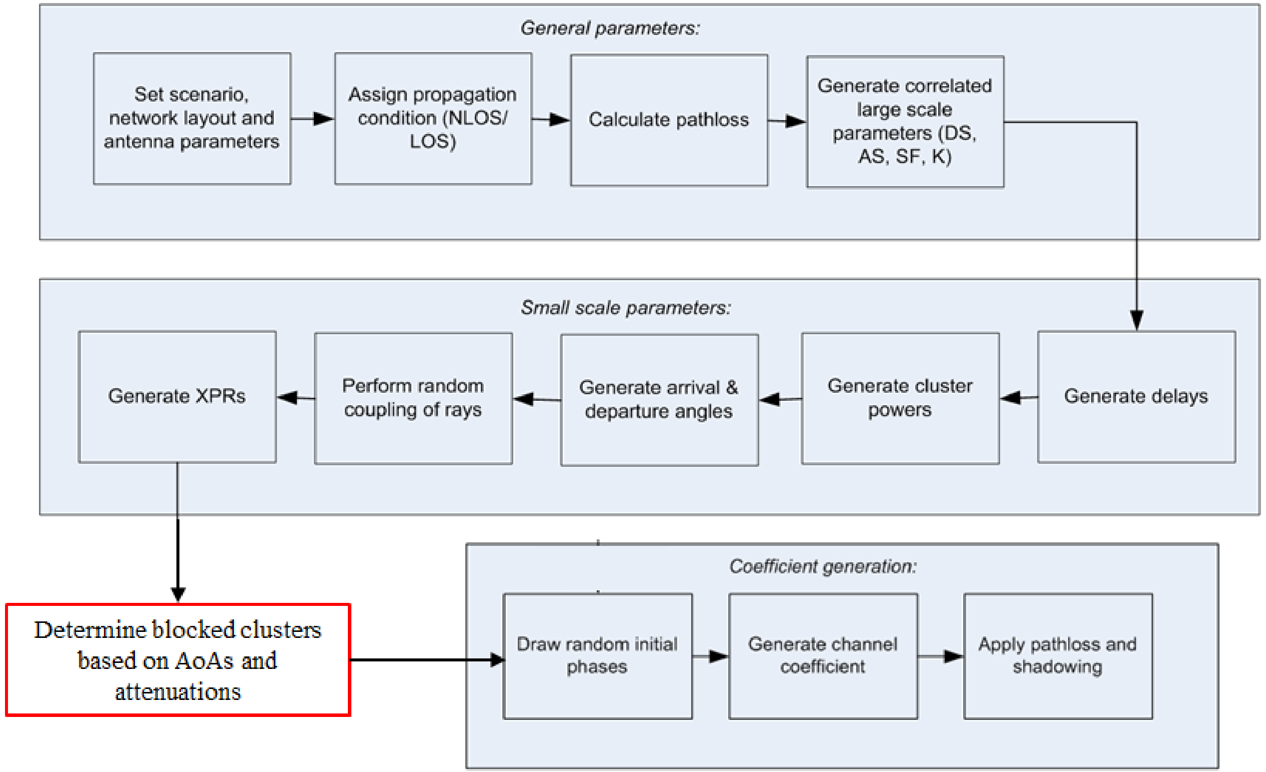
- New Radio Channel Model specified in 3GPP TR 38.900 and 3GPP TR 38.901 V15.0.0 (2018-06)
- Other channel models for 5G or NR outside of 3GPP:
  - METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society)
  - MiWEBA (Millimetre-Wave Evolution for Backhaul and Access)
  - ITU-R M
  - COST2100
  - IEEE 802.11
  - NYU WIRELESS: interdisciplinary academic research center
  - Fraunhofer HHI QuaDRiGa channel model (MATLAB® at http://quadriga-channel-model.de)
- Comprehensive list in Section 6.1 in 3GPP TR 38.900
- Many other efforts underway for measurement campaigns in mmW bands

Channel Model Application

- What is the 3GPP 5G Channel Model Used for?
  - Research, innovation and standardization
  - Product development during receiver design and implementation
  - Physical link performance to establish benchmark and optimize algorithmic design
  - Unit testing, certification, systems testing and systems deployment
  - Network deployment and optimization
- Channel models are not perfect
  - Model parameters are revised and updated based on feedback from trials and updated measurement campaigns
- The use of channel models is iterative

Channel Model Implementation

Channel model is implemented in link and systems performance simulation expressed in terms of Power Delay Profile (PDP) (Clustered or Tapped)



How To Use 5G NR Channel Model

- Establish the main characteristics of the Radio Access Technology being evaluated
  - ***Frequency domain parameters:*** carrier frequency band, bandwidth mode, subcarrier size, granularity of resource allocation
  - ***Time domain parameters:*** duplexing, frame and subframe structure and timing, smallest units of transmission
  - ***Power domain parameters:*** power class for both user equipment and base station including heterogeneous deployment
  - ***Antenna configuration*** including multiple antenna and beamforming
- Establish the main characteristics of the deployment scenario

NR Channel Model Parameters (Dimensions)

- Deployment scenarios (Urban Micro, Urban Macro, Rural, Indoor, Backhaul, D2D, V2V)
- Antenna heights (UE and base stations, indoor, outdoor)
- Antenna type (arrays, cross polarization)
- Azimuth, elevation and departure angles
- Path loss with Probability (NLOS, LOS) including Indoor to Outdoor and penetration loss
- Frequency range {(6–20 GHz), (20–30 GHz), (30–60 GHz), > 60 GHz}
- Penetration loss (material, outdoor to indoor)
- Auto-correlation of shadow fading
- Fast Fading
- Time varying Doppler shift
- UT rotation
- Blockage

Example of NR Channel Bandwidth for Frequency Region 2
26.5 to 40 GHz

New NR band / SCS / Channel bandwidth					
NR Band	**SCS kHz**	**50 MHz**	**100 MHz**	**200 MHz**	**400 MHz**
n257	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n258	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n260	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes

Example of UE Power Class for NR

EUTRA band	Class 1 (dBm)	Tolerance (dB)	Class 2 (dBm)	Tolerance (dB)	Class 3 (dBm)	Tolerance (dB)
n41			**26**	**+2/-3**[3]	**23**	**± 2**[3]
n71					**23**	**+2/-2.5**
n78					**23**	**+2/-2.5**
n80					**23**	**+2/-2.5**

Beamforming Requirements

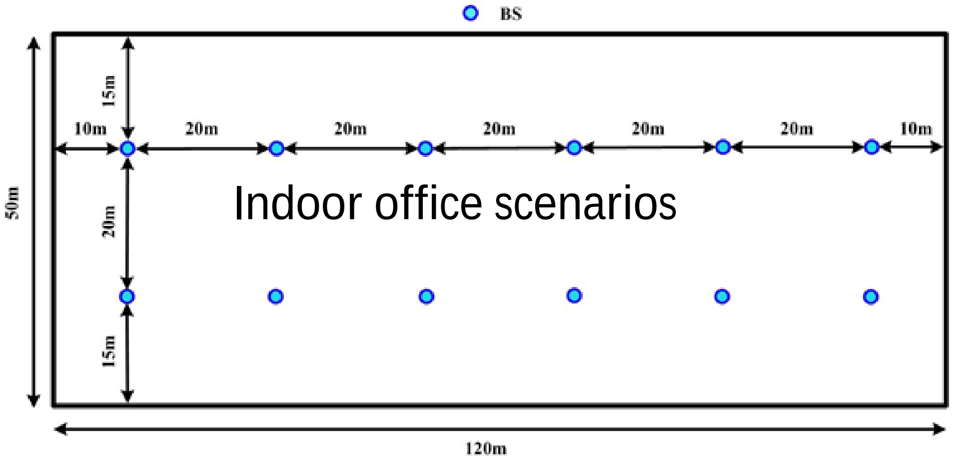
From one OFDM symbol to the next <=80% CP (TR 38.817 to be in TS 38.101)

