Abstract— This paper presents the proposed wireless multipath propagation model based on multipath power delay profile for short-range and near to the ground for the frequencies range of 1 to 3GHz. In wireless sensor networks (WSN) localization algorithm, the propagation model has been used as a function of distance to estimate the range. The multipath phenomenon causes the errors in estimation of the received power. Without directly use the received power value to estimate the range, we can be increase the accuracy by exploiting the periodicity of the deep fade since multipath behave differently in the certain frequency range.

Index Terms — Propagation model, short-range communication, near ground communication, wireless sensor networks, cognitive radio

I. INTRODUCTION

The propagation of wireless signals in indoor and outdoor environments such as foliage, urban and in the building has different characteristic and multipath is one of the causes factor. Multipath is a propagation phenomenon resulting from a transmitted signal reaching at receiver by finite number of paths and dependent on the density of the scattering along the paths. These result the signal received at the receiver experiencing random delays, reflected, scattered and diffracted. Depending on the nature of the radio propagation environment, different models are required to represent the statistical behaviour of the signal. As the range estimate in WSN become more difficult [1].

Increasing the number of wireless users make the frequency spectrum over crowded. It caused some of the user been blocked when the numbers of users reach certain limit. Cognitive radio introduced by [2] is capable to increase the number of user, by reusing the frequency of white space. Other technique to increase the frequency reuse rate is by reducing the radio radius zone size as in cellular communication [3]. Therefore short-range wireless communications over distances of less than 100 meters is the most rapidly growing segment of wireless engineering [4], such as vehicle-to-vehicle or inter-vehicle communication and WSN communication.

In WSN the maximum range of the communication between the sensor nodes is in short range normally 50 to 100 meters. Therefore the probability the line-of-sight (LOS) exist is high [5]. The range is short is due to the low transmitting power and the sensitivity of the sensor node antenna. Low power sensor node is required since the small size of the power cell due to limited the physical size and assumes to be unattended after deployed.

When the antenna height is decreased the Ricean $K$ factor drops, indicating an increase in the relative strength of the multipath component compared with that of the direct component of the received signal. The relative strength remains large for short distances and significantly decreases with increasing distance [6]. At a certain antenna height the fluctuation of the received power become more obvious as shown in [7].

The reduction in the strength of the direct component relative to that of the multipath component with increasing distance and decreasing height suggests that the difference in the path length between the direct and the multipath components approaches zero, leading to less phase difference. Also at grazing incidence the magnitude of the reflection coefficient of plane earth for vertical polarization approaches unity, indicating that the multipath due to ground reflection become as strong as the direct LOS component [8].

The rest of this paper is organised as follows. Section II describes the multipath decaying power profile used to calculate the delays and amplitude attenuation coefficients of the paths. Then in Section III, proposed propagation model for short-range and near ground. The comparisons follow in Section IV, where the results are compared and analysed. Finally, Section V concludes and discusses future extensions.

II. MULTIPATH DELAY SPREAD MODEL

The delay spread or excess delay is one of the important parameters need to be considered when designing communication systems. By knowing the delay spread the distortion with the symbol with the other symbol which is intersymbol interference (ISI) can be eliminated. The multipath is the one of the causes to the ISI problem.

In reality multipath depends on the surrounding area, with a random and finite number of echoes reaching the receiver.
other than LOS signal is also subject to time dispersion, because multiple replicas of the transmitted signal propagate over different transmission paths and reach the receiver antenna at different times and different inter arrival rate with different attenuation factor.

The arrival times of signal on various paths are proportional to the lengths of the paths [8], which are in turn affected by the size and architecture of the environment and locations of objects around the transmitter and receiver. The inter arrival rate is depending on the density of the scatters in the environment. The strengths of such paths depend on the attenuation caused by passage of the signal through, or reflection of the signal by, various objects in the path.

The time delay spread is defined as the different time between the delays of the last path with the first path arrived at the receiver.

\[ \Delta \tau_i = \tau_{\text{max}} - \tau_{\text{min}} \]  

The shortest path and the strongest signal which will arrive should be LOS path when there is no obstruction between the transmitter and the receiver. The attenuation of the LOS signal is only due to the propagation distance. In short range communication the probability to get the LOS is high. Therefore we assume the minimum delay is propagation delay of the LOS path.

The delay is proportional to the distance signal travels to the receiver. In outdoor environment the distances of the scatters are longer, it caused the delays between arriving paths are larger, resulting in a larger multipath spread of the received signal. The delay spread in the indoor environment is short that is due to the cubical size of the room. The excess delay of ground reflection path is small for the low antenna height and approaching zeros when the distance is increased. Considering the movement of the scatters, it is noted that the random variable changes rapidly with small variation in path length. For this reason, it is commonly to assume the time arrival of the paths is in uniform normal distribution \( (\tau_{\text{min}}, \tau_{\text{max}}) \). When the distance increased the maximum delay also increased.

