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Re:	Call for comments and contributions for session#44 (IEEE 802.16j-06/006)	
Abstract	This contribution compares different multipath models for IEEE 802.16j Relay TG.	
Purpose	Response the chair's call for comments on Evaluation Methodology (C802.16j_06/040)	
Notice		
Release		
Patent Policy and Procedures		

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Comparison of multipath channel models for IEEE 802.16j Relay Task Group

1 Summary of contribution

In the last meeting, there have been a number of channel model contributions. We will need to make a decision on which channel model to adapt. Before a decision can be reached, we need to understand what each channel model provides. Hence, in this contribution, we would like to characterize the following multipath channel models: 802.16[3], ITU[2] and WINNER[1] for a 5MHz channel bandwidth with OMNI antennae. For details regarding the channel parameters, refer to 5.1. Evaluations on new channel model will be added as we receive more channel model proposals.

The purpose of this document is not to choose a channel model. Rather, we aim to provide analytical information on each model such that the task group can use it to arrive at a decision. The channel model that best reflects the propagation environment for 802.16j shall be chosen.

802.16 multipath models are derived from the SUI models[7] and there are 6 of them with each one coming from a different propagation environment. Hence, we would like to refer to the six multipath channels as 802.16 SUI 1 to 6. The measurements that are performed to derive these channels are done at 1.9GHz and 2.5GHz in outdoor sub-urban environment in the US. For details regarding this model, please refer to [3] and [7]. From our analysis, we found that the higher the channel number is, the worse the channel propagation environment. In fact, the RMS delay spread is worst with SUI channels than the other models.

Details on ITU multipath models can be found in [2]. Again, they have a total of 6 multipath channels with each one representing a different propagation environment which can be indoor, outdoor, indoor to outdoor, slow moving, fast moving, small or large cell sizes in mostly urban environments. Our analysis shows that ITU multipath channels provide the second worst RMS delay spread. However, ITU channels have deeper fades than SUI channel models and therefore provide a harsher propagation environment than the SUI channels.

Details on WINNER multipath channel models can be found in [1]. We have chosen 4 WINNER multipath channel models to analyze and they reflect the propagation environment of small cells in Manhattan like city environment. Due to the small cell sizes, WINNER channels have smaller delay spread and reflect a more benign propagation environment.

To simulate the effect of MS movement, Doppler spectra are added to the multipath channel model. 802.16 and WINNER propose the same Doppler spectrum while ITU proposes the flat and classical Doppler spectra for the various propagation environment. From our analysis, the classical Doppler spectrum provides the shortest coherence time while the 802.16 Doppler spectrum provides the longest coherence time for MS traveling at the same speed.

2 Multipath fading model comparison

The following parameters for each multipath channel model are evaluated in the comparison:

1. mean and rms delay spread. This information can be used as a reference to design the equalizer length for single carrier system and cyclic prefix duration for OFMD systems;
2. channel coherence bandwidth using its spaced-frequency correlation function. This parameter answers the question of how selective the channel can be;

3. channel coherence time using various Doppler spectrums. This parameter answers the question of how fast the channel can change.

2.1 Mean and RMS delay spread

Mean delay spread provides information on the mean value of delay spread expected for a certain channel RMS delay spread provides the delay spread variations. From [3], the RMS delay spread (τ_{rms}) is:

$\tau_{rms}^2 = \sum_j P_j \tau_j^2 - (\tau_{mean})^2$ where

- $\tau_{mean} = \sum_j P_j \tau_j$ is the mean delay spread
- τ_j is the delay of the jth delay component and P_j = (power in the jth delay component) / (total power of all components).

Using the above definition, the mean and RMS delay spread of the channels can be found in Table 1. WINNER channel models provide the smallest RMS delay spread while 802.16 SUI channels provide the worst RMS delay spread.

