MODELING AND SIMULATION OF IEEE 802.11 WIRELESS-LAN AND BLUETOOTH PICONET RANGE INTERFERENCE

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Abstract[1]

The proximity of wireless devices with one another often results in interference in the unlicensed 2.4 GHz ISM bandwidth. Interference has been recognized as a major problem to wireless network performance and improvement. In this paper we report a proposed and investigated Interference Range Model (IRM), a model that allows a user to determine the acceptable range of interference in a given environment. A Java environment for modeling, simulating, and analyzing acceptable/cutoff ranges of interference based on the IRM is discussed. The model was tested on ranges of interferences for Bluetooth devices in a piconet and IEEE 802.11 devices in the wireless LAN setup, which consequently provided a method for determining the signal-to-interference ratio (SIR) for the two protocols. With this approach, it is expected that a model for calculating and calibrating particular threshold values, or SIRs, and the corresponding ranges of interference can be determined for other wireless protocols.

1. Introduction

The widespread use of wide-range Wireless-based Local Area Network (WLAN) and its counterpart, the short-range Bluetooth piconet, has put a tremendous pressure on designers of wireless protocols to assure fidelity and reliability within the freely available 2.4 GHz Industrial Scientific and Medical (ISM) bandwidth. Whenever two wireless networks overlap in their coverage and operate at the same frequency, and time, they interfere with one another if there is no access coordination. Wireless networks are said to interfere with one another if one's radio frequency causes a significant performance degradation of any device in the other network. Interference is the major limiting factor in the performance of radio systems. Interference is severe in urban areas due to greater Radio Frequency (RF) noise from nearby mobile radio devices.

Consequently, interference has been recognized as a major problem in the need to widen the wireless capacity and is often responsible for dropped calls. It is stated that, "Interference is often very difficult to control in practice due to random propagation effects of radio frequencies" [9]. Research further points to the unwanted-noise signals from the nearby devices such as Bluetooth devices, microwave oven, and cordless phones as the main cause of interference in WLANs. An interfering signal generally deviates from the IEEE 802.11 protocol standards, thus such signals may start abruptly while IEEE 802.11 stations are in the process of transmitting packets. If this occurs, the receiver will receive an error packet, causing the receiver to refrain from returning, e.g., an acknowledgement (ACK) message to the sender station. In return, the sender station will attempt to re-transmit the packet, adding overhead on the network.

This paper focuses on the range of interference of Bluetooth and WLAN in a free space such as a building-corridor environment. In section 2, we discuss the IEEE 802 .11 standards and the Bluetooth protocols. Section 3 is on previous research work done on the interference problem. Section 4 focuses on the interference Range Model, which we have developed and simulated, driven by a set of hypothesis or scenarios. The underlying mathematical equations that define the IRM are also discussed. Lastly, section 5 is on the performance data from the simulation, which compare the range tolerable distance for the IEEE 802.11 (Wi-Fi) and Bluetooth wireless protocols.

2. Common wireless protocols

In order to understand the impact of interference on WLAN's and model the range of interference phenomenon, we first review the IEEE 802.11 standards as well as the Bluetooth standards. The review also points to the differences and similarities of the two protocols, and provides a basis for their comparison and calculation of the acceptable SIRs and ranges of interference.

2.1 IEEE 802.11x protocols

The IEEE 802.11 protocol is the first WLAN standard and, so far, the most dominating of the wireless market. The development of the first IEEE 802.11 standard for 1Mps and 2 Mbps, which supports Direct Sequence Spread Spectrum (DSSS), Frequency Hopping Spread Spectrum (FHSS) and diffused infrared physical layer, was completed in 1997. An extension to the physical layer of the 802.11 initial protocol using the Complementary Code Keying (CCK) modulation

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technique, with a data rate of 11Mbps, resulted in the 802.11b protocol. Further extensions using the Orthogonal Frequency Division Multiplexing (OFDM) technique led to the 802.11a. The 802.11a has a capacity of 54Mbps and operates at 5GHz. In the recent past the 802.11g protocol has been developed to be backward compatible with 802.11b and has a capacity of 54Mbps.

