**IEEE P802.15**

**Wireless Personal Area Networks**

|  |  |
| --- | --- |
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
| Title | **Channel Models for IEEE 802.15.4q (Draft)** |
| Date Submitted | 16 May 2013 |
| Source | Jinesh P. NairKiran BynamYoungsoo Kim | Voice: +918041819999  Fax: +918041819000 E-mail:jinesh.p@samsung.com kiran.bynam@samsung.comkimyoungsoo@samsung.com  |
| Re: | Task Group 15.4q Channel Models Recommended to evaluate Proposals  |
| Abstract | TG4q – Channel Models for IEEE 802.15.4q  |
| Purpose | To specify channel models suitable for applications mentioned in IEEE 802.15.4q to serve as reference for fair comparison of proposals and system evaluation |
| Notice | This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein. |
| Release | The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15. |

Contents

[Introduction 2](#_Toc292353314)

[Purpose 2](#_Toc292353315)

[Methodology 2](#_Toc292353316)

[Large Scale Fading 2](#_Toc292353317)

[Outdoor Path Loss Models 3](#_Toc292353318)

LOS Path Loss Model

NLOS Path Loss Model

Path Loss Model for 900 MHz

Path Loss Model for 2.4 GHz

[Indoor Path Loss Models 6](#_Toc292353319)

Path Loss Model for 900 MHz and 2.4 GHz

[Small Scale Fading 7](#_Toc292353320)

Considerations in Small Scale Fading

Impulse Response Models

 Flat Fading Channel Models

Delay Spread Models

Outdoor Environments

Indoor Environments

Power Delay Profile based Models

[References 10](#_Toc292353327)

Channel Models for IEEE 802.15.4q

# Introduction

There have been numerous contributions made capturing the large scale fading and small scale fading characteristics in the literature for the target frequency bands in TG4q PAR namely sub-1 GHz and 2.4 GHz. This document recommends the path loss and impulse response models most relevant to scenarios encountered by applications discussed in TG4q. The channel models are recommended for the bands of interest namely 902-928 MHz and 2400-2483.5 MHz bands.

***1.1*** ***Purpose***

The purpose of the document is to create a reference specifying the path loss models and the impulse response models relevant to TG4q for system evaluation and fair comparison of PHY proposals

## 1.2 Methodology

The typical application scenarios described in TG4q [1]-[4] are characterized based on the channel parameters namely the range, the environments encountered namely outdoor or indoor, the presence or absence of line of sight (LOS) components, the extent of shadowing, and also the impact of multipath fading. Based on this characterization, the channel models most appropriately capturing these scenarios are identified from the existing literature and recommended for TG4q.

1. **Large Scale Fading**

The typical application scenarios relevant to TG4q are smart utility, building automation, inventory and warehouse management, medical and healthcare applications, retail services, telecommunication services, industrial and infrastructure monitoring and environmental monitoring.

From the application scenarios it is observed that the maximum range that needs to be supported is around 100 m. This comes from applications like inventory and warehouse management, industrial and infrastructure monitoring and environmental monitoring. However, in most cases the range that needs to be supported is below 30 m. Also, for a good number of applications, the range is below 10 m. As regards the environment encountered, both outdoor and indoor scenarios are observed in most cases. The LOS scenarios exist in all the applications mentioned and NLOS scenarios although not that common are nevertheless observed in many scenarios. Moreover, shadowing is low to moderate in most cases and is high in applications like retail outlets.

***2.1 Outdoor Path Loss Models***

The outdoor path loss models are relevant to scenarios like smart utility, telecom services and industrial and environmental monitoring. The outdoor path loss models presented here is based on ITU-R P.1411-6 “Propagation data and prediction methods for the planning of short-range outdoor radio communication systems and radio local area networks in the frequency range 300 MHz to 100 GHz” [5]. This effectively covers the UHF, SHF and EHF frequency bands. It provides an up to date recommendation for propagation over paths of length less than 1 Km, which is affected primarily by buildings and trees.