- Digital beam forming by phase adjustment in baseband; negligible adjustment of beam direction
- Analogue beam forming — probably the slowest reacting method of phase shift
  - Analogue phase shifters implement a controllable phase shift such as PIN diodes: 10–100 ns
  - Switched phase shifters react based on the RF switching time: GaAs switches ≈10 ns
- Worst-case beam switching time is based on analogue implementation and estimated as < 100ns

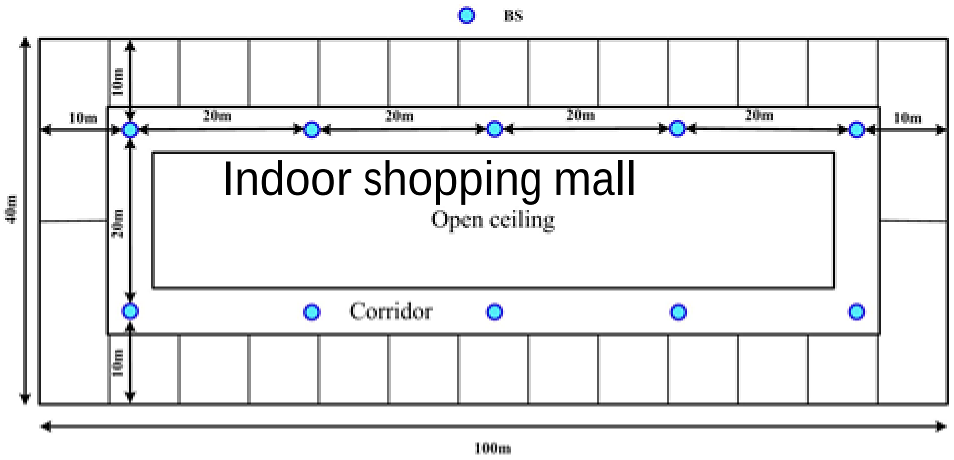
SCS (KHz)	CP Length $l \neq \{0,7\}$	CP length L={0,7}	Max Beam switching time	RX/TX or TX/RX switch time	Symbol Time no CP	Lost OS DL/UL UL/DL
15	4.69 µs	5.19 µs	3.75 µs	13 µs	66.7 µs	1
30	2.34 µs	2.59 µs	1.87 µs	13 µs	33.3 µs	1
60	1.17 µs	1.29 µs	938 ns	13 µs , 7 µs	16.7 µs	1
120	586 ns	648.3 ns	469 ns	7 µs	8.33 µs	1
240	293 ns	324 ns	234.5 ns	7 µs	4.17 µs	2

NR Specific Channel Model
Characterized by Deployments in Several Scenarios

Indoor



Indoor office scenarios



Indoor shopping mall

Outdoor

Parameters		UMi – street canyon	UMa
Cell layout		Hexagonal grid, 19 micro sites, 3 sectors per site (ISD = 200m)	Hexagonal grid, 19 macro sites, 3 sectors per site (ISD = 500m)
BS antenna height h_{BS}		10m	25m
UT location	Outdoor/indoor	Outdoor and indoor	Outdoor and indoor
	LOS/NLOS	LOS and NLOS	LOS and NLOS
	Height h_{UT}	Same as 3D-UMi in TR36.873	Same as 3D-UMa in TR36.873
Indoor UT ratio		80%	80%
UT mobility (horizontal plane only)		3km/h	3km/h
Min. BS - UT distance (2D)		10m	35m
UT distribution (horizontal)		Uniform	Uniform

Parameters	RMa
Carrier Frequency	Up to 7Ghz
BS height h_{BS}	35m
Layout	Hexagonal grid, 19 Macro sites, 3sectors per site, ISD = 1732m or 5000m
UT height h_{UT}	1.5m
UT distribution	Uniform
Indoor/Outdoor	50% indoor and 50% in car
LOS/NLOS	LOS and NLOS
Min BS- UT distance(2D)	35m

Table 7.7.1-1. CDL-A

CDL and TDL Profiles Provided with Normalized Delay

NLOS CDL-A Example

Cluster #	Normalized delay	Power dB	AoD °	AoA °	ZoD °	ZoA °
1	0.0000	-13.4	-178.1	51.3	50.2	125.4
2	0.3819	0	-4.2	-152.7	93.2	91.3
3	0.4025	-2.2	-4.2	-152.7	93.2	91.3
4	0.5868	-4	-4.2	-152.7	93.2	91.3
5	0.4610	-6	90.2	76.6	122	94
6	0.5375	-8.2	90.2	76.6	122	94
7	0.6708	-9.9	90.2	76.6	122	94
8	0.5750	-10.5	121.5	-1.8	150.2	47.1
9	0.7618	-7.5	-81.7	-41.9	55.2	56
10	1.5375	-15.9	158.4	94.2	26.4	30.1
11	1.8978	-6.6	-83	51.9	126.4	58.8
12	2.2242	-16.7	134.8	-115.9	171.6	26
13	2.1718	-12.4	-153	26.6	151.4	49.2
14	2.4942	-15.2	-172	76.6	157.2	143.1
15	2.5119	-10.8	-129.9	-7	47.2	117.4
16	3.0582	-11.3	-136	-23	40.4	122.7
17	4.0810	-12.7	165.4	-47.2	43.3	123.2
18	4.4579	-16.2	148.4	110.4	161.8	32.6
19	4.5695	-18.3	132.7	144.5	10.8	27.2
20	4.7966	-18.9	-118.6	155.3	16.7	15.2
21	5.0066	-16.6	-154.1	102	171.7	146
22	5.3043	-19.9	126.5	-151.8	22.7	150.7
23	9.6586	-29.7	-56.2	55.2	144.9	156.1

Per-Cluster Parameters

Parameter	c_{ASD}	c_{ASA}	c_{ZSD}	c_{ZSA}	XPR
Unit	°	°	°	°	dB
Value	5	11	3	3	10

LOS CDL-D Example

Cluster #	Cluster PAS	Normalized Delay	Power dB	AoD °	AoA °	ZoD °	ZoA °
1	Specular(LOS path)	0	-0.2	0	-180	98.5	81.5
	Laplacian	0	-13.5	0	-180	98.5	81.5
2	Laplacian	0.035	-18.8	89.2	89.2	85.5	86.9
3	Laplacian	0.612	-21	89.2	89.2	85.5	86.9
4	Laplacian	1.363	-22.8	89.2	89.2	85.5	86.9
5	Laplacian	1.405	-17.9	13	163	97.5	79.4
6	Laplacian	1.804	-20.1	13	163	97.5	79.4
7	Laplacian	2.596	-21.9	13	163	97.5	79.4
8	Laplacian	1.775	-22.9	34.6	-137	98.5	78.2
9	Laplacian	4.042	-27.8	-64.5	74.5	88.4	73.6
10	Laplacian	7.937	-23.6	-32.9	127.7	91.3	78.3
11	Laplacian	9.424	-24.8	52.6	-119.6	103.8	87
12	Laplacian	9.708	-30.0	-132.1	-9.1	80.3	70.6
13	Laplacian	12.525	-27.7	77.2	-83.8	86.5	72.9

