Abstract—This paper explains an important requirement for assessing technology for Broadband Fixed Wireless channel presented by a time-varying broadband wireless channel. The paper determined the major factor affecting the broadband wireless channels. We study BER with SNR for multipath Fading Channel with different modulation type, coding and multi requirements and conditions that can be used to as a recommendation in communication system. With the introduced techniques, it is even possible in many cases to take advantage of what were originally viewed as impedance and working to solve it.

Keywords—WiMAX, wireless networking, Channel Models, propagation loss, Multipath Fading Channel.

I. INTRODUCTION

An important requirement for assessing technology for Broadband Fixed Wireless Applications is to have an accurate description of the wireless channel [2]. Channel models are heavily dependent upon the radio architecture. For example, in first generation systems, a super-cell or “single-stick” architecture is used where the Base Station (BTS) and the subscriber station are in Line-of-Sight (LOS) condition and the system uses a single cell with no co-channel interference. For second generation systems a scalable multi-cell architecture with Non-Line-of-Sight (NLOS) conditions becomes necessary. The wireless channel is characterized by that Path loss (including shadowing), Multipath delay spread, Fading characteristics, Doppler spread and Co-channel and adjacent channel interference. It is to be noted that these parameters are random and only a statistical characterization is possible. Typically, the mean and variance of parameters are specified. The parameter of wave propagation depend upon terrain, tree density, antenna height and beam width, wind speed, and season (time of the year). The Physics of radio propagation depends on Free-space propagation, reflection, diffraction, scattering, and multipath fading.

The paper is organized as follows. In section II, System Model and Analysis, Section III, simulated results, Section V, Conclusion.

II. SYSTEM MODEL AND ANALYSIS

A. There are two types of propagation models:

1. Large-scale models

   Variation in mean received signal strength over large T-R distances (100s or 1000s of meters) and long-time-scales. Measured by averaging over 5λ to 40λ, i.e. 1-10m in cellular/PCS 1-2GHz band.

2. Small scale effects

   Fluctuations of the received signal strength about a local mean for small travel distances (few λs) and short time intervals (seconds) fading. The main goal is to explain the fundamental factors affecting the received signal in a wireless system and how they can be modeled using a handful of parameters. The relative values of these parameters, which are summarized in Table 1. The overall model used for describing the channel in discrete time is a simple tape-delay line (TDL):

\[ h[k,t] = h_0[k,t] + h_1[\delta k - 1,t] + \ldots + h_c[\delta k - v,t] \]

(1)

Here, the discrete-time channel is time-varying—so it changes with respect to t, and has non-negligible values over a span of \( v + 1 \) channel taps. Generally, assume that the channel is sampled at a frequency \( f_s = 1/T \).

Where T is the symbol period, and hence, the duration of the channel in this case is about \( vT \). The sampled values are in general complex numbers.

Assuming that the channel is static over a period of seconds, we can then describe the output of the channel as

\[ y[k,t] = \sum_{j=-\infty}^{\infty} h[j,t] x[k-j] \]

(2)

\[ \equiv h[k,t] \otimes x[k] \]

(3)
Where $x[k]$ is an input sequence of data symbols with rate $1/T$, and $*$ denotes convolution. In simpler notation, the channel can be represented as a time-varying $(v+1)*1$ column vector

$$h(t) = [h_0(t) h_1(t) \ldots h_v(t)]^T$$

(4)

Although this tapped-delay-line model is general and accurate, it is difficult to design a communication system for the channel without knowing some of the key attributes about $h(t)$.

There are a number of effects cause the received power to vary from overlong (Path loss), medium (Shadowing), and short (Fading) distance.