ITU-R P.1411-6 divides the physical environments typically encountered in short range communications into four categories namely urban, sub-urban, residential and rural environments. TG4q applications fall under all these categories. For each of the categories, two possible scenarios of the mobile are considered namely pedestrian and vehicular. TG4q applications can be either fixed or at the most pedestrian. The type of propagation mechanism that dominates depends also on the height of the base station antenna relative to the surrounding buildings. Depending on the range and relative antenna heights, outdoor environments are further classified into micro-cell, dense urban micro-cell and pico-cell. Under this classification the TG4q applications fall under dense urban micro-cell and pico-cell scenarios.

Based on this, we specify a LOS path loss models for 900 MHz and 2.4 GHz bands. Two separate NLOS models once each for 900 MHz and 2.4 GHz bands are also specified.

***2.1.1 LOS Path Loss Models for 900 MHz and 2,4 GHz bands***

The path loss is characterized by two slopes and a single break point. Although approximate lower bounds and upper bounds are specified, we adopt the median path loss model for outdoor environments. The path loss $L\_{LoS,m} $in dB at a distance $d$ is given by

$$L\_{LoS,m}=L\_{bp}+6+\left\{\begin{matrix}20log\_{10}\left(\frac{d}{R\_{bp}}\right) for d\leq R\_{bp}\\\\40log\_{10}\left(\frac{d}{R\_{bp}}\right) for d>R\_{bp}\end{matrix}\right. (1)$$

Here $R\_{bp}$ is the break-point distance given by

$$R\_{bp}≈ \frac{4h\_{b}h\_{m}}{λ} (2)$$

Here $h\_{b}$ the height in meters of the base station, $h\_{m}$ is the height in meters of the mobile station, and $λ$ is the wavelength in meters. $L\_{bp}$ is a value for the basic transmission loss at the break point defined as

$$L\_{bp}≈ \left|20log\_{10}\left(\frac{λ^{2}}{8πh\_{b}h\_{m}}\right)\right| (3)$$

***2.1.2 NLOS Path Loss Models***

The figure below depicts the situation for a typical dense urban micro-cellular NLOS case. This is called NLoS2.

The relevant parameters for this situation are

$w\_{1}:$ Street width at the position of the BS (m)

$w\_{2}:$ Street width at the position of the MS (m)

$x\_{1}:$ Distance of BS to street crossing (m)

$x\_{2}:$ Distance of BS to street crossing (m)

$α:$ is the corner angle (rad.)



Fig.1 Definition of parameters for the NLoS2 case

***2.1.2.1 NLOS Path Loss Model for 900 MHz band***

Refer Fig. 1. In this model, the diffracted and reflected waves at the corners of the street crossings have been considered.

$$L\_{NLos2}= -10log\_{10}\left(10^{\frac{-L\_{r}}{10}}+10^{\frac{-L\_{d}}{10}}\right) dB (4)$$

Where $ L\_{r}$ is the reflection path loss defined by

$$L\_{r}=20log\_{10}\left(x\_{1}+x\_{2}\right)+x\_{1}x\_{2}\frac{f\left(α\right)}{w\_{1}w\_{2}}+20log\_{10}\left(\frac{4π}{λ}\right) dB \left(5\right)$$

Where

$$f(α)= \frac{3.86}{α^{3.5}} dB \left(6\right)$$

Where $0.6 <α (radians)<π$

And $ L\_{r}$ is the diffraction path loss defined by

$$L\_{d}=10log\_{10}\left(x\_{1}x\_{2}\left[x\_{1}+x\_{2}\right]\right)+2D\_{a}-0.1\left(90-α\frac{180}{π }\right)+20log\_{10}\left(\frac{4π}{λ}\right) dB (7)$$

$$D\_{a}= \frac{40}{2π}\left[tan^{-1}\left(\frac{x\_{2}}{w\_{2}}\right)+tan^{-1}\left(\frac{x\_{1}}{w\_{1}}\right)-\frac{π}{2}\right] (8)$$