Per-Cluster Parameters

Parameter	c_{ASD}	c_{ASA}	c_{ZSD}	c_{ZSA}	XPR
Unit	°	°	°	°	dB
Value	5	8	3	3	11

TDL Example

TDL-B NLOS

Tap #	Normalized delay	Power in dB	Fading distribution
1	0.0000	0	Rayleigh
2	0.1072	-2.2	Rayleigh
3	0.2155	-4	Rayleigh
4	0.2095	-3.2	Rayleigh
5	0.2870	-9.8	Rayleigh
6	0.2986	-1.2	Rayleigh
7	0.3752	-3.4	Rayleigh
8	0.5055	-5.2	Rayleigh
9	0.3681	-7.6	Rayleigh
10	0.3697	-3	Rayleigh
11	0.5700	-8.9	Rayleigh
12	0.5283	-9	Rayleigh
13	1.1021	-4.8	Rayleigh
14	1.2756	-5.7	Rayleigh
15	1.5474	-7.5	Rayleigh
16	1.7842	-1.9	Rayleigh
17	2.0169	-7.6	Rayleigh
18	2.8294	-12.2	Rayleigh
19	3.0219	-9.8	Rayleigh
20	3.6187	-11.4	Rayleigh
21	4.1067	-14.9	Rayleigh
22	4.2790	-9.2	Rayleigh
23	4.7834	-11.3	Rayleigh

TDL D LOS

Tap #	Normalized delay	Power in dB	Fading distribution
1	0	-0.2	LOS path
	0	-13.5	Rayleigh
2	0.035	-18.8	Rayleigh
3	0.612	-21	Rayleigh
4	1.363	-22.8	Rayleigh
5	1.405	-17.9	Rayleigh
6	1.804	-20.1	Rayleigh
7	2.596	-21.9	Rayleigh
8	1.775	-22.9	Rayleigh
9	4.042	-27.8	Rayleigh
10	7.937	-23.6	Rayleigh
11	9.424	-24.8	Rayleigh
12	9.708	-30.0	Rayleigh
13	12.525	-27.7	Rayleigh

NOTE: **The first tap follows a Ricean distribution with a K-factor of K_1 = 13.3 dB and a mean power of 0dB.**

How to Calculate Absolute Delay Values

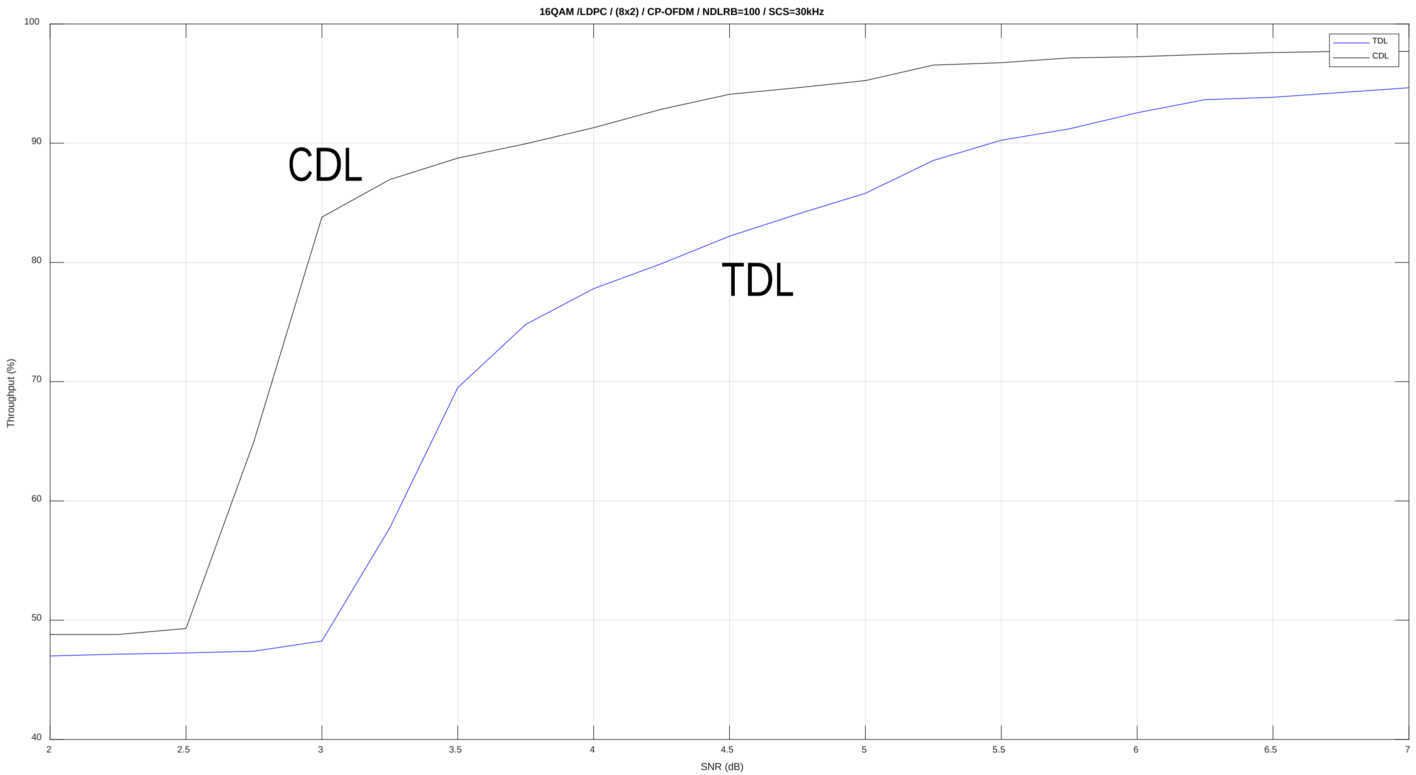
Pick delay spread desired from scenario and calculate: $t_{n,\text{scaled}} = t_{n,\text{model}} \times \mathrm{DS}_{\text{desired}}$

Proposed Scaling Factor Delay Spread desired [ns])		Frequency [GHz]						
		2	6	15	28	39	60	70
Indoor office	Short-delay profile	20	16	16	16	16	16	16
	Normal-delay profile	39	30	24	20	18	16	16
	Long-delay profile	59	53	47	43	41	38	37
UMi Street-canyon	Short-delay profile	65	45	37	32	30	27	26
	Normal-delay profile	129	93	76	66	61	55	53
	Long-delay profile	634	316	307	301	297	293	291
UMa	Short-delay profile	93	93	85	80	78	75	74
	Normal-delay profile	363	363	302	266	249	228	221
	Long-delay profile	1148	1148	955	841	786	720	698
RMa & RMa O2I	Short-delay profile	32	32	N/A	N/A	N/A	N/A	N/A
	Normal-delay profile	37	37	N/A	N/A	N/A	N/A	N/A
	Long-delay profile	153	153	N/A	N/A	N/A	N/A	N/A
UMi / UMa O2I	Normal-delay profile	240						
	Long-delay profile	616						