Path loss

The free-space path loss formula, or Fries formula, is given more precisely as

$$P_r = P_t \frac{\lambda^2 G_t G_r}{(4\pi d)^2}$$

(5)

And the common two-ray approximation for path loss is

$$P_r = P_t \frac{G_t G_r h_0^2 h_r^2}{d^4}$$

(6)

In order to more accurately describe various propagation environments, empirical models are often developed using experimental data. One of the simplest and most common is the empirical path loss formula:

$$P_r = P_t P_0 \left( \frac{d_0}{d} \right)^\alpha$$

(7)

**TABLe 1. KEY WIRELESS CHANNEL PARAMETERS [1].**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Path loss exponent</td>
</tr>
<tr>
<td>$\sigma_s$</td>
<td>Lognormal shadowing standard deviation</td>
</tr>
<tr>
<td>$f_D$</td>
<td>Doppler spread (maximum Doppler frequency), $f_D = \frac{vf_c}{c}$</td>
</tr>
<tr>
<td>$T_C$</td>
<td>Channel coherence time, $T_C \approx f_D^{-1}$</td>
</tr>
<tr>
<td>$\tau_{max}$</td>
<td>Channel delay spread (maximum)</td>
</tr>
<tr>
<td>$\tau_{RMS}$</td>
<td>Channel delay spread (RMS)</td>
</tr>
<tr>
<td>$B_C$</td>
<td>Channel coherence bandwidth,</td>
</tr>
<tr>
<td>$\theta_{RMS}$</td>
<td>Angular spread (RMS)</td>
</tr>
</tbody>
</table>

Shadowing

With shadowing, the empirical pathloss formula becomes

$$P_r = P_t P_0 \chi \left( \frac{d_0}{d} \right)^\alpha$$

(8)

Shadowing is often alternatively called large-scale fading.

The shadowing value $\chi$ is typically modeled as a lognormal random variable, that is,

$$\chi = 10^{x/10}, \text{where} \ldots x \sim N(0, \sigma_s^2)$$

(9)

B. SUBURBAN PATH LOSS MODEL

The Hata-Okumura model [3, 4] is valid for the 500-1500 MHz frequency range, receiver distances greater than 1 km from the base station, and base station antenna heights greater than 30 m.
Table 2
The terrain category given [3].

<table>
<thead>
<tr>
<th>Category</th>
<th>Path loss</th>
<th>Terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Maximum</td>
<td>hilly terrain with moderate-to-heavy tree densities</td>
</tr>
<tr>
<td>B</td>
<td>Intermediate</td>
<td>Intermediate tree density</td>
</tr>
<tr>
<td>C</td>
<td>Minimum</td>
<td>mostly flat terrain with light tree densities</td>
</tr>
</tbody>
</table>

\[ PL = A + 10\gamma \log_{10}\left(\frac{d}{d_o}\right) + s \]

For \( d > d_o \)

\[ \text{Where} \quad A = 20\log_{10}\left(\frac{4\pi d_o}{\lambda}\right) \quad (\lambda \text{ being the wavelength in m}), \quad \gamma = \text{is the path-loss exponent with} \quad \gamma = (a - bh_b + c/h_b) \quad \text{for} \quad h_b \text{ between} \quad 10 \text{ m and} \quad 80 \text{ m} \]

\( (h_b \text{ is the height of the base station in m}), \quad d_o = 100\text{m} \text{ and} \quad a, b, c \text{ are constants dependent on the terrain category given in [5] and shown in table 2.} \)

The shadowing effect is represented by \( s \), which follows lognormal distribution. The typical value of the standard deviation for \( s \) is between 8.2 and 10.6 dB, depending on the terrain/tree density type.

\[ K = F_s F_h F_b K_o d^\gamma u \]

\[ F_s \] Is a seasonal factor, \( F_s = 1.0 \) in summer (leaves); 2.5 in winter (no leaves).

\[ F_h \] Is the receive antenna height factor,

\[ F_b \] Is the beam width factor

\[ F_b = (b/17)^{-0.62}; \quad (b \text{ in degrees}) \]

\[ K_o \quad \text{And} \quad \gamma \quad \text{are regression coefficients}, \quad K_o = 10; \quad \gamma = -0.5 \]

\( u \) Is a lognormal variable which has zero dB mean and a std. deviation of 8.0 dB.

Using this model, one can observe that the K-factor decreases as the distance increases and as antenna beam width increases. We would like to determine K-factors that meet the requirement that 90% of all locations within a cell have to be services with 99.9% reliability. The calculation of K-factors for this scenario is rather complex since it also involves path loss, delay spread, antenna correlation (if applicable), specific modem characteristics, and other parameters that influence system performance. However, we can obtain an approximate value as follows: First we select 90% of the users with the highest K-factors over the cell area. Then we obtain the approximate value by selecting the minimum K-factor within the set.