***2.1.2.2 NLOS Path Loss Model for 2.4 GHz band***

Refer Fig. 1. This model is derived based on measurements with the corner angle $α=\frac{ π}{2}$ and $w\_{2}$ is up to 10 m. The path loss characteristics can be divided into two parts namely corner loss region and the NLOS region. The corner loss region extends for $d\_{corner}$ from the point which is 1 m down the edge of the LOS street into the NLOS street. The corner loss $L\_{corner}$ is expressed as the additional attenuation over the distance$ d\_{corner}$. The NLOS region lies beyond the corner loss region, where a co-efficient parameter $β$ applies. The overall path loss $L\_{NLos2} $ in dB beyond the corner region $x\_{2}>\frac{w\_{1}}{2}+1$ is found using

$$L\_{NLoS2}=L\_{LoS}+L\_{c}+L\_{att} (9)$$

Where

$$L\_{c}=\left\{\begin{matrix}\frac{L\_{corner}}{log\_{10}(1+d\_{corner})}log\_{10}\left(x\_{2}-\frac{w\_{1}}{2}\right) \frac{w\_{1}}{2}+1\leq x\_{2}\leq \frac{w\_{1}}{2}+1+d\_{corner}\\\\L\_{corner} x\_{2}>\frac{w\_{1}}{2}+1+d\_{corner}\end{matrix}\right. (10)$$

$$L\_{att}=\left\{\begin{matrix}10βlog\_{10}\left(\frac{x\_{1}+x\_{2}}{x\_{1}+\frac{w\_{1}}{2}+d\_{corner}}\right) x\_{2}>\frac{w\_{1}}{2}+1+d\_{corner}\\\\0 x\_{2}< \frac{w\_{1}}{2}+1+d\_{corner}\end{matrix}\right. (11)$$

Where $L\_{LoS}$ is the path loss in the LoS street for $x\_{1}$(>20m) is as calculated in (1). In equation (10) $L\_{corner}$ is given as 20 dB in an urban environment and 30 dB in a residential environment. $d\_{corner}$is 30 m in both environments. In equation (11), $β$is given by 6 in both environments.

***2.2 Indoor Path Loss Models***

All applications discussed in TG4q except for environmental monitoring have indoor scenarios. The Recommendation ITU-R P.1238-7 “Propagation and prediction methods for the planning of indoor radio communication systems and radio local area networks in the frequency range 900 MHz to 100 GHz” is employed [6]. This effectively covers the UHF, SHF and EHF frequency bands. It provides an up to date recommendation for propagation over paths of length less than 1 Km.

 A general model is specified applicable for NLOS/LOS and for 900 MHz and 2.4 GHz frequency bands depending on the choice of parameters. The propagation model accounts for the loss through multiple floors to allow for such characteristics as frequency reuse between floors. When this component is absent, the model reduces to the case with LOS propagation.

***2.2.1 Indoor Path Loss Model for 900 MHz and 2.4 GHz bands***

The basic model has the following form

$L\_{total}=20log\_{10}f+Nlog\_{10 }d+L\_{f}\left(n\right)-28 $(12)

Where

$ N:$ Distance power loss co-efficient

$ f:$ Frequency in MHz

$ d:$ Separation distance (m) between the base station and the portable terminal ($d>1m$)

$ L\_{f} :$Floor penetration loss factor

$ n:$ Number of floors between the base station and the portable terminal ($n\geq 1$)

Table 1: Values of *N* and *Lf* in different scenarios

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Frequency** | **Residential** | **Office** | **Commercial** |
| *N* | 2.4 GHz | 28 | 30 | - |
| *Lf* | 2.4 GHz | 10(Per concrete wall in apartment)5 (house) | 14 | - |
| *N* | 900 MHz | 33 | 33 | 20 |
| *Lf* | 900 MHz | 9 (1 Floor)19 (2 Floors)24 (3 Floors) | 9 (1 Floor)19(2 Floors)24 (3 Floors) | - |

The values to be chosen for the various parameters are shown in Table 1.

Paths with a LOS component are dominated by free space loss and have a distance power loss co-efficient of around 20. Also in the absence of any floors, *Lf* (n)=0.