All the versions of the IEEE 802.11x share the same MAC sub-layer, which uses the Carrier Sense Multiple Access and Collision Avoidance (CSMA/CA) for contention, a Request-To Send/Clear-To-Send (RTS/CTS) mechanism to accommodate the hidden terminal problem, and an optional mechanism called point coordination function (PCF) to support real time applications.

The family of IEEE 802.11 standards supports both infrastructure WLANs connection through access points and allows peer-to-peer communication between terminals. Figure 1 depicts a typical WLAN infrastructure for basic services.

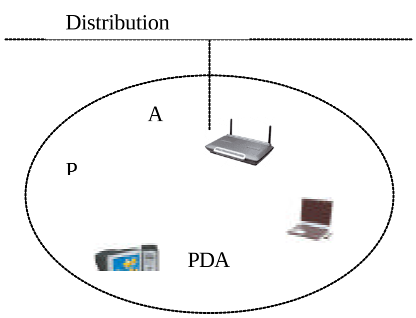

Figure 1: Infrastructure for Basic Services

The 802.11b protocol uses DSSS for communication using non-overlapping pulses at the chip rate of 11Mcps, which occupies around 26MHz of bandwidth [1]. The ISM band at 2.4GHz is divided into 11 overlapping channels spaced by 5 MHz to provide several choices for coexisting networks in the same area. The maximum transmitted power is recommended at 100mW.

In an attempt to understand the logical relationship between the ISO-OSI and the IEEE 802.11 architecture, we have mapped the IEEE 802.11 protocol stack onto the ISO-OSI stack to illustrate the layer-by-layer comparison or matching of the two standards.

IEEE 802.3 Logical Link Control (LLC)					OSI data link layer
IEEE 802.11 Media Access Control (MAC)				MAC	
DSSS PHY	FHSS PHY	Infra Red PHY	OFDM PHY	PHY	OSI PHY

Figure 2 IEEE 802.11 Standards mapped to the OSI Layers.

Figure 2 depicts layer-by-layer comparison of the two protocols.

2.2 Bluetooth

Bluetooth is a wireless standard for short range, low power and low cost wireless voice and data communication that was originally developed for cable replacement in personal area network [10]. It has an embedded mechanism to support voice applications but transmits at a lower data rate. The Bluetooth uses a fast frequency hopping technique of 1600 per second and transmits one small packet per fixed hop slot every 625 microseconds and hops over 79 MHz of bandwidth. The maximum transmitted power of Bluetooth is recommended to be 1mW.

The Bluetooth protocol stack is different from any known standard protocol stack such as ISO, IEEE, or TCP/IP [5], [6]. Presently, efforts are being made to unify the Bluetooth standard with other popular wireless standards, such as the IEEE 802.11 protocols. The modulation technique employed by the Bluetooth is the Gaussian Frequency Shift Keying (GFSK). Since the radio transmission of Bluetooth is based on FHSS, multiple channels can co-exist in the same band without interfering with each other. Two types of links are present in Bluetooth devices: the Synchronous Connection Oriented (SCO) link, which is similar to circuit switching connection and the Asynchronous ConnectionLess (ACL) link, which is similar to the packet switching connection.

The Bluetooth baseband layer manages asynchronous and synchronous links, handles packets and uses paging and inquiry to access and inquire Bluetooth devices in the area. The baseband transceiver of Bluetooth devices applies a Time-Division Duplex (TDD) scheme.

2.3. Piconet

Bluetooth devices are usually connected in a fashion that does not require pre-planning as required in other wireless networks. Normally, a maximum of eight devices can be networked into Bluetooth piconets. Once connected, each device has an equal access to the others. However, only one device must be a master, and the others are slaves. When two piconets overlap and link to each other, it becomes a scatternet. The Bluetooth clock of the master determines the phase in the hopping sequence. All slaves adjust their clocks with respect to the master clock. For example, in Figure 3, the segment labeled ‘a’ illustrates the Bluetooth piconet with a single slave, the segment labeled ‘b’ illustrates a multi-slave piconet and the segment labeled ‘c’ illustrates the scatternet operation.