In [8], an excellent agreement with the model was reported using an independent set of experimental data collected in San Francisco Bay Area at 2.4 GHz and similar antenna heights. The narrowband K-factor distribution was found to be lognormal, with the median as a simple function of season, antenna height, antenna beam width, and distance. The standard deviation was found to be approximately 8 dB. The model presented in [7] is as follows

\[ K = F_s F_h F_b K_o d^\gamma u \]

\[ F_s \]

\[ F_h \]

\[ F_b \]

\[ F_{b} = (b/17)^{-0.62}; \quad (b \text{ in degrees}) \]

\[ K_{o} \quad \text{And} \quad \gamma \quad \text{are regression coefficients}, \quad K_{o} = 10; \quad \gamma = -0.5 \]

\[ u \]

\[ \text{Is a lognormal variable which has zero dB mean and a std. deviation of 8.0 dB.} \]
For a typical deployment scenario (see later section on SUI channel models) this value of $K$-factor can be close or equal to 0.

Figure 1 shows fading cumulative distribution functions (CDFs) for various $K$ factors. For example, for $K = 0 \text{ dB}$ (linear $K = 1$) a 30 dB fade occurs $10^{-3}$ of the time, very similar to a Rayleigh fading case (linear $K = 0$). For a $K$ factor of 6 dB, the probabilities of a 30 dB fade drops to $10^{-4}$. The significance of these fade probabilities depends on the system design, for example whether diversity or retransmission (ARQ) is provided, and the quality of service (QoS) being offered.

These models can be used for simulations, design, and development and testing of technologies suitable for fixed broadband wireless applications. The parameters were selected based upon statistical models described in previous sections.

The parametric view of the SUI channels is summarized in the following tables.

**Table 3**

<table>
<thead>
<tr>
<th>Terrain Type</th>
<th>SUI Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>SUI-1, SUI-2</td>
</tr>
<tr>
<td>B</td>
<td>SUI-3, SUI-4</td>
</tr>
<tr>
<td>A</td>
<td>SUI-5, SUI-6</td>
</tr>
</tbody>
</table>

**Table 4**

<table>
<thead>
<tr>
<th>Doppler</th>
<th>Low delay spread</th>
<th>Moderate delay spread</th>
<th>High delay spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>SUI-3</td>
<td>SUI-5</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>SUI-4</td>
<td>SUI-6</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5**

<table>
<thead>
<tr>
<th>Doppler</th>
<th>Low delay spread</th>
<th>Moderate delay spread</th>
<th>High delay spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>SUI-1, SUI-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The generic structure for the SUI Channel model is given below in figure 2.

**Figure 1**: Ricean fading distributions [1].

**Figure 2**: The generic structure for the SUI Channel model [2].
The above structure is general for Multiple Input Multiple Output (MIMO) channels and includes other configurations like Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) as subsets. The SUI channel structure is the same for the primary and interfering signals.

Input Mixing Matrix: This part models correlation between input signals if multiple transmitting antennas are used.

Tapped Delay Line Matrix: This part models the multipath fading of the channel. The multipath fading is modeled as a tapped-delay line with 3 taps with non-uniform delays. The gain associated with each tap is characterized by a distribution (Ricean with a K-factor > 0, or Rayleigh with K-factor = 0) and the maximum Doppler frequency.

Output Mixing Matrix: This part models the correlation between output signals if multiple receiving antennas are used.

Using the above general structure of the SUI Channel and assuming the following scenario, six SUI channels are constructed which are representative of the real channels.