Table 1. Mean and RMS delay spread of 802.16 SUI, ITU and WINNER channel profiles

Channel Type	Mean delay spread (υs)	RMS delay spread (υs)
802.16 SUI channel 1 (Terrain Type A: Hilly terrain with moderate-to-heavy tree densities)	0.0208	0.1105
802.16 SUI channel 2 (Terrain Type A: Hilly terrain with moderate-to-heavy tree densities)	0.0548	0.2029
802.16 SUI channel 3 (Terrain Type B: Intermediate path-loss condition)	0.1529	0.2637
802.16 SUI channel 4 (Terrain Type B: Intermediate path-loss condition)	0.7909	1.2566
802.16 SUI channel 5 (Terrain Type C: Flat terrain with light tree densities)	1.5993	2.8418
802.16 SUI channel 6 (Terrain Type C: Flat terrain with light tree densities)	1.9268	5.2397
ITU Indoor Office Environment Channel A	0.0245	0.0370
ITU Indoor Office Environment Channel B	0.0675	0.0992
ITU Outdoor to Indoor and Pedestrian Environment Channel A	0.0144	0.0460
ITU Outdoor to Indoor and Pedestrian Environment Channel B	0.4091	0.6334
ITU Vehicular Environment (High Antenna) Channel A	0.2544	0.3704
ITU Vehicular Environment (High Antenna) Channel B	1.4981	4.0014
WINNER model B5A for (BS↔RS, LOS) and (RS↔RS, LOS)	0.0104	0.0406

WINNER model C2 for (BS↔RS, NLOS), (RS↔MS, NLOS), and (RS↔RS, NLOS)	0.2992	0.3130
WINNER model B1 LOS for (RS↔MS, LOS)	0.0141	0.0198
WINNER model B1 NLOS for (RS↔MS, NLOS)	0.1011	0.0947

2.2 Channel coherence bandwidth evaluation

The channel coherence bandwidth refers to the channel bandwidth where the channel responses are similar. Frequency selective channels have small coherence bandwidth and flat channels have wider coherence bandwidth. From 14.5.1 of [6] and using the tap delay channel model, the lowpass impulse response for a channel can be written as

$$c(\tau;t)=\sum_{n=-\infty}^{\infty}c_n(t)\delta(\tau-n/W) \qquad \text{Equation 1}$$

where *W* is the system sampling rate. The corresponding time-variant Fourier transfer is

$$C(f;t)=\sum_{n=-\infty}^{\infty}c_n(t)e^{-j2\pi fn/W} \qquad \text{Equation 2}$$

To investigate the frequency selectivity of a channel, we would analyze the autocorrelation of the channel over frequency defined in 14.1.1 of [6]. Hence, the autocorrelation function of C*(f;t)* where *f* is the frequency variable can be defined as

$$\phi_C(f_1,f_2;\Delta t)=\frac{1}{2}E\left[C^*(f_1;t)C(f_2;t+\Delta t)\right] \qquad \text{Equation 3}$$

Since we are interested in the frequency selectivity of an instance of the channel, $\Delta t = 0$. Let $\Delta f = f_1 - f_2$, we have

$$\begin{aligned}\phi_C(\Delta f)&=\frac{1}{2}E\left[\sum_{n=-\infty}^{\infty}c_n^*(t)e^{j2\pi f_1 n/W}\sum_{m=-\infty}^{\infty}c_m(t)e^{-j2\pi f_2 m/W}\right]\\&=\frac{1}{2}\sum_{n=-\infty}^{\infty}E\left(\left|c_n\right|^2\right)e^{j2\pi(f_1-f_2)n/W}=\frac{1}{2}\sum_{n=-\infty}^{\infty}E\left(\left|c_n\right|^2\right)e^{j2\pi\Delta fn/W}\end{aligned} \qquad \text{Equation 4.}$$

Note that $E(|c_n|^2)$ are the various power profile specified in Table 4 to **Table 9**. Plots of Equation 4 for 802.16 SUI, ITU and WINNER channel models can be found in Figure 1, Figure 2 and Figure 3 respectively. In theory, the larger the frequency separation, the smaller the autocorrelation shall be. WINNER channel models in Figure 3 provide the best approximation to a real multipath channel autocorrelation followed by the ITU channel models in Figure 2. Even though the 802.16 SUI channels are more selective in frequency, the ITU channels generate deeper fades. Hence, ITU channels can provide a harsher propagation environment than the SUI channels.