The scatters surrounding the sensor nodes cause the randomness of the delay spreads. Assuming the sensor nodes location is not change with time and the movement of the scatters is minimum, therefore the maximum delay can be assumed is dependent on the distance of the scatters from the sensor nodes and the number of paths. Considering \( N \) multipath signals arrived at the receiver, the maximum delay is defined as

\[ \tau_{\text{max}} = \max(\tau_1, \cdots, \tau_N) \]  

where \( \tau_{\text{max}} \) is the random variable which is depend on environment.

The height of the antenna near to the ground can caused the ground reflection signal and the small excess delay. At certain antenna height the reflected signal from the ground can be the second dominant path. Assuming the ground is flat and ignoring the roughness factor, therefore the ground reflection path length can be estimated, therefore the delay of the ground reflection becomes deterministic.

The delays for every path can be calculated if the lengths of the paths are known. The delay can be calculated using

\[ \tau_i = \frac{d_i}{c} \]  

Where \( d_i \) is path length and \( c \) is the propagation speed.

RMS delay spread increases as the distance increased or antenna height decreased as the Rician K factor decreases, and the number of multipath components increases as the frequency and distance increased [a].

The amplitude of a signal arriving at the receiver is dependent not only on the reflections, transmission and diffractions in the environments, but also on the length of the path, that is delay. Theoretically the received power is inversely proportional to the distance. Therefore the signal, which travels the longest path, has the longest delay and low power compared to the signal with smallest path length. This allows the assumption to be made that the path delay distribution is negative exponential function. The exponential profile is a pragmatic solution where the average power decays exponentially as the path length increases. Therefore we proposed decaying power coefficient for every path as exponential trend.

\[ c(\tau) = \begin{cases} e^{-h(\tau - \tau_{\text{min}})} & , \tau_{\text{min}} \leq \tau \leq \tau_{\text{max}} \\ 0 & , \text{else} \end{cases} \]  

Figure 1 shows the power delay decaying coefficient profile for the paths. We modified power delay profile was introduced in [9] as decaying coefficient factor by considering the existence of LOS path as

\[ c(\tau) = \begin{cases} e^{-h(\tau - \tau_{\text{min}})} & , \tau_{\text{min}} \leq \tau \leq \tau_{\text{max}} \\ 0 & , \text{else} \end{cases} \]  

where \( c_{\text{max}} \) is the maximum decaying coefficient factor and always has value 1, \( c_{\text{min}} \) is the minimum decaying coefficient depend on the sensitivity of the antenna and the noise floor.
value and $b$ is the constant value. When the distance is increased the $b$ decreased, therefore the $\tau_{\text{min}}$ also increased.

$$\tau_{\text{max}} = \tau_{\text{min}} - \frac{\ln r_{\text{min}}}{b} \quad (5)$$

Small changes in the path delay can lead to large phase changes in the $i$-th multipath component. This causes rapid variation in the received signal strength and this phenomenon is called fading. It is mean that the inter arrival of the path is small which is caused by the dense of the scatters in the surrounding both transmitter and receiver. By knowing the inter arrival rate $\gamma$ and delay spread we can estimate the number of paths $N$ that arrived at receiver.

$$N \leq \frac{\Delta \tau}{\gamma} \quad (6)$$

III. MULTIPATH PROPAGATION MODEL

The most widely used model for signal propagation in wireless sensor networks is the log-normal shadowing model [1][10]. Where log-normal shadowing represents the average received power and on a logarithmic scale tends to be an exponential trendline using least squares (log-distance attenuation). In reality, the received power will randomly fluctuate around the average. This model yields an acceptable performance when the WSN is employed in an ideal setup. However this is not true by ignoring the fading effect at short range and the effect on the ground or flat surface for low antenna height.

Due to the requirement that most sensor network applications, require deployment of nodes near to planes such the ground, wall etc, the transmission is subject to reflection and diffraction from the nearby plane and the surroundings, producing multipath.

The two-ray propagation model as in Fig. 2 is suitable as a starting point for modeling WSN propagation. It has also been shown [7] that the fluctuation in the received power are more obvious in short range conditions and at certain antenna heights.

The reflection can enhance the power of the received signal if the reflection signal and the direct signal arrive in phase which means reflection coefficient nearly to 1, whilst reducing the power when the signals are out of phase or reflection coefficient approaching to -1.