Figure 4 depicts a topological arrangement of a network server PC, which serves as the master in a piconet while all other devices are slaves. All slave devices synchronize their clocks to the master’s clock.

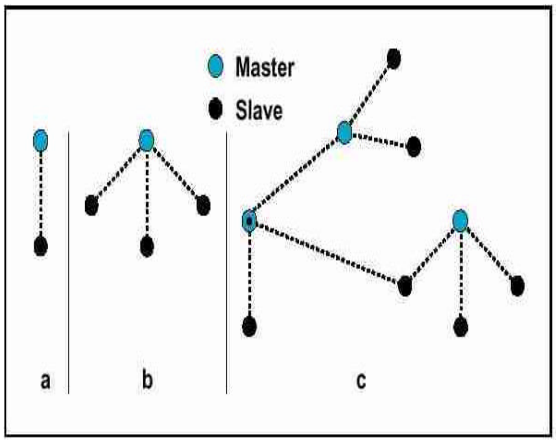

Figure 3: The Bluetooth piconet Designs. (Courtesy of Bluetooth special Interest group [10])

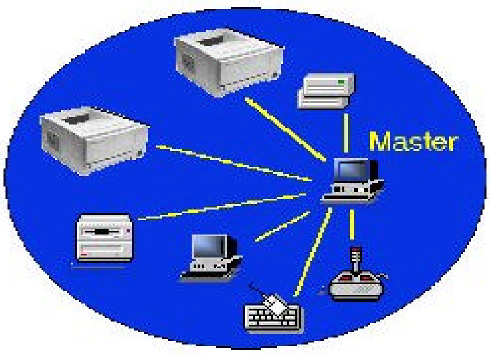

Figure 4: Bluetooth piconet with a master and seven slaves

3. Related Research

The idea of interference is not new to the wireless community. Lansford's work was on developing a multi standard radio technology called 'Alphabet Soup' that allows the coexistence of wireless personal area networks (Bluetooth piconet) and the wireless LAN [13]. Soltanian et al's work focused on performance at the physical layer for coexisting Bluetooth and IEEE 802.11b [12] devices. Simulations were employed in both studies to evaluate the performance in an interference-limited environment.

Selby et al did electrical level simulation on interference issues between Bluetooth piconets, and 802.11b and 802.11g WLANs [14]. In Selby's studies, the network performance degradation was determined as a function of the relative power and frequency offset of interfering signals. The performance degradation of 802.11b and 802.11g due to Bluetooth interference was compared to that produced by broadband noise interference sources. Selby and others also used Agilent Design System (ADS) and a virtual vector Signal Analyzer (VSA) for the simulation and data analysis. An adaptive hopping standard algorithm for Bluetooth devices was proposed by Selby et al in an attempt to solve the interference problem.

Another research by the Mobilan Corporation focused on combating interference at the silicon chip level [15]. The resultant product, called Driver-level (Modal), switches between Wi-Fi and Bluetooth and acts like a dual-mode radio switching that switches 'ON' and 'OFF' depending on the either the device is transmitting or receiving at that time.

There were some of the shortcomings of the Mobilan System from our review and analysis of the literature. For example, the system could introduce overhead in the switching mechanism and also the performance is bound to degrade because both Bluetooth and Wi-Fi cannot transmit or receive at the same time.

The reports of the above research efforts do not clearly identify the fundamental cause of the range interference problem, *which is the separation distance between the source of the noise (transmitter) and the receiver*. The problem has been left to the wireless device manufacturers; hence since it is not properly addressed.

The research reported in this paper attempts to tackle or address the open problem: What is the separation distance for IEEE 802.11 and Bluetooth piconet transmission within which no interference and distortion in signal quality would be experienced?

To understand the nature of the problem and offer some guidelines, we have proposed a system of equations that model the IRM problem. The models serve as a basis for developing a number of scenarios for simulating the IRM (or range of distances). The result is the development of the Signal-to-Interference-Ratio (SIR) for given ranges of interference for the two common protocols – WLAN and Bluetooth.