Figure 1. Plot of Equation 4 (spaced-frequency correlation) for 802.16 SUI channel models

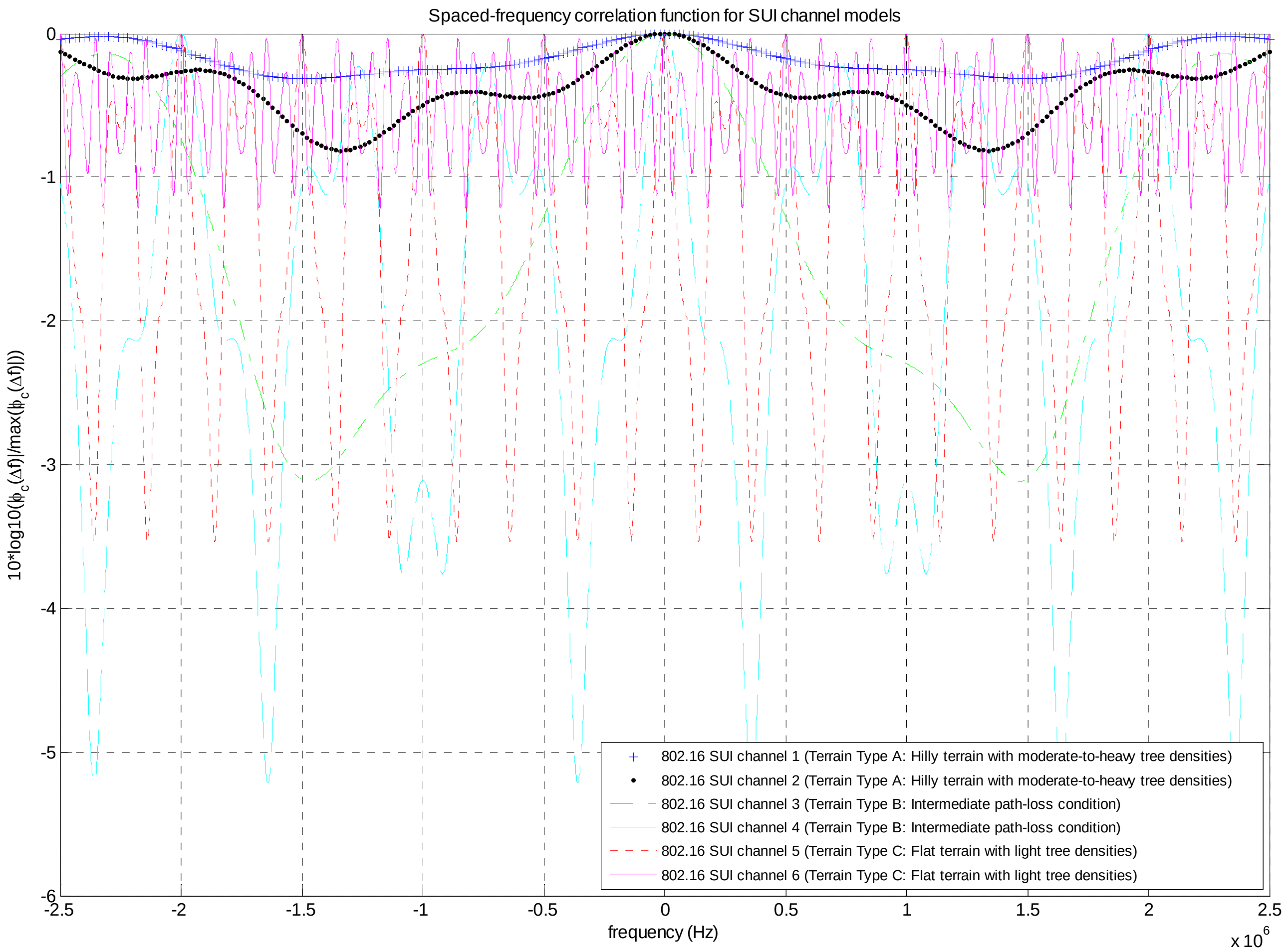


Figure 2. Plot of equation 4 (spaced-frequency correlation) for ITU channel models