Tap #	Normalized delay	Power in dB	Fading distribution
1	0.0000	0	Rayleigh
2	0.1072	-2.2	Rayleigh
3	0.2155	-4	Rayleigh
4	0.2095	-3.2	Rayleigh
5	0.2870	-9.8	Rayleigh
6	0.2986	-1.2	Rayleigh
7	0.3752	-3.4	Rayleigh
8	0.5055	-5.2	Rayleigh
9	0.3681	-7.6	Rayleigh
10	0.3697	-3	Rayleigh
11	0.5700	-8.9	Rayleigh
12	0.5283	-9	Rayleigh
13	1.1021	-4.8	Rayleigh
14	1.2756	-5.7	Rayleigh
15	1.5474	-7.5	Rayleigh
16	1.7842	-1.9	Rayleigh
17	2.0169	-7.6	Rayleigh
18	2.8294	-12.2	Rayleigh
19	3.0219	-9.8	Rayleigh
20	3.6187	-11.4	Rayleigh
21	4.1067	-14.9	Rayleigh
22	4.2790	-9.2	Rayleigh
23	4.7834	-11.3	Rayleigh

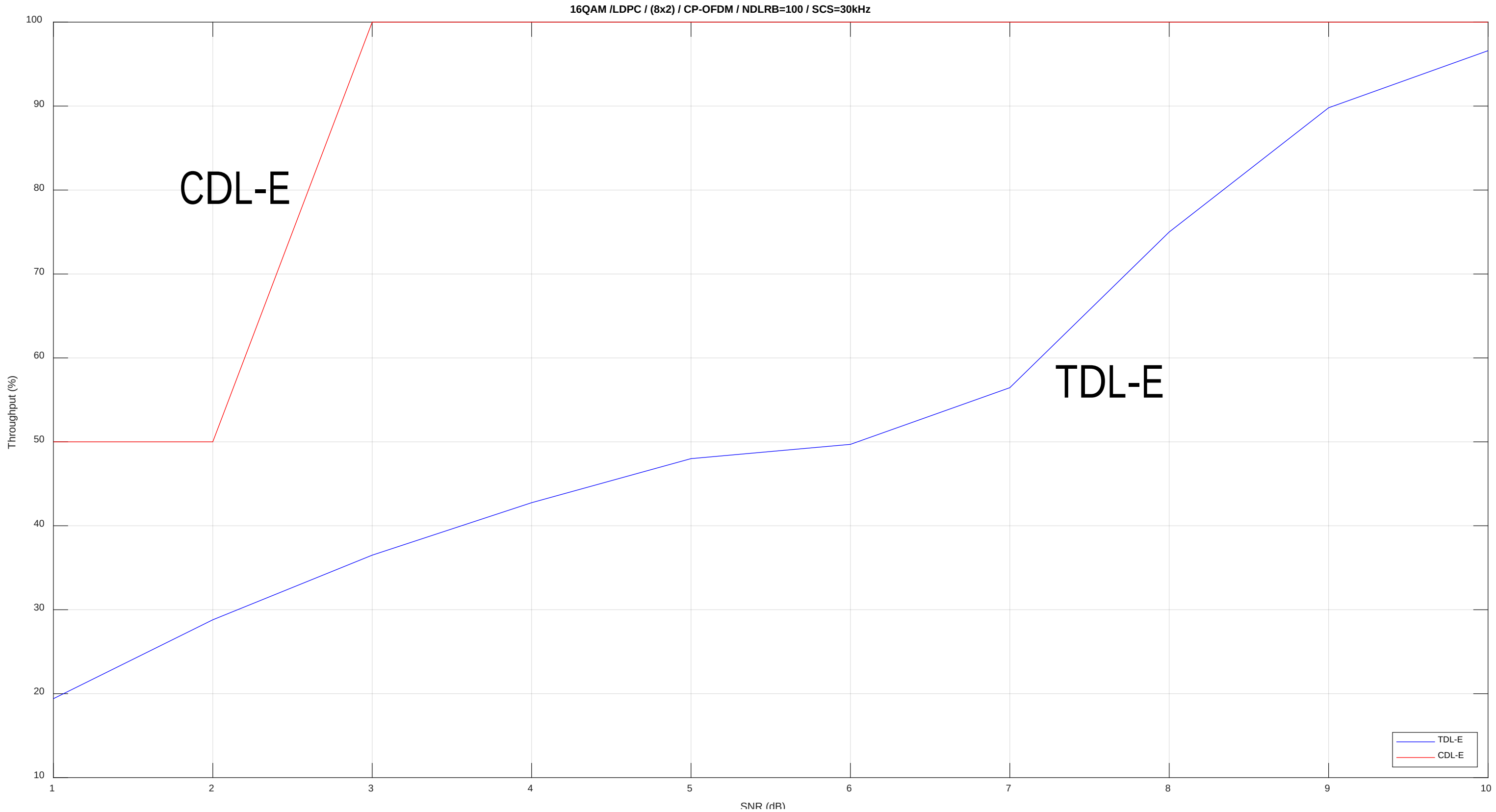
NR PDSCH Throughput: Urban Micro Deployment (Outdoor to Indoor)

Cluster Delay Line (CDL-C) and Tap Delay Line (TDL-C, usually for non MIMO channel) both N-LOS with delay spread 300 ns