Large open rooms have a distance power loss co-efficient of 20. This may be due to strong LOS component in most areas of the room. These situations are prevalent in open rooms in offices, factories, sports arenas and retail stores. Corridors have a typical distance power co-efficient o around 18. Corridors with their long linear aisles exhibit the corridor loss characteristic.

Propagation around obstacles and through walls increases the distance power loss co-efficient to around 40 for a typical environment. Examples include paths between rooms and in closed plan office buildings.

For long unobstructed paths the first Fresnel’s zone breakpoint may occur. At this distance, the distance power loss co-efficient may change from about 20 to about 40.

1. **Small Scale Fading**

Small scale fading models are described here for indoor and outdoor scenarios. Models based on the channel delay spread and power delay profiles are specified. Typically the bandwidth of legacy IEEE 802.15.4 systems is around 3 MHz. Assuming a 75% coherence bandwidth of 3 MHz, the associated delay spread is $σ\_{τ}$ ≈ 1/(30 ×3 ×106) ≈ 10ns [9]. So as the dominant multipath components begin to appear beyond 10 ns, the frequency selectivity of the channel begins to affect the signals. The associated distances at which this happens is beyond 3 m ( d =st = 3×108×10×10-9).

***3.1 Flat Fading Channels***

There are many application scenarios wherein the range is below 3 m. In such cases the channel can be considered to be flat Ricean/Rayleigh fading and system evaluation and benchmarking can be based on such channel models. Typical scenarios include medical/healthcare, telecom services, building automation and retail services.

Also there are many scenarios wherein the associated range is beyond 3 m. In such cases, multipath channel models need to be specified. This is described next.

***3.2 Delay Spread Models***

In such cases, the range dependent parameters are related to the delay spread which may be then employed to specify the channel models.

***3.2.1 Outdoor Channel Models***

This model describes the characteristics of the multipath delay spread for the LOS omnidirectional antenna case [5]. The rms delay spread *S* at a distance *d* m follows a normal distribution with the mean value given by

$$a\_{s}=C\_{a}d^{γ\_{a}} (13)$$

And the standard deviation given by

$$σ\_{s}=C\_{σ}d^{γ\_{σ}} (14)$$

Where $C\_{a}, γ\_{a}, C\_{σ}, γ\_{σ}$ depends on the propagation environment and have typical values are given in Table 2. These may be adopted for 900 MHz and 2.4 GHz respectively.

Table 2

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sr. No | Frequency(GHz) | $$C\_{a}$$ | $$γ\_{a}$$ | $$ C\_{σ}$$ | $$γ\_{σ}$$ |
| 1 | 0.781 | 1254.3 | 0.06 | 102.2 | 0.04 |
| 2 | 2.5 | 55 | 0.27 | 12 | 0.32 |

The average power delay profile was found to be

$$P(t)=P\_{0}+50 (e^{-\frac{t}{τ}}-1) dB (15)$$

Where

$P\_{0}$: Peak Power (dB)

$τ:$ decay factor and *t* is in nano-seconds

From the measured data for an r.m.s delay spread S, $τ$ can be estimated as

$$τ=4S+266 (16)$$

 A linear relationship between $τ$ and *S* is only valid for the LOS case. Also the instantaneous properties of the power delay profile have also been characterized. The energy arriving in the first 40 ns has a Ricean distribution with a K-factor of about 6 to 9 dB, while the energy arriving later has a Rayleigh or Ricean distribution with a K-factor of up to about 3 dB.

***3.2.2 Indoor Channel Models***

The model is applicable to 900 MHz and 2.4 GHz [6]. The rms delay spread *S* is roughly in proportion to the area of the floor space $F\_{s}$ and is given by

$$10log\_{10}S=2.3log\_{10}F\_{s}+11.0 (17)$$

Where, the units of $F\_{s}$and $S$ are $m^{2}$ and *ns*$ $respectively. Within a given building, the delay spread tends to increase as the distance between antennas increases and hence the path loss increases. With greater distances between antennas, it is more likely that the path will be obstructed and that the received signal will consist of entirely of scattered paths.