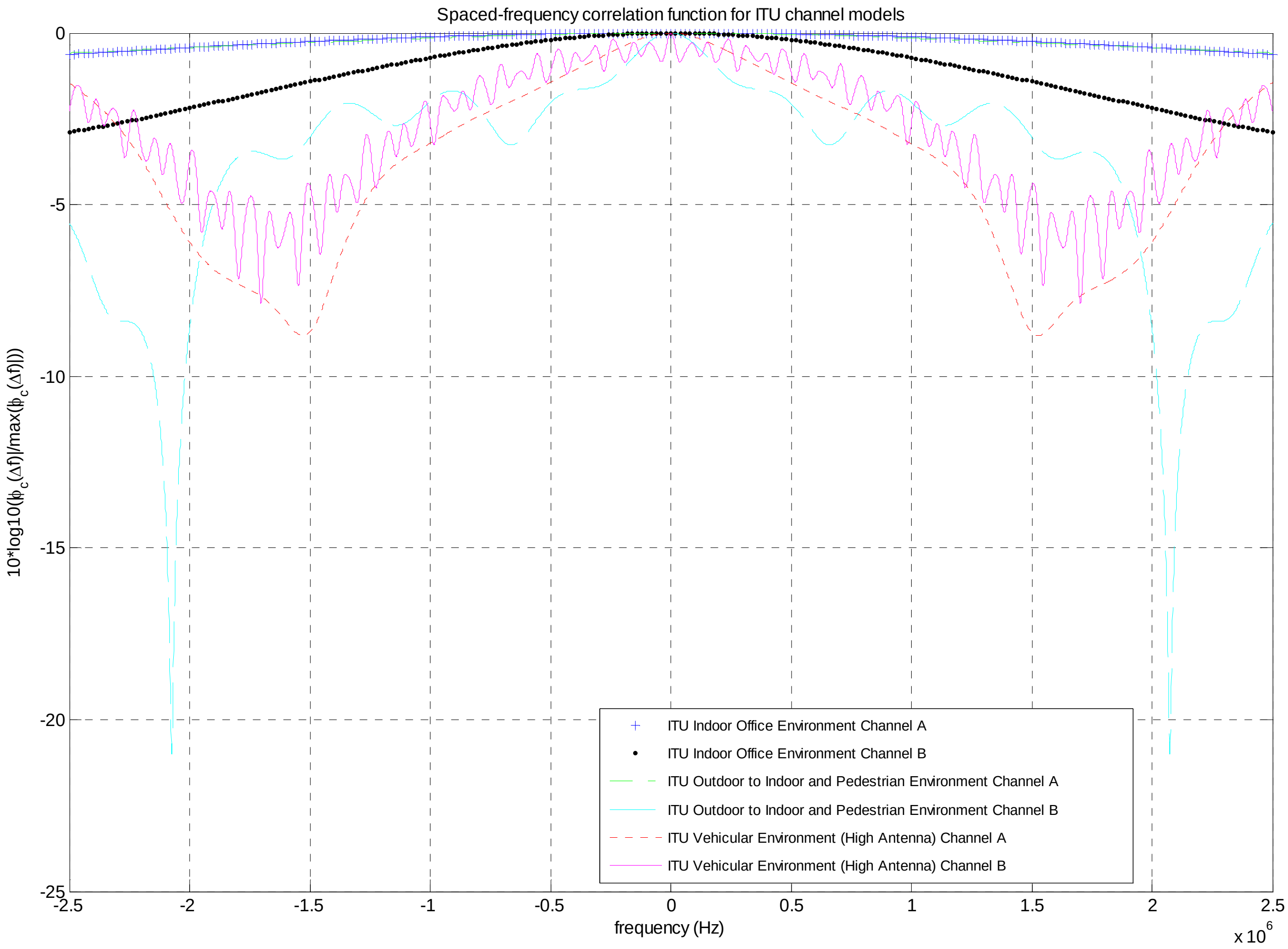