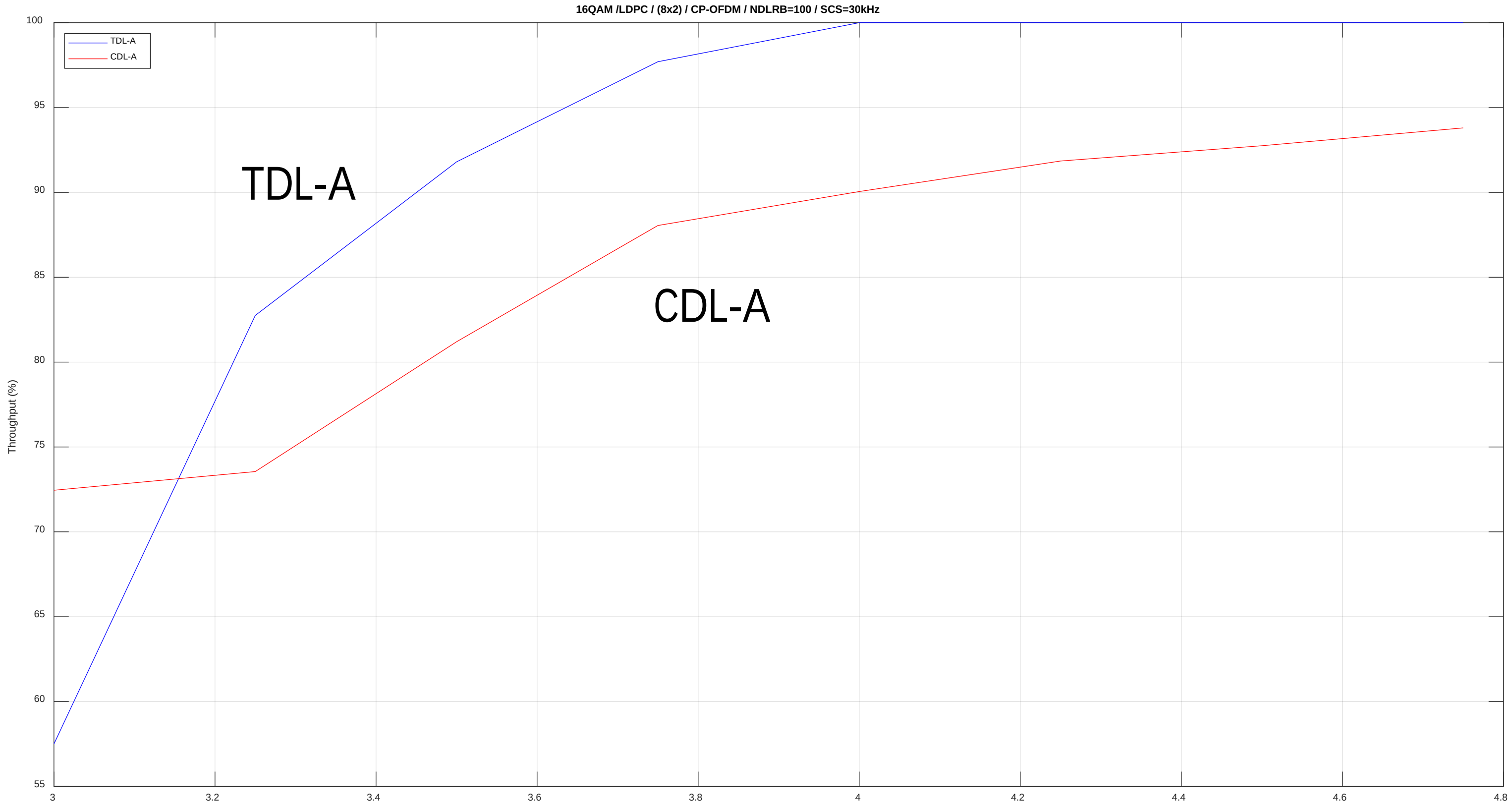
NR PDSCH Throughput: UMI Canyon

Cluster Delay Line (CDL-E) and Tap Delay Line (TDL-E) both LOS with delay spread 30 ns



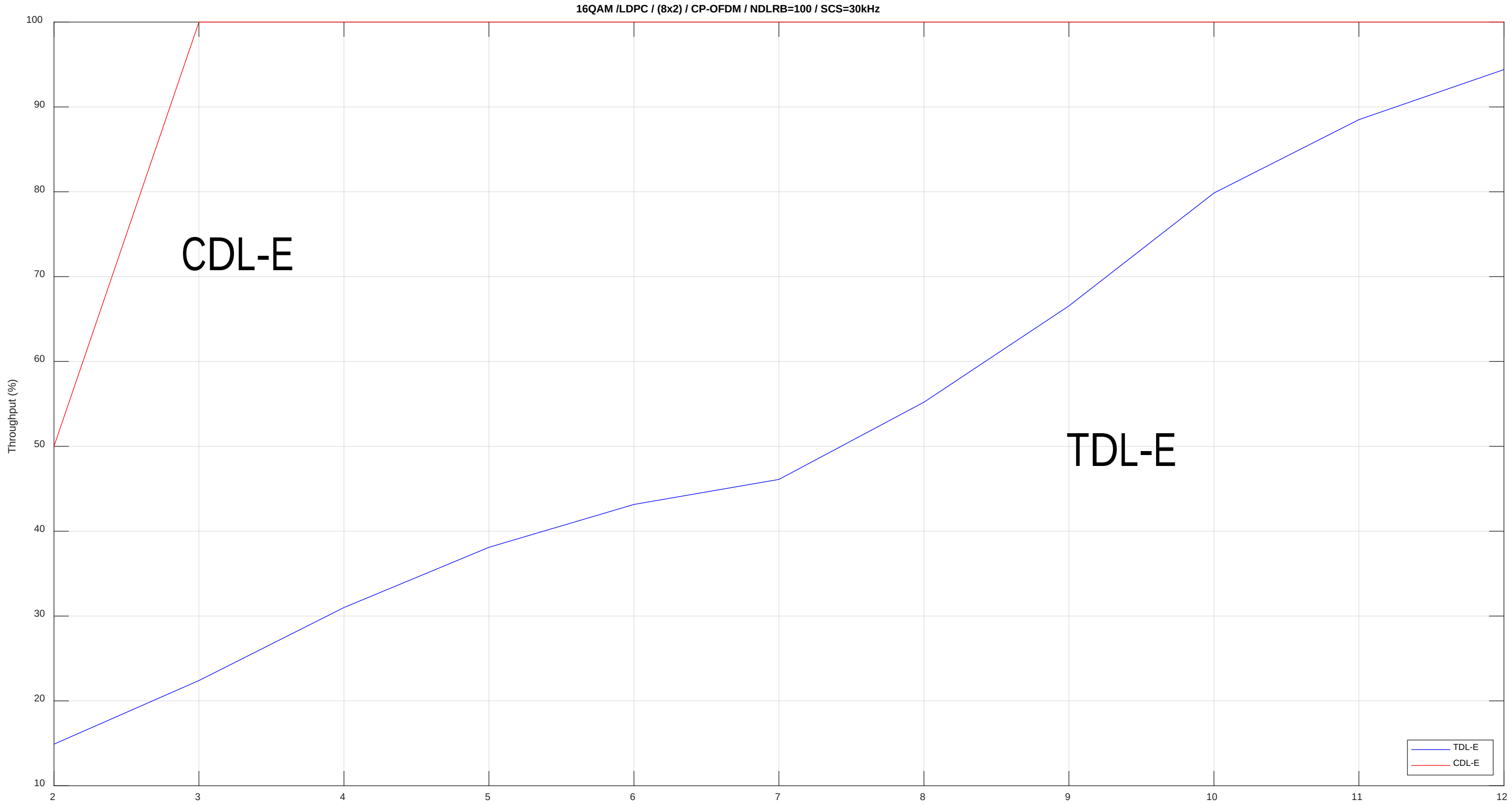
NR PDSCH Throughput: Indoor

Cluster Delay Line (CDL-A) and Tap Delay Line (TDL-A) both NLOS delay spread 20 ns



NR PDSCH Throughput: Indoor (large hall factory type)

Cluster Delay Line (CDL-E) and Tap Delay Line (TDL-E) both LOS delay spread 76 ns



Observations: CDL vs. LDL

- Small difference (2dB) for outdoor throughput (90%) in Urban Micro scenario NLOS with 300 ns delay spread
- Substantial (6dB) difference for shorter delay spread 30 ns and LOS, also Urban Micro scenario
  - CDL lower SNR outdoors
- Minimal difference (< 1 dB) indoor with delay spread of 20 ns
  - LDL lower SNR indoors
- For indoor with delay spread of 76 ns LOS, difference is as large as for the Urban Micro case, but LDL is responsive to larger delay spread