Notes: See Appendix A (tables 8, 9, 10, 11, 12, 13)

1) The total channel gain is not normalized. Before using a SUI-X model, the specified normalization factors have to be added to each tap to arrive at 0dB total mean power (included in the tables).
2) The specified Doppler is the maximum frequency parameter (f_m) of the rounded spectrum, as described above.
3) The Gain Reduction Factor (GRF) is the total mean power reduction for a 30° antenna compared to an Omni antenna. If 30° antennas are used the specified GRF should be added to the path loss. Note that this implies that all 3 taps are affected equally due to effects of local scattering.
4) K-factors have linear values, not dB values.
5) K-factors in the tables were rounded to the closest integer.
6) K-factors for the 90% and 75% cell coverage are shown in the tables, i.e. 90% and 75% of the cell locations have K factors greater or equal to the K-factor value specified, respectively. For the SUI channels 5 and 6, 50% K-factor values are also shown in the tables in Appendix A.

III. SIMULATED RESULTS

Simulate the channel impulse response for BPSK and BW 10MHZ: [H. axis SNR (dB) - V. axis BER]

All the simulation runs for \( N_{\text{fft}} = 256 \), BPSK rate \( \frac{1}{2} \text{ CC} \), QPSK, 16QAM, and 64QAM rate \( \frac{3}{4} \text{ CC} \)

For 1000 OFDM Symbols.


Figure 3: BER & SNR plot for different channel type (SUI) on BW 10MHz and cyclic prefix 1/4

For 100 OFDM Symbols.

Time taken for the simulation = 49.3043 minutes [11].

Figure 4: BER & SNR plot for different channel type (SUI) on BW 10MHz and cyclic prefix 1/8

For 100 OFDM Symbols.

Time taken for the simulation = 49.3043 minutes [11].
Figure 5: BER & SNR plot for different channel type (SUI) on BW 10MHz and cyclic prefix 1/8
For 1000 OFDM symbols.

Figure 6: BER & SNR plot for different channel type (SUI) On BW 10MHz and cyclic prefix 1/8
For 1000 OFDM symbols in another time $h (+\Delta t)$

Figure 7: BER & SNR plot for different channel type (SUI) on BW 10MHz and cyclic prefix 1/16
For 100 OFDM symbols.
Time taken for the simulation = 53.3043 minutes [11].

Figure 8: BER & SNR plot for different channel type (SUI) on BW 10MHz and cyclic prefix 1/32
For 1000 OFDM symbols.
Time taken for the simulation = 7.6925 hours [11].
Simulate the channel impulse response for QPSK and BW 10MHz.

For 100 OFDM symbols, the time taken for the simulation is approximately 1.0134 hours [11].

Figure 9: BER & SNR plot for different channel type (SUI) on BW 10MHz and cyclic prefix 1/32

For 100 OFDM symbols in another time $h(t+\Delta t)$, the time taken for the simulation is 55.1903 minutes [11].

Figure 11: BER & SNR plot for different channel type (SUI) on BW 10MHz, QPSK and cyclic prefix 1/8

For 100 OFDM symbols, the time taken for the simulation is approximately 1.0134 hours [11].

Figure 10: BER & SNR plot for different channel type (SUI) on BW 10MHz, QPSK and cyclic prefix 1/4

For 100 OFDM symbols, the time taken for the simulation is approximately 1.01 hours [11].

Figure 12: BER & SNR plot for different channel type (SUI) on BW 10MHz, QPSK and cyclic prefix 1/8

For 100 OFDM symbols, the time taken for the simulation is approximately 1.0134 hours [11].
Simulate the channel impulse response for 16QAM and BW 10MHz:

Figure 13: BER & SNR plot for different channel type (SUI) on BW 10MHz, QPSK and cyclic prefix 1/16
For 200 OFDM symbols.
Time taken for the simulation = 1.8519 hours [11].

Figure 14: BER & SNR plot for different channel type (SUI) on BW 10MHz, QPSK and cyclic prefix 1/32
For 200 OFDM symbols.
Time taken for the simulation = 1.7672 hours [11].

Figure 15: BER & SNR plot for different channel type (SUI) on BW 10MHz, 16QAM and cyclic prefix 1/4
For 2000 OFDM symbols.

Figure 16: BER & SNR plot for different channel type (SUI) on BW 10MHz, 16QAM and cyclic prefix 1/8
For 500 OFDM symbols.
Figure 17: BER & SNR plot for different channel type (SUI) on BW 10MHz, 16QAM and cyclic prefix 1/8
For 100 OFDM symbols in another time $h (t+\Delta t)$.
Time taken for the simulation = 1.3583 hours [11].