Fig. 3 shows that, there are two regions, where the first region consists of ripples, where peaks and troughs exist and falloff is $d^2$, while the second region exhibits $d^4$ falloff and no humps/nulls exist. When the frequency increases, the ripple region becomes wider according to equation (7).

$$d_e = \frac{4\pi h_i h_j}{\lambda} \quad (7)$$

The nulls are representative of points where direct and reflected signals cancel while the humps show points where the signals add. The nulls exist in the range of $d^2 r^2$ falloff, before the breakpoint $d_c$. The breakpoint is the position, where the transition of $d^4$ falloff started. After this point no nulls exist. The authors of [10] also show the wireless sensor network channel has two different slopes, which cross at the breakpoint.

Formalising the previous discussion: In a typical short-range wireless application, the transmitted signal will experience ripple until certain distance, which caused by LOS path and echoes path due to reflection, diffraction and scattering. Arrived signal therefore reach at the receiver from different directions with different amplitudes, phase, and time delays. The radio channel is then the sum of contributions from all of the paths and modeled by a multi-rays propagation model as in equation (8).

$$P_r(\lambda, d) = P_t \left( \frac{\lambda}{4\pi} \sum \sqrt{G_i c_i e^{-\lambda d}} \right)^2$$

where $P_r$ and $P_t$ are received power and transmitted power and distance $d$ between antennas and frequency with wavelength $\lambda$, $c$ is decaying factor, $\Gamma$ is reflection coefficient and phase different for the $i$-th path is $\Delta \phi = 2\pi (d_i - d_j) / \lambda$, $d_i$ is path length of the signals and $G$ is antenna gain.

Multipath propagation model in equation (7) can be reduced by removing the exponential factor $K_c$ which is
\[ K_{e} = P_{i}\left(\frac{\lambda}{4\pi}\right) \]  
(9)

and to become as deep fade function
\[ P_{ab}(\lambda, d) = |K_{e}(\tau, \lambda, d)|^2 \]  
(10)

Although multipath interference seriously degrades the performance of communication systems, it will behave differently in different frequency bands; where at certain distance the deep fade has constant periodicity as shown in Fig. 4. The experiments conducted in [11] show the frequency response for the range of 800-1000MHz with the antenna near to ground (15cm) at 10 meter separation. The work showed the fading to be clearly periodic, although no attempt was made to explain the observation.

In [12] the measurement of RSSI has been conducted at different distances (1cm < d < 500cm, in 50cm steps) in a room (7x5 meters) for different power levels. Sensor nodes placed onto carpet exhibit reflections at a given distance. This has been shown by the fade at 250cm which is independent of the power level.

In [13] wireless sensors sensing wireless (WSSW) has been demonstrated for in-vehicle wireless sensor applications. The researcher demonstrates the use of frequency scanning in the 902-928MHz ISM band with 500kHz frequency resolution. The results show that at certain operating frequencies a null or deep fade will exist.

We modeled the deep fade tapped-delay power shown in Fig. 5 as
\[ K_{e}(\tau) = \sum_{i=1}^{N} c_{i} x(\tau - \tau_{i}) \]  
(11)

where
\[ x(\tau) = \frac{\Gamma_{1}^{\gamma} e^{-\gamma\tau_{b}}}{d_{i}} \]  
(12)

\[ \Delta \tau_{i} = \tau_{i} - \tau_{i-1} \]  
(13)

In [14] assumed the inter-arrival path by using poisson distribution function. Therefore, we assumed poisson distribution is used to model the N number of path arriving at receiver within a given distance interval with path arrival rate \(1/\gamma\).

\[ P(n) = \frac{\gamma^{n} e^{-\gamma}}{n!}, \quad n = 0, 1, 2, \ldots, N \]  
(14)

IV. SIMULATION RESULTS

In the simulation we use measured delay spread in urban area for low antenna height (5 meters) and distance 100, 200 and 300 meters that has been conducted by [15] to calculate constant \(b\). The results in Table 1 show that the value of \(b\) decreased as the distance increased.

<table>
<thead>
<tr>
<th>Distance, m</th>
<th>Delay Spread, (\mu)sec</th>
<th>Constant, (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.10</td>
<td>16.1</td>
</tr>
<tr>
<td>200</td>
<td>0.12</td>
<td>13.4</td>
</tr>
<tr>
<td>300</td>
<td>0.15</td>
<td>10.7</td>
</tr>
</tbody>
</table>

In this simulation the inter arrival of the path generated using passion random distribution generator with inter arrival rate \(\gamma\). Increasing the distance between transmitter and receiver caused the increase the number of paths as shown in Fig. 6. The comparison between different inter arrival rate \(\gamma\) (1/10ns and 1/20ns) as shown in Fig. 7, Fig. 8 and Fig. 9. Deep fade can be seen clearly when the inter arrival rate is low. At high path arrival rate, the number of paths increases and will cause the strength of the direct component relative to that of the multipath component with reduces as a result the deep fade is difficult to be detected.
In this paper we propose a multipath propagation model based on deep fade decaying power profile. This model can be used as multipath propagation for short-range and near to ground in unobstructed environments.

REFERENCES