References

- 3GPP TR 38.900 V15.0.0 (2018-06) Study on channel model for frequency spectrum above 6 GHz
- 3GPP TR 38.901 V15.0.0 (2018-06) Study on channel model for frequencies from 0.5 to 100 GHz
- 3GPP TS 38.101-1 V15.1.0 User Equipment (UE) radio transmission and reception
- 3GPP TS 38.211 V15.1.0 (2018-03) Physical channels and modulation
- MIMO-OFDM Wireless Communications with MATLAB (Y. S. Cho, J. Kim, W. Y. Yang, C.G. Kang) Wiley and Sons 2010.
- Principles of Communications Engineering (J. M. Wozencraft and I. M Jacobs) Wiley and Sons 1965

Additional Background Information

Basics of channel model and propagation

Frequency regions and subcarrier spacing of 5G New Radio

Path Loss (distance, frequency)

Reference MIMO-OFDM Wireless Communications with MATLAB (Cho, Kim, Yan, Kang)

Free space line of sight path loss is derived from Harald Trap Friis :

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{4\pi^2 d^2 L} \quad \Longrightarrow PL_F\ (d)[dB] = 10log\left(\frac{(4\pi)^2 d^2}{G_t G_r \lambda^2}\right)$$

Log-distance path loss model

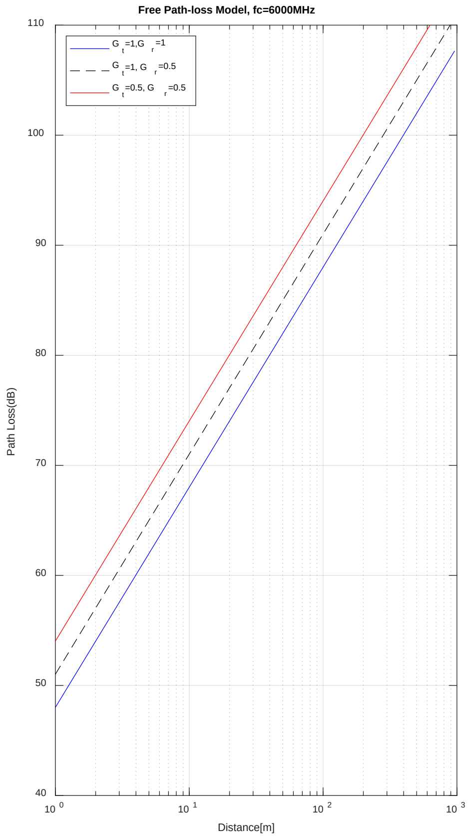
$$PL_{LD}(d)[dB] = PL_F(d_0) + 10nlog\left(\frac{d}{d_0}\right)$$

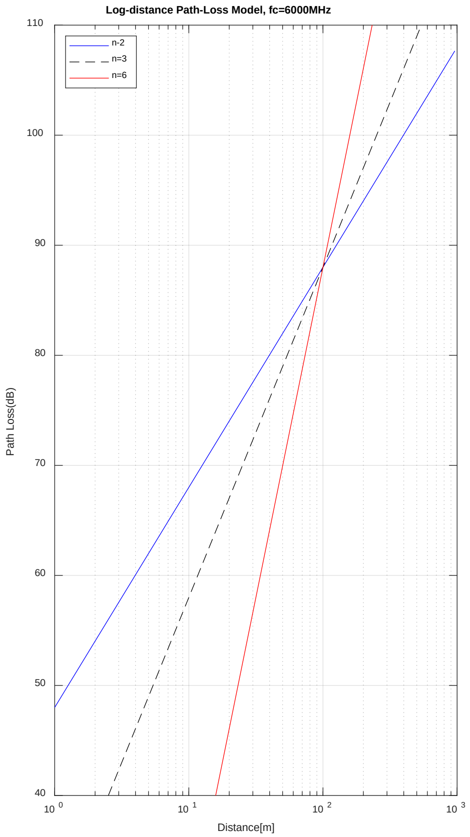
where $n = \begin{cases} 1.6 - 1.8 & in\ building\ LOS \\ 2 & free\ space \\ 2\ -\ 3 & In\ \ Factories \\ 2.7 - 3.5 & Urban\ cellular \\ 3 - 5 & Shadowed\ Urban \\ 4\ - 6 & In\ \ building \end{cases}$

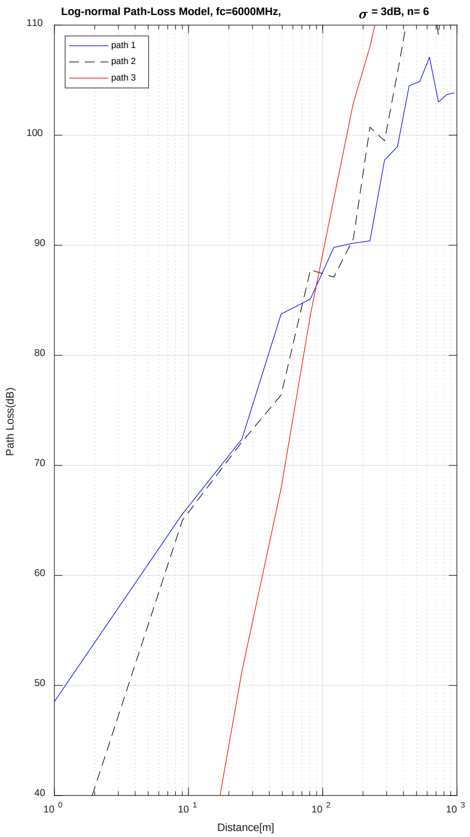
Log-normal shadowing model

$$PL_{LD}(d)[dB] = PL_F(d_0) + 10nlog\left(\frac{d}{d_0}\right) + X_\sigma \qquad X_\sigma \triangleq \{random\ shadowing\ effect(GN(0,\sigma)\}$$