Figure 18: BER & SNR plot for different channel type (SUI) on BW 10MHz, 16QAM and cyclic prefix 1/16
For 100 OFDM symbols.

Figure 19: BER & SNR plot for different channel type (SUI) on BW 10MHz, 16QAM and cyclic prefix 1/32
For 100 OFDM symbols.
Time taken for the simulation = 59.1083 minutes [11].

Simulate the channel impulse response for 64QAM and BW 10MHZ:

Figure 20: BER & SNR plot for different channel type (SUI) on BW 10MHz, 64QAM and cyclic prefix 1/4
For 100 OFDM symbols.
Time taken for the simulation = 2.2276 hours [11].
Figure 21: BER & SNR plot for different channel type (SUI) on BW 10MHz, 64QAM and cyclic prefix 1/8

For 100 OFDM symbols.

Figure 22: BER & SNR plot for different channel type (SUI) on BW 10MHz, 64QAM and cyclic prefix 1/16

For 100 OFDM symbols.
Time taken for the simulation = 2.2685 hours [11].

Figure 23: BER & SNR plot for different channel type (SUI) on BW 10MHz, 64QAM and cyclic prefix 1/32

For 200 OFDM symbols.
Time taken for the simulation = 2.1312 hours [11].

Figure 24: BER & SNR plot for different channel type (SUI) on BW 10MHz, 64QAM and cyclic prefix 1/32

For 1000 OFDM symbols in another time $h + \Delta t$
Table 6
SNR required at BER level $10^{-3}$ for different Modulation and Coding profile [11].

<table>
<thead>
<tr>
<th>Channel SNR (dB) at BER level $10^{-3}$</th>
<th>BPSK $\frac{1}{2}$</th>
<th>QPSK $\frac{1}{2}$</th>
<th>QPSK $\frac{3}{4}$</th>
<th>16-QAM $\frac{1}{2}$</th>
<th>16-QAM $\frac{3}{4}$</th>
<th>64-QAM $\frac{2}{3}$</th>
<th>64-QAM $\frac{3}{4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUI-1</td>
<td>4.3</td>
<td>6.6</td>
<td>10</td>
<td>12.3</td>
<td>15.7</td>
<td>19.4</td>
<td>21.3</td>
</tr>
<tr>
<td>SUI-2</td>
<td>7.5</td>
<td>10.4</td>
<td>14.1</td>
<td>16.25</td>
<td>19.5</td>
<td>23.3</td>
<td>25.4</td>
</tr>
<tr>
<td>SUI-3</td>
<td>12.7</td>
<td>17.2</td>
<td>22.7</td>
<td>22.7</td>
<td>28.3</td>
<td>30</td>
<td>32.7</td>
</tr>
</tbody>
</table>

Figure 25: Scatter Plots for 16-QAM modulation (RS-CC 1/2) in SUI-1
Channel model ‘+’ transmitted data and ‘*’ received data [11].

Figure 26: BER & SNR plot for 16-QAM modulation (RS-CC 1/2) in SUI-2

Figure 27: BER & SNR plot for 16-QAM $\frac{1}{2}$ On different SUI channel [11].

Figure 28: BER & SNR plot for different modulation and Coding profiles on SUI-1 [11].
Table 7: SNR required at BLER level $10^{-2}$ for different Modulation and coding profile [11].

<table>
<thead>
<tr>
<th>Channel</th>
<th>SNR (dB) at BLER level $10^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUI-1</td>
<td>7.3 7 11 12.6 15.6 19.6 21.3</td>
</tr>
<tr>
<td>SUI-2</td>
<td>10.7 12.7 15.4 16.5 20.8 23.8 26.1</td>
</tr>
<tr>
<td>SUI-3</td>
<td>15 17.7 22.7 24.4 28.8 31.2 33.8</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

In this paper, we attempted to understand and characterize the challenging and multifaceted broadband wireless channel.

• The average value of the channel power can be modeled based simply on the distance between the transmitter and the receiver, the carrier frequency, and the pathless exponent.