The rms delay spread may be used in exponentially decaying power delay profiles. The impulse response in this case is

$h(t)=\left\{\begin{matrix}e^{-\frac{t}{S}} for 0<t\leq t\_{max}\\0 otherwise\end{matrix}\right. (18)$

Here $t\_{max}$ is the maximum delay and $t\_{max}\gg $*S*

 ***3.3 Power Delay Profiles***

In this case the channel impulse response model is assumed to be wide sense stationary with uncorrelated scatterers (WSSUS) [7]. The many scattered paths that may exist in a real channel are replaced with only a few *N* multi-path components in the model. Then a complex Gaussian time variant process $g\_{n}(t)$ models the super-position of unresolved multipath components arriving from different angles with delays close to the delay $τ\_{n}$of the $n-$th model multipath component and a Doppler spectrum of$ S\_{k}(f)$. Then, the impulse response $h(t)$ is given by

$$h(t)=\sum\_{n=1}^{N}\sqrt{p\_{n}}g\_{n}(t)δ(t-t\_{n}) (19)$$

Where $p\_{n}$ is the received power from the $n-$th model multipath component. Such a statistical model such as this requires appropriate parameters for each component. Since the mobility is at the most pedestrian and there are many scenarios for fixed wireless channels the Doppler spectrum is either flat or classical.

The flat Doppler spectrum is given by

$$S(f)=\frac{1}{2f\_{d}} \left|f\right|<f\_{d} (20)$$

The classic Doppler spectrum is given by

$$S(f)=\frac{1}{πf\_{d}\sqrt{1-\left(\frac{f}{f\_{d}}\right)^{2}}}, \left|f\right|<f\_{d}, f\_{d}=\frac{vf\_{c}}{c} (21) $$

The power $p\_{n}$ for each realization of (19) may be chosen from the following ITU power delay profiles in Table 3 and Table 4. These are applicable to both 900 MHz and 2.4 GHz frequency bands.

Table 3 ITU Indoor office

|  |  |  |  |
| --- | --- | --- | --- |
| Tap | Relative delay (ns) | Average power (dB) | Doppler spectrum |
| 1 | 0 | 0 | Flat |
| 2 | 50 | -3 | Flat |
| 3 | 110 | -10 | Flat |
| 4 | 170 | -18 | Flat |
| 5 | 290 | -26 | Flat |
| 6 | 310 | -32 | Flat |

Table 4 ITU outdoor to indoor and pedestrian

|  |  |  |  |
| --- | --- | --- | --- |
| Tap | Relative delay (ns) | Average power (dB) | Doppler spectrum |
| 1 | 0 | 0 | Classic |
| 2 | 110 | -9.7 | Classic |
| 3 | 190 | -19.2 | Classic |
| 4 | 410 | -22.8 | Classic |

# References

1. Chunhui (Allan) Zhu , Betty Zhao, Hou-Cheng Tang “Applications of ULP Wireless Sensors” IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), DCN: 15-12-0258-00 , May 2012.
2. Jinesh Nair, Kiran Bynam and Youngsoo Kim, “Applications and channels” IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), DCN: 15-12-0081-00, Jan. 2013.
3. Rick Powell, “Applications for ULP Radios” IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), DCN: 15-12-0074-00, Jan. 2013.
4. E. Callaway and D. Flynn, “Large volume ULP applications” IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), 15-13-0125-02, March 2013.
5. ITU-R P.1411-6 “Propagation methods for the planning of short range outdoor radio-communication

 systems and radio local area networks in the frequency range 300 MHz to 100 GHz” 02/2012

1. ITU-R P.1238-7 “Propagation data and prediction methods for the planning of indoor radio-communication systems and radio local area networks in the frequency range 900 MHz to 100 GHz” 02/2012
2. Marco Hernandez et al, “Channel models for TG8” IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)”, Sept 2012
3. Seidel P and Rappaport T.S, “914 MHz Path Loss Prediction Models for Indoor Wireless Communications in Multi-floored Buildings” IEEE Transactions on Antennas and Propagation, vol. 40, no. 2, Feb. 1992
4. T. Rappaport, “Wireless Communications: Principles and Practice” Pearson Education, 2nd Edition, 2002