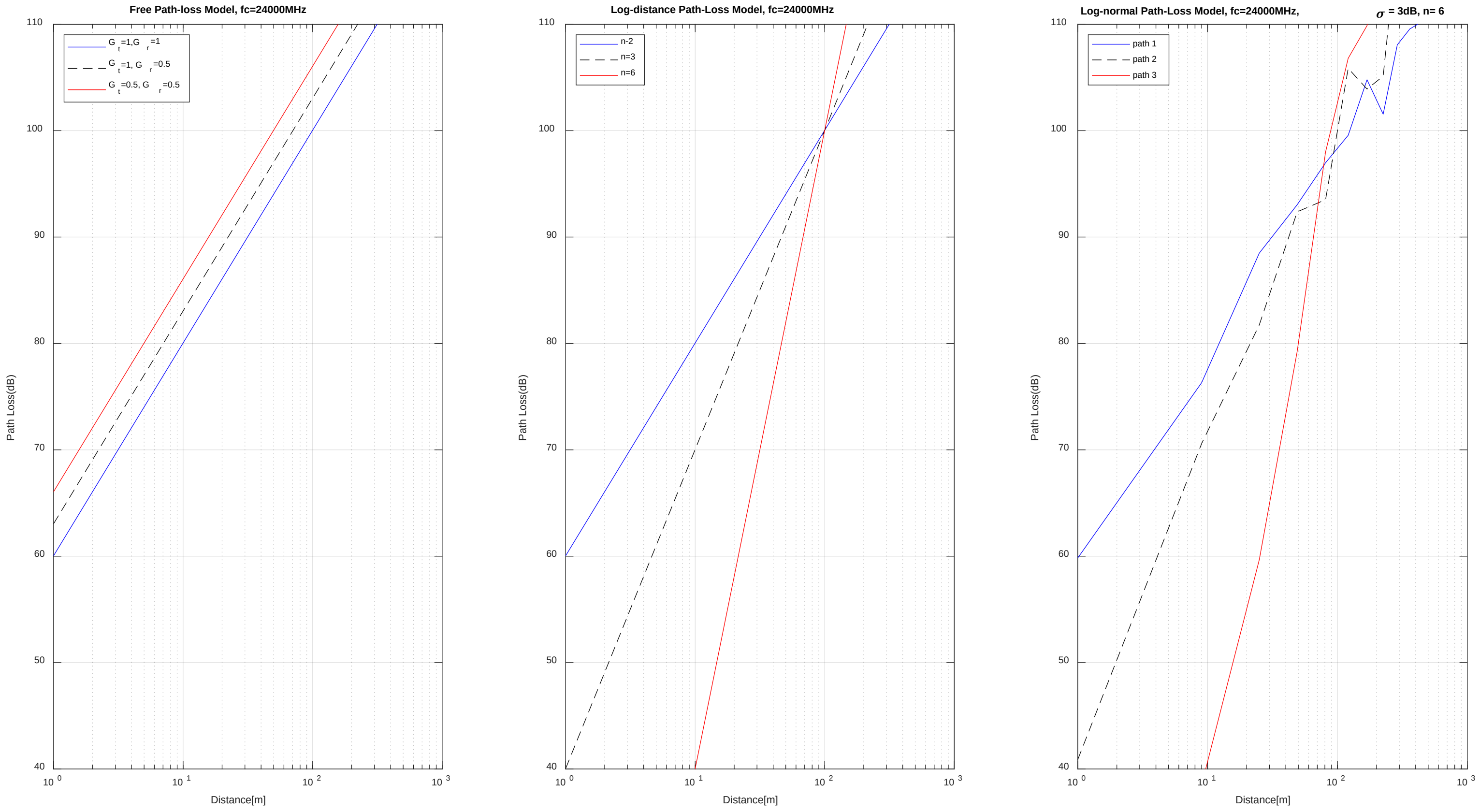
LOS, Log distance and Log normal path loss 6 GHz







LOS, Log distance and Log normal path loss 24 GHz

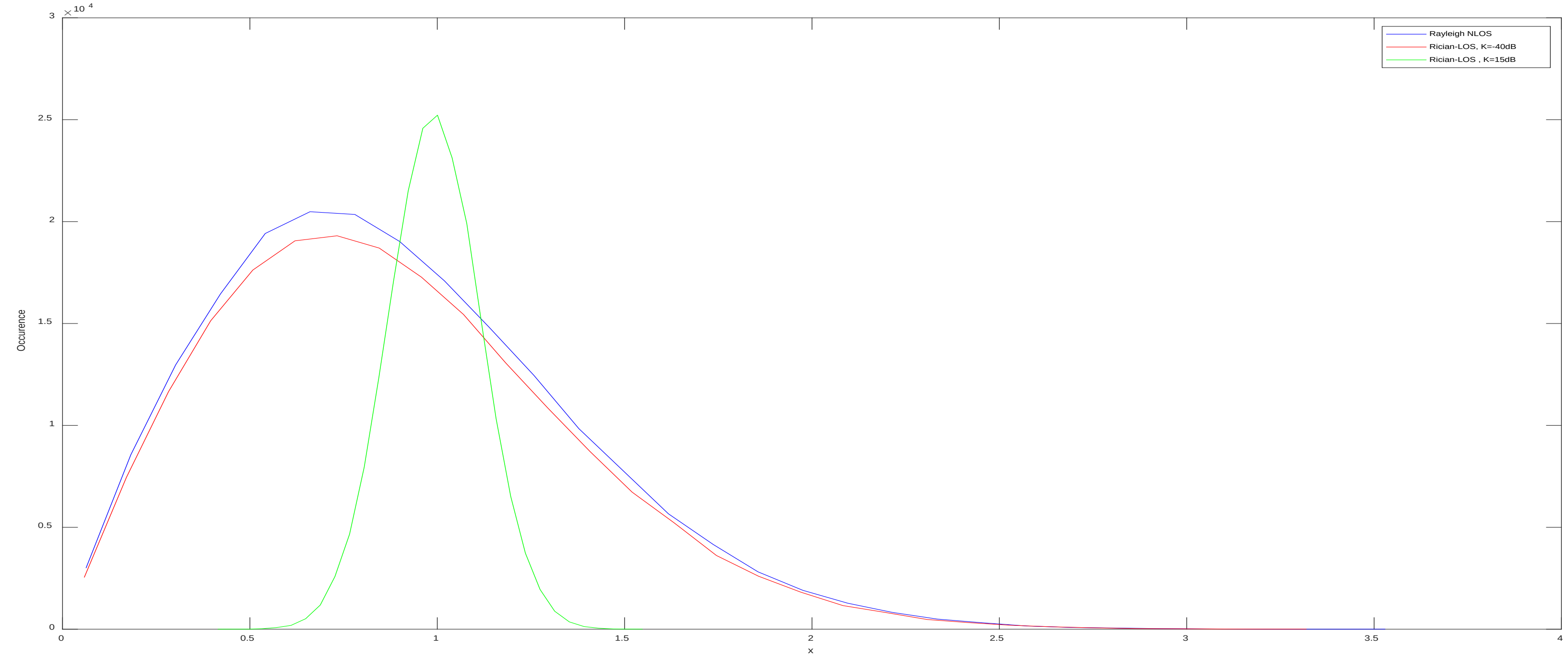


Fading {correlation of [timing and bandwidth of signal and channel]}

Ref: Multi-Carrier Dig. Comm. Theory and Application of OFDM (Bahai, Saltzberg, Ergen), Principles of Communications Engineering (Wozencraft and Jacobs), 3GPP TS 38.211

In the absence of AWGN and OFDM symbol transmitted appears at the RX as:

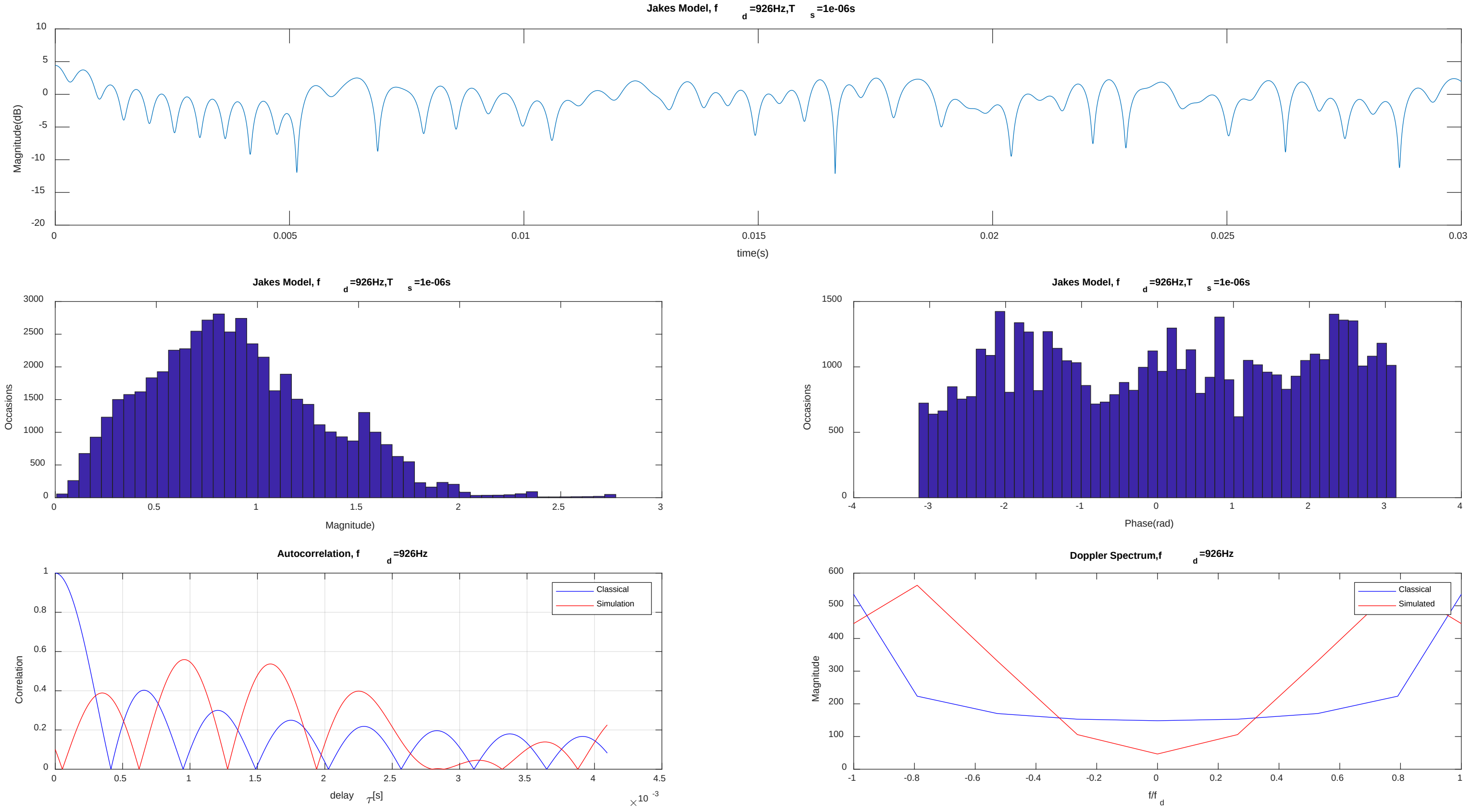
$R_{rx}(l) = \alpha(t) \cdot \sum_{k=0}^{L} a_{k,l} \cdot e^{j\pi\Delta_f(k+1)} \cdot e^{j2\pi f_c}$ where $\alpha(t)$ is Raleigh or Rician.



K-Factor is the ratio of the dominant component over the local mean. Since Raleigh has no LOS K=0 i.e. ∞ dB. For Rician, for example indoors, k is around 4 to 12 dB.

Jakes' Synthesis for Time-varying Channel

Amplitude, Phase, Autocorrelation and Doppler



Band, SCS, Channel Bandwidth for FR1 (1 of 3) TS 38.101

600 MHz – 5 GHz

NR Band	SCS kHz	5 MHz	10[2,3] MHz	15[3] MHz	20[3] MHz	25[3] MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
n1	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									
n2	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									
n3	15	Yes	Yes	Yes	Yes	Yes	Yes							
	30		Yes	Yes	Yes	Yes	Yes							
	60		Yes	Yes	Yes	Yes	Yes							
n5	15	Yes	Yes											
	30		Yes											
	60													
n7	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									
n8	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
N20	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n25	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									
n26	15	Yes	Yes	Yes										
	30		Yes	Yes										
	60		Yes	Yes										

Band, SCS, Channel Bandwidth for FR1 (2 of 3) TS 38.101

600 MHz – 5 GHz

NR Band	SCS kHz	5 MHz	$10^{2,3}$ MHz	15^{3} MHz	20^{3} MHz	25^{3} MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
n28	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n34	15	Yes	Yes	Yes										
	30		Yes	Yes										
	60		Yes	Yes										
n38	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									
n39	15	Yes	Yes	Yes	Yes	Yes	Yes	Yes						
	30		Yes	Yes	Yes	Yes	Yes	Yes						
	60		Yes	Yes	Yes	Yes	Yes	Yes						
n40	15	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes					
	30		Yes	Yes	Yes	Yes	Yes	Yes	Yes					
	60		Yes	Yes	Yes	Yes	Yes	Yes	Yes					
n41	15		Yes	Yes	Yes			Yes	Yes					
	30		Yes	Yes	Yes			Yes	Yes	Yes		Yes		Yes
	60		Yes	Yes	Yes			Yes	Yes	Yes		Yes		Yes
n50	15	Yes	Yes	Yes	Yes			Yes	Yes					
	30		Yes	Yes	Yes			Yes	Yes	Yes		Yes		
	60			Yes	Yes									
n51	15	Yes												
	30													
	60													
n66	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes			Yes						
	60		Yes	Yes	Yes			Yes						
n70	15	Yes	Yes	Yes	Yes	Yes								
	30		Yes	Yes	Yes	Yes								
	60		Yes	Yes	Yes	Yes								

Band, SCS, Channel Bandwidth for FR1 (3 of 3)

600 MHz to 5 GHz

NR Band	SCS	5 MHz	$10^{2,3}$ MHz	15^{3} MHz	20^{3} MHz	25^{3} MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
n71	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n74	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									
n75	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60			Yes	Yes									
n76	15	Yes												
	30													
	60													
n77	15		Yes	Yes	Yes		Yes^1	Yes	Yes					
	30		Yes	Yes	Yes		Yes^1	Yes	Yes	Yes	Yes^1	Yes	Yes^1	Yes
	60		Yes	Yes	Yes		Yes^1	Yes	Yes	Yes	Yes^1	Yes	Yes^1	Yes
n78	15		Yes	Yes	Yes		Yes^1	Yes	Yes					
	30		Yes	Yes	Yes		Yes^1	Yes	Yes	Yes	Yes^1	Yes	Yes^1	Yes
	60		Yes	Yes	Yes		Yes^1	Yes	Yes	Yes	Yes^1	Yes	Yes^1	Yes
n79	15							Yes	Yes					
	30							Yes	Yes	Yes		Yes		Yes
	60							Yes	Yes	Yes		Yes		Yes
n80	15	Yes	Yes	Yes	Yes	Yes	Yes							
	30		Yes	Yes	Yes	Yes	Yes							
	60		Yes	Yes	Yes	Yes	Yes							
n81	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n82	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n83	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n84	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									

NOTE 1: The channel bandwidth is defined only as a BS channel bandwidth in these bands.
NOTE 2: 90% spectrum utilization may not be achieved for 30kHz SCS.
NOTE 3: 90% spectrum utilization may not be achieved for 60kHz SCS.