4. Interference Range Model (IRM).

WLAN and Bluetooth are designed to work in an interference-rich environment. Research has shown that user throughput and performance change radically when access points or clients are located near an interfering transmitter or when frequency planning is not carefully conducted [9]. However, the ability to measure and predict the range and interference effects caused by specific placement of other devices can provide orders of magnitude of relevant information about Quality of Service (QoS) in cost and data throughput and, hence, the predictability of performance in a densely wireless environment.

The overarching goal of our effort is to use IRM to find the distance of separation between any two wireless devices, setting a boundary for acceptable level of interference (if any) without degrading the received signals. Theoretically, the range of interference is related to propagation of the environment (path loss index), processing gain of the receivers, and the transmitted powers from different devices. However, the interference between Bluetooth piconet and WLAN cannot be eliminated by simply increasing the transmitted power since this will in turn increase the interference to the neighboring device. A decrease in the transmitted power will also cause the degradation in the received signals at the receiver. In an attempt to solve the problem of this kind of interference, a Java-based environment was developed for simulating the behavior of WLAN and piconet devices, data collection and analysis; and coupled with the underlying models of equations, for providing some guidelines.

4.1 The Simulation of the IRM

To appropriately model the range of interference problem, a number of network interference scenarios were hypothesized for different possible situations. Below are some of the possible simulation scenarios that were identified.

4.1.1 Hypothesis, Scenarios and Assumptions

Scenario 1:
If both Bluetooth device and WiFi or WLAN device are transmitting data, the interference is negligible. It is assumed that the net interference effects can be neglected. The hypothesis is that, the only effect of noise is on the receiver's own terminals or environment and not from the transmitter.

Scenario 2:
If both Bluetooth and mobile WLAN devices are receiving, what is the effect of one on the other? The effect of noise depends on the power of the transmitted signals. It is assumed that the signals transmitted with the highest power may interfere with the other (weaker) one.

Scenario 3:
A Bluetooth device transmits data to another mobile Bluetooth device and a receiving mobile WLAN device at the same time. In this case, there is the possibility of the Bluetooth signals introducing some noise into the WLAN mobile device's received signals. If so, the effects would be manifest in the simulation depending on the separation between the two devices.

Scenario 4
A Bluetooth device is receiving data and a nearby WLAN device is transmitting at the same time, with the possibility of an interference occurring – a reverse of Scenario 3.

We focus on the Scenarios 3 and 4, since these two subsume Scenarios 1 and 2, with the noted assumptions.

Bluetooth devices, as stated earlier, use Frequency Hopping Spread Spectrum while WiFi devices use Direct Sequence Spread Spectrum. Although, the Bluetooth hops at 1600 hops per second in 79 channels made up of 1Mz frequency bandwidth, there is still the possibility of the two overlapping and transmitting a noise to IEEE 802.11 devices.

4.1.2 The Java-based Modeling System.

The Java API environment developed to formulate the proposed model is a collection of front-end graphical tools and middle-layer software for data collection and calculations. To illustrate using Figure 5, let the graphical objects BT1 and BT2 represent Bluetooth devices and MS1 and MS2 represent WLAN devices. BT1 is modeled as a master device and BT2 as a slave device. The large square box, modeling a 300m by 300m area, sets a variable bound on the free space of mobility for BT2 and MS2. The large circle sets a bound or acceptable range of interference for BT1 and MS1. The behavior of the modeled devices, BT1, BT2, MS1, and MS2 are governed by equation (1), (2), (3) discussed in section 4.1.3.