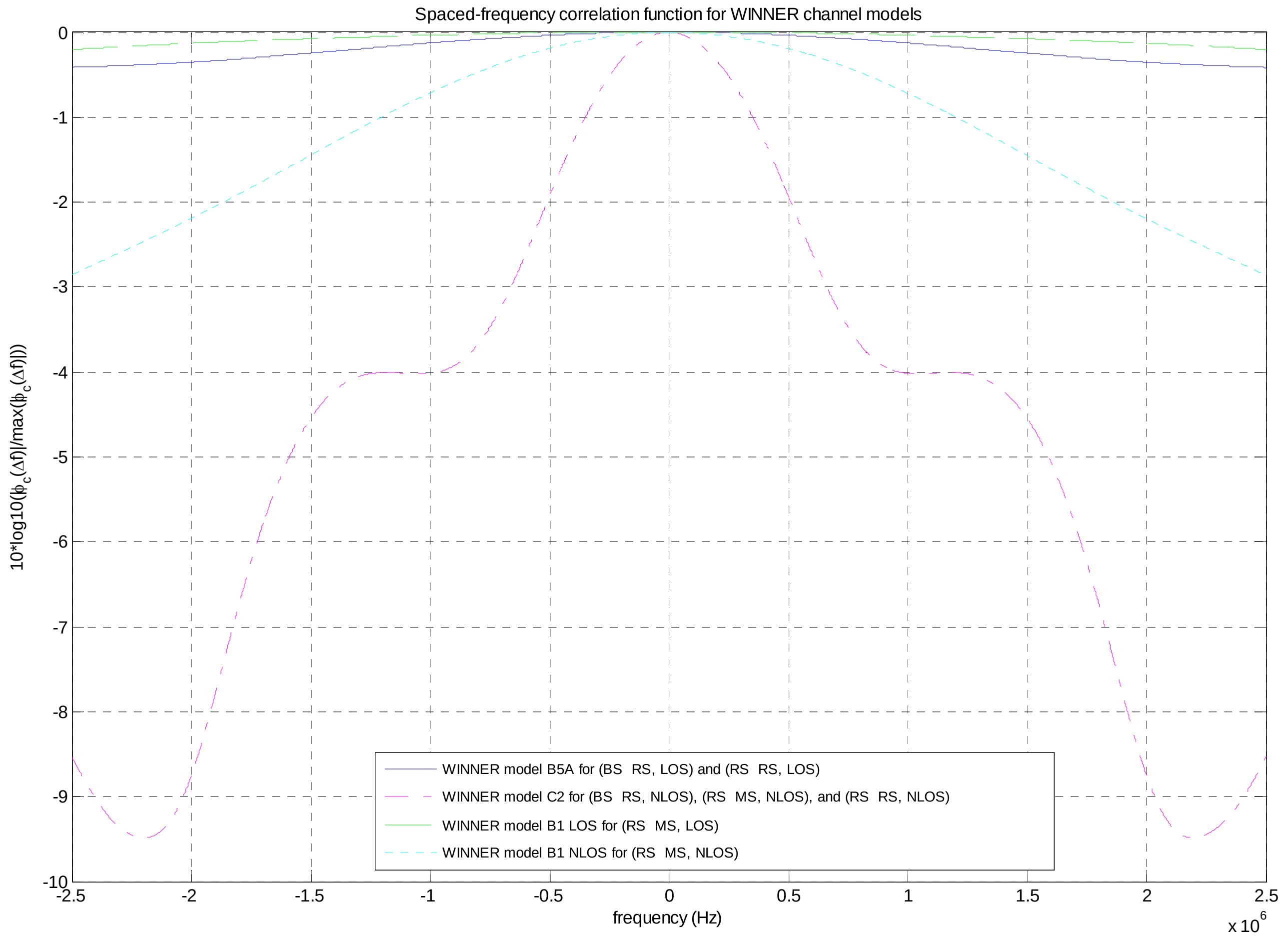