• The large-scale perturbations from this average channel can be characterized as lognormal shadowing.

• The small-scale channel effects are known collectively as fading. Broadband wireless channels have autocorrelation functions that tell us a lot about their behavior.

Acknowledgements

The authors would like to thank Dr. Amr Hassan Yassin for his helpful comments.

REFERENCES

### Table 8
#### SUI – 1 Channel [11]

<table>
<thead>
<tr>
<th>SUI – 1 Channel</th>
<th>Tap 1</th>
<th>Tap 2</th>
<th>Tap 3</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0</td>
<td>0.4</td>
<td>0.9</td>
<td>µs</td>
</tr>
<tr>
<td>Power (omni ant.)</td>
<td>0</td>
<td>-15</td>
<td>-20</td>
<td>dB</td>
</tr>
<tr>
<td>90% K-fact. (omni)</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>75% K-fact. (omni)</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Power (30° ant.)</td>
<td>0</td>
<td>-21</td>
<td>-32</td>
<td>dB</td>
</tr>
<tr>
<td>90% K-fact. (30°)</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>75% K-fact. (30°)</td>
<td>72</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Doppler</td>
<td>0.4</td>
<td>0.3</td>
<td>0.5</td>
<td>Hz</td>
</tr>
</tbody>
</table>

- **Antenna Correlation:** $\rho_{\text{ENV}} = 0.7$
- **Gain Reduction Factor:** $\text{GRF} = 0$ dB
- **Normalization Factor:**
  - $F_{\text{omni}} = -0.1771$ dB
  - $F_{30°} = -0.0371$ dB

#### Terrain Type: C
- **Omni antenna:** $\tau_{\text{RMS}} = 0.111$ µs
- Overall K:
  - 3.3 (90%); $K = 10.4$ (75%)
- **30° antenna:** $\tau_{\text{RMS}} = 0.042$ µs
- Overall K:
  - 14.0 (90%); $K = 44.2$ (75%)

### Table 9
#### SUI – 2 Channel [11]

<table>
<thead>
<tr>
<th>SUI – 2 Channel</th>
<th>Tap 1</th>
<th>Tap 2</th>
<th>Tap 3</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0</td>
<td>0.4</td>
<td>1.1</td>
<td>µs</td>
</tr>
<tr>
<td>Power (omni ant.)</td>
<td>0</td>
<td>-12</td>
<td>-15</td>
<td>dB</td>
</tr>
<tr>
<td>90% K-fact. (omni)</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>75% K-fact. (omni)</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Power (30° ant.)</td>
<td>0</td>
<td>-18</td>
<td>-27</td>
<td>dB</td>
</tr>
<tr>
<td>90% K-fact. (30°)</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>75% K-fact. (30°)</td>
<td>36</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Doppler</td>
<td>0.2</td>
<td>0.15</td>
<td>0.25</td>
<td>Hz</td>
</tr>
</tbody>
</table>

- **Antenna Correlation:** $\rho_{\text{ENV}} = 0.5$
- **Gain Reduction Factor:** $\text{GRF} = 2$ dB
- **Normalization Factor:**
  - $F_{\text{omni}} = -0.3930$ dB
  - $F_{30°} = -0.0678$ dB

#### Terrain Type: C
- **Omni antenna:** $\tau_{\text{RMS}} = 0.202$ µs
- Overall K:
  - 1.6 (90%); $K = 5.1$ (75%)
- **30° antenna:** $\tau_{\text{RMS}} = 0.069$ µs
- Overall K:
  - 6.9 (90%); $K = 21.8$ (75%)
### Table 10  
**SUI – 3 Channel** [11].