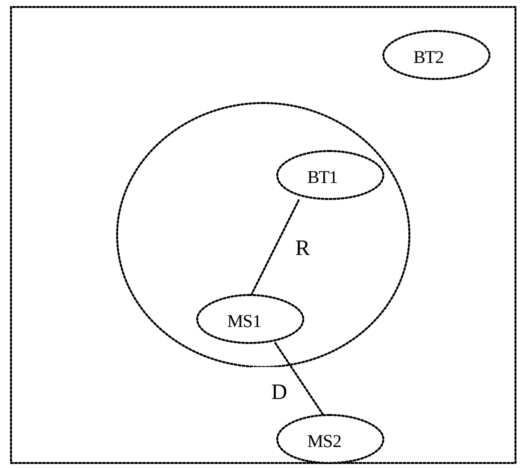

Figure 5 Simulation setup of Bluetooth Piconet devices and IEEE 802.11 (Mobile Devices)

The following parameters and assumptions were made to control the simulation:

- The two different wireless technologies operate at the 2.4Ghz wireless band
- Transmitting power of Bluetooth device is 0dBm (1mW).
- Transmitting power of IEEE 802.11 is about 20dBm (100mW)
- The coverage area of IEEE 802.11 is about 300 meters by 300 meters.

R and D in Figure 5 are the relevant distances of communication between the modeled devices. Correspondingly to Figure 5, the outer square in Figure 6a represents the region of transmission and the inner square sets a variable boundary for the large circle within which the range of interference is constrained. Any movement of devices BT1 and MS1 within the boundary (the inner square) confirms an accepted or valid interference range for the Bluetooth and WLAN simulation devices. As indicated, these movements or behaviors of BT1 and MS1 relative to MS2 and BT2 are based on equation (1) to (3).

4.1.2 The Behavior Models and the SIR

To model the SIR, first, let P_t be the power of the transmitted WLAN device and α be the power-to-distant gradient or path loss index of the device. The signal strength, S_r, of the emitted radio signals is proportional to the product of the transmitted power (P_t) and the distance (d) between the transmitter and the receiver raised to the negative exponent of the index as related in Eq. (1) [1].

$$S_r = K * P_t * d^{-\alpha} \qquad (1)$$

S_r is the received signals, K is constant of proportionality, d and r are the distances (between the transmitter and receiver – see Figure 6a), and a is the path loss index of the environment.

From Figure 5, when the MS1 is receiving and BT1 and MS2 are transmitting, we expect the signal received by MS1 from MS2 to be far greater than that of signal received from BT1 due to the higher power of transmission. For clearer reception of signals, the noise signals (due to BT1's signal) need to be minimized. Since the goal is to determine the SIR, we deduced Equations (2) and (3) from (1) to establish a basis for simulating the transmission behavior/pattern of the devices accurately. The signal-to-interference Ratio (SIR) can thus be calculated as follows:

$$\frac{S_r}{S_{BT\,1}} = \frac{K * P_{MS\,2} * d^{-a}}{K * P_{BT\,1} * r^{-a}} \qquad (2)$$

$$SIR = \left(\frac{P_{MS\,2}}{d^{a} * P_{BT\,1}}\right) r^{a} \qquad (3)$$

Equation (3) indicates that the SIR is directly proportional to the α-power of the distant-ratio between the interference source and the receiver. It is known that the path loss index, α, is always greater than 1 ($\alpha > 1$) [9]. We infer from equation (3) that the greater the separation, r, the higher the SIR, hence the better the received signals. As the separation distance, r, approaches zero the lower the SIR and the higher the noise or interference in the received signals.

5. Analysis of simulation result

The simulation data are tabulated at the bottom-halves of Figures 6a and 7a, respectively for the Bluetooth interference (effect) on WLAN and WLAN interference (effect) on Bluetooth piconet devices. The corresponding graphs or plots from the simulation data are shown in Figures 6b and 7b.

To understand the effects of mutual interference range between the Bluetooth piconet devices and the WLAN device from the simulation, we compare the resulting graphs in Figures 6b and 7b. For Example, if the device manufacturer specifies the acceptable SIR as 25dB (see the 25dB mark on the SIR-axes of Figure 6b), the corresponding distance/range is about 60 meters (on the Distant-axes), which represents the noise-effect of mobile Bluetooth on a stationary WLAN device. Conversely, an SIR of 25 dB corresponds to an acceptable distance of 100 meters, shown in Figure 7b, for the mobile WLAN device on a stationary Bluetooth piconet device.

Furthermore, Figures 6b