Figure 3. Plot of Equation 4 (spaced-frequency correlation) for WINNER channel models



2.3 Channel coherence time evaluation

2.3.1 Conventional channel coherence time evaluation

Channel coherence time T_C is the time over which the channel may be considered coherent. The definition of coherence time implies that two signals arriving with a time separation greater than T_C are affected differently by the channel. The inverse of the channel coherence time T_C is the minimum channel update rate required for proper channel estimation and equalization, which can be calculated [5] using the Equation 5:

$$T_C = \frac{9}{16 \cdot \pi \cdot f_M} \qquad \text{Equation 5}$$

Table 2 provides a coherence time evaluation for mobiles moving at various speeds using Equation 5. Since each uplink OFDMA slot extends over 3 symbol durations (implying that channel conditions are expected to be constant for 3 symbol durations), 802.16e system may encounter problems for mobile speed of more than 200km/hr since the channel coherence time starts to drop below 3 OFDMA symbol durations.

Table 2. Channel coherence time calculation assuming operating frequency of 3.5GHz

Mobile Speed (km/hr)	$f_M = V/\lambda$ in Hz, V is vehicle speed in m/s and λ is wavelength of RF transmission	Channel coherence time (ms)	Number of OFDMA symbol durations
0	0	∞	∞
20	64.8148	2.7625	30.8189
40	129.6296	1.3812	15.4094
60	194.4444	0.9208	10.2730
80	259.2593	0.6906	7.7047
100	324.0741	0.5525	6.1638
120	388.8889	0.4604	5.1365
140	453.7037	0.3946	4.4027
160	518.5185	0.3453	3.8524
180	583.3333	0.3069	3.4243
200	648.1481	0.2762	3.0819
220	712.9630	0.2511	2.8017
240	777.7778	0.2302	2.5682

2.3.2 Channel coherence time evaluation using Doppler spectra and [6]

Channel coherence time measured how fast a channel can change in the time domain. It is mainly a function of the terminal speed and the propagation environment. In general, the fast a terminal moves, the faster its channel condition will change. If we set $f_1 = f_2$ in Equation 3, we will have

$$\phi_C(f;\Delta t) = \frac{1}{2}E\left[C^*(f;t)C(f;t+\Delta t)\right] \qquad \text{Equation 6.}$$

From Equation 2, assume that $c_n(t) = x_n(t) \otimes D(t)$ where *D(t)* is a Doppler filter and $x_n(t)$ is a i.i.d. random process. Equation 6 will become

$$\begin{aligned}\phi_C(f;\Delta t) &= \frac{1}{2}E\left[\left(\sum_{n=-\infty}^{\infty} c_n(t)e^{-j2\pi fn/W}\right)^*\left(\sum_{m=-\infty}^{\infty} c_m(t+\Delta t)e^{-j2\pi fm/W}\right)\right] \\ &= \frac{1}{2}\sum_{n=-\infty}^{\infty} E\left(c_n(t)\cdot c_n^*(t+\Delta t)\right) = \frac{1}{2}\sum_{n=-\infty}^{\infty}\left(E\left(\left|x_n(t)\right|^2\right)\delta(\Delta t)\right)\otimes D(\Delta t)\otimes D^*(-\Delta t)\end{aligned} \qquad \text{Equation 7}$$

where $\otimes$ denotes convolution.

We ignore the contribution due to the small cross terms in Equation 7 when the second and third taps have nonzero K factor in WINNER channel models.

2.3.3 Doppler spectrum used in our evaluation

Three Doppler spectra were considered in our studies: 802.16, ITU classical and flat spectrum.

The 802.16 Doppler spectrum is

$$S(f)=\begin{cases}1-1.72\,f_0^2+0.785\,f_0^4 & |f_0|\le 1\\ 0 & |f_0|>1\end{cases}\quad \text{where } f_0=\frac{f}{f_D}\qquad \text{Equation 8.}$$

WINNRE uses this spectrum as well.

ITU classical Doppler spectrum is

$$S(f)=\frac{1}{\pi f_D\sqrt{1-(f/f_D)^2}}\qquad \text{Equation 9.}$$

The ITU flat Doppler spectrum is

$$S(f)=\begin{cases}1 & |f_0|\le 1\\ 0 & |f_0|>1\end{cases}\quad \text{where } f_0=\frac{f}{f_D}\qquad \text{Equation 10.}$$

where f_D is the maximum Doppler frequency.

2.3.4 Coherence time calculation result using Doppler spectra

The coherence time is defined to be the time when the magnitude of the correlation values in Equation 7 falls below 3dB for the first time compared to its value at time equal to 0. From Table 3, the ITU classical Doppler spectrum provides the shortest coherence time while 802.16 Doppler spectrum provides the longest coherence time. Using Equation 7, the coherence time calculated is longer than the one calculated in 2.3.1. In this case, the MS speed can go up to 280km/h instead of 200km/h before problem arises.