<table>
<thead>
<tr>
<th>Units</th>
<th>Tap 1</th>
<th>Tap 2</th>
<th>Tap 3</th>
<th>Delay (µs)</th>
<th>Power (omni)</th>
<th>Power (30°)</th>
<th>Doppler (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0</td>
<td>0.4</td>
<td>0.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>Power (omni)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>90% K-fact.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>(omni)</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>75% K-fact.</td>
<td>0</td>
<td>-11</td>
<td>-22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>(omni)</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Antenna Correlation:**
\[ \rho = 0.4 \]

**Gain Reduction Factor:**
GRF = 3 dB

**Normalization Factor:**
F<sub>omni</sub> = -1.5113 dB,
F<sub>30°</sub> = -0.3573 dB

---

### Table 11  
**SUI – 4 Channel** [11].

<table>
<thead>
<tr>
<th>Units</th>
<th>Tap 1</th>
<th>Tap 2</th>
<th>Tap 3</th>
<th>Delay (µs)</th>
<th>Power (omni)</th>
<th>Power (30°)</th>
<th>Doppler (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0</td>
<td>1.5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Power (omni)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
<td>90% K-fact.</td>
<td>0</td>
<td>-4</td>
<td>-8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>(omni)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>75% K-fact.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>(omni)</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Antenna Correlation:**
\[ \rho = 0.3 \]

**Gain Reduction Factor:**
GRF = 4 dB

**Normalization Factor:**
F<sub>omni</sub> = -1.9218 dB,
F<sub>30°</sub> = -0.4532 dB

---

**Terrain Type: B**

**Omni antenna:**
\[ \tau_{RMS} = 0.264 \mu s, \]

Overall K:
K = 0.5 (90%);
K = 1.6 (75%)

**30° antenna:**
\[ \tau_{RMS} = 0.123 \mu s, \]

Overall K:
K = 2.2 (90%);
K = 7.0 (75%)

---

**Terrain Type: B**

**Omni antenna:**
\[ \tau_{RMS} = 1.257 \mu s, \]

Overall K:
K = 0.2 (90%);
K = 0.6 (75%)

**30° antenna:**
\[ \tau_{RMS} = 0.563 \mu s, \]

Overall K:
K = 1.0 (90%);
K = 3.2 (75%)
### Table 12
**SUI – 5 Channel** [11].

<table>
<thead>
<tr>
<th>Units</th>
<th>Tap 1</th>
<th>Tap 2</th>
<th>Tap 3</th>
<th>Power (omni ant.)</th>
<th>Power (30° ant.)</th>
<th>Gain Reduction Factor: GRF = 4 dB</th>
<th>Normalization Factor: F_{omni} = -1.5113 dB, F_{30°} = -0.3573 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Power (omni)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>90% K-fact. (omni)</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>75% K-fact. (omni)</td>
<td>10</td>
<td>-10</td>
<td>-22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>50% K-fact. (omni)</td>
<td>14</td>
<td>-14</td>
<td>-26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Antenna Correlation: $\rho_{ENV} = 0.3$</td>
<td>Doppler</td>
<td>2.842 µs, $\tau_{RMS}$</td>
<td>2.370 µs, $\tau_{RMS}$</td>
<td>0.4 Hz, $\tau_{RMS}$</td>
<td>0.3 Hz, $\tau_{RMS}$</td>
<td>0.5 Hz, $\tau_{RMS}$</td>
<td></td>
</tr>
</tbody>
</table>

### Table 13
**SUI – 6 Channel** [11].

<table>
<thead>
<tr>
<th>Units</th>
<th>Tap 1</th>
<th>Tap 2</th>
<th>Tap 3</th>
<th>Power (omni ant.)</th>
<th>Power (30° ant.)</th>
<th>Gain Reduction Factor: GRF = 4 dB</th>
<th>Normalization Factor: F_{omni} = -0.5683 dB, F_{30°} = -0.1184 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Power (omni)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>90% K-fact. (omni)</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>75% K-fact. (omni)</td>
<td>14</td>
<td>-14</td>
<td>-26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>50% K-fact. (omni)</td>
<td>20</td>
<td>-20</td>
<td>-30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Antenna Correlation: $\rho_{ENV} = 0.3$</td>
<td>Doppler</td>
<td>5.240 µs, $\tau_{RMS}$</td>
<td>2.370 µs, $\tau_{RMS}$</td>
<td>0.4 Hz, $\tau_{RMS}$</td>
<td>0.3 Hz, $\tau_{RMS}$</td>
<td>0.5 Hz, $\tau_{RMS}$</td>
<td></td>
</tr>
</tbody>
</table>