Table 3. Coherence time calculation using 802.16, Flat and ITU Doppler spectrum

Speed (km/h)	f_D (=f_M) Hz	Doppler Spectrum		
		802.16	ITU Flat	ITU Classical
		Channel Coherence time (ms)		
20	64.8	6.4795	4.6282	3.7026
40	129.6	3.2402	2.3145	1.8516
60	194.4	2.1600	1.5429	1.2343
80	259.3	1.6200	1.1571	0.9257

100	324.1	1.2960	0.9257	0.7406
120	388.9	1.0800	0.7714	0.6172
140	453.7	0.9257	0.6612	0.5290
160	518.5	0.8100	0.5786	0.4629
180	583.3	0.7200	0.5143	0.4114
200	648.1	0.6480	0.4629	0.3703
220	713	0.5891	0.4208	0.3366
240	777.8	0.5400	0.3857	0.3086
260	842.6	0.4985	0.3560	0.2848
280	907.4	0.4629	0.3306	0.2645
300	972.2	0.4320	0.3086	0.2469
320	1037	0.4050	0.2893	0.2314
340	1101.9	0.3812	0.2723	0.2178
360	1166.7	0.3600	0.2571	0.2057
380	1231.5	0.3411	0.2436	0.1949
400	1296.3	0.3240	0.2314	0.1851
420	1361.1	0.3086	0.2204	0.1763
440	1425.9	0.2945	0.2104	0.1683
460	1490.7	0.2817	0.2012	0.1610
480	1555.6	0.2700	0.1929	0.1543
500	1620.4	0.2592	0.1851	0.1481

3 References

[1] "Final Report on Link Level and System Level Channel Model", IST-2003-507581 WINNER, D5.4 v 1.4, https://www.ist-winner.org/.

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[3] IEEE 802.16c-01/029r4: "Channel Models for Fixed Wireless Applications", V. Erceg, et al, 2001-07-16, IEEE 802.16 Broadband Wireless Access Working Group http://ieee802.org/16

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[7] D.S. Baum et.al., "Measurements and characterization of broadband MIMO fixed wireless channels at 2.5GHz", Proceedings of ICPWC'2000, Hyderabad, Dec. 2000.

4 Acknowledgements

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5 Appendix

5.1 Multipath fading model parameters

A tap delay line is used to emulate the multipath fading channel. The channel parameters are derived from actual channel measurements. Depending on the K-factor, each tap coefficient is generated from either a Ricean or Rayleigh random variables. 802.16 (derived from SUI), ITU and WINNER multipath fading model parameters are summarized in Table 4 to Table 9. Details regarding the channel models can be found in [1], [2] and [3].

Table 4. 802.16 - SUI channel models

Terrain Type A: Hilly terrain with moderate-to-heavy tree densities: SUI 1				
	Tap1	**Tap2**	**Tap3**	**Unit**
Delay	0	0.4	0.9	μs
Power	0	-15	-20	dB
K factor	4	0	0	
Doppler	0.4	0.3	0.5	Hz
Terrain Type A: Hilly terrain with moderate-to-heavy tree densities: SUI 2				
	Tap1	**Tap2**	**Tap3**	**Unit**
Delay	0	0.4	1.1	μs
Power	0	-12	-15	dB
K factor	2	0	0	
Doppler	0.2	0.15	0.25	Hz
Terrain Type B: Intermediate path-loss condition: SUI 3				
	Tap1	**Tap2**	**Tap3**	**Unit**
Delay	0	0.4	0.9	μs
Power	0	-5	-10	dB
K factor	1	0	0	
Doppler	0.4	0.3	0.5	Hz
Terrain Type B: Intermediate path-loss condition: SUI 4				
	Tap1	**Tap2**	**Tap3**	**Unit**
Delay	0	1.5	4.0	μs

Power	0	-4	-8	dB
K factor	0	0	0	
Doppler	0.2	0.15	0.25	Hz
Terrain Type C: Flat terrain with light tree densities: SUI 5				
	Tap1	**Tap2**	**Tap3**	**Unit**
Delay	0	4	10	μs
Power	0	-5	-10	dB
K factor	0	0	0	
Doppler	2.0	1.5	2.5	Hz
Terrain Type C: Flat terrain with light tree densities: SUI 6				
	Tap1	**Tap2**	**Tap3**	**Unit**
Delay	0	14	20	μs
Power	0	-10	-14	dB
K factor	0	0	0	
Doppler	0.4	0.3	0.5	Hz

Table 5. ITU channel models

Indoor Office Environment					
Tap	**Channel A (Model No. 1)**		**Channel B (Model No. 2)**		**Doppler Spectrum**
	Relative Delay (ns)	**Average power (dB)**	**Relative Delay (ns)**	**Average power (dB)**	
1	0	0	0	0	Flat
2	50	-3.0	100	-3.6	“
3	110	-10.0	200	-7.2	“
4	170	-18.0	300	-10.8	“
5	290	-26.0	500	-18.0	“
6	310	-32	700	-25.2	“

Outdoor to Indoor and Pedestrian Environment					
Tap	**Channel A (Model No. 3)**		**Channel B (Model No. 4)**		**Doppler Spectrum**
	Relative Delay (ns)	**Average power (dB)**	**Relative Delay (ns)**	**Average power (dB)**	
1	0	0	0	0	Classic

2	110	-9.7	200	-0.9	“
3	190	-19.2	800	-4.9	“
4	410	-22.8	1200	-8.0	“
5	-	-	2300	-7.8	“
6	-	-	3700	-23.9	“

Vehicular Environment (High Antenna)					
Tap	**Channel A (Model No. 5)**		**Channel B (Model No. 6)**		**Doppler Spectrum**
	Relative Delay (ns)	**Average power (dB)**	**Relative Delay (ns)**	**Average power (dB)**	
1	0	0	0	-2.5	Classic
2	310	-1.0	300	0	“
3	710	-9.0	8,900	-12.8	“
4	1,090	-10.0	12,900	-10.0	“
5	1,730	-15.0	17,100	-25.2	“
6	2,510	-20.0	20,000	-16.0	“

Table 6. WINNER model B5A for BS↔RS, LOS) and (RS↔RS, LOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	-0.39	0.0	0.0	21.8
2	10	-20.6	0.9	0.2	$-\infty$
3	20	-26.8	0.3	1.5	
4	50	-24.2	-0.3	2.0	
5	90	-15.3	3.9	0.0	
6	95	-20.5	-0.8	3.6	
7	100	-28.0	4.2	-0.7	
8	180	-18.8	-1.0	4.0	
9	205	-21.6	5.5	-2.0	
10	260	-19.9	7.6	-4.1	

Table 7. WINNER model C2 for (BS↔RS, NLOS), (RS↔MS, NLOS), and (RS↔RS, NLOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	-0.5	0	0	$-\infty$
2	5	0.0	4	4	
3	135	-3.4	-3	7	
4	160	-2.8	-4	10	
5	215	-4.6	-7	21	
6	260	-0.9	8	-45	
7	385	-6.7	10	-75	
8	400	-4.5	17	65	
9	530	-9.0	-8	160	
10	540	-7.8	-8	155	
11	650	-7.4	-4	88	
12	670	-8.4	-7	80	
13	720	-11.0	-9	-90	
14	750	-9.0	-9	-105	
15	800	-5.1	12	8	
16	945	-6.7	-17	45	
17	1035	-12.1	19	50	
18	1185	-13.2	12	-15	
19	1390	-13.7	19	-25	
20	1470	-19.8	21	100	

Table 8. WINNER model B1 LOS for (RS↔MS, LOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	0	0	0	16
2	10	-1.2	-22	-10	9
3	30	-4.4	-12	20	3
4	45	-8.4	-2	-123	$-\infty$
5	65	-13.0	10	-31	
6	85	-15.1	-4	161	
7	105	-16.1	8	-7	

Table 9. WINNER model B1 NLOS for (RS↔MS, NLOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	-1.25	4	0	9
2	10	0	40	25	6
3	40	-0.38	-10	29	$-\infty$
4	60	-0.10	48	-31	
5	85	-0.73	-36	37	
6	110	-0.63	-40	21	
7	135	-1.78	-26	13	
8	165	-4.07	-28	117	
9	190	-5.12	-12	21	
10	220	-6.34	-14	1	
11	245	-7.35	14	15	
12	270	-8.86	8	9	
13	300	-10.1	-24	19	
14	325	-10.5	-14	1	
15	350	-11.3	-22	-13	
16	375	-12.6	2	11	
17	405	-13.9	8	-1	
18	430	-14.1	-2	43	
19	460	-15.3	-10	33	
20	485	-16.3	-54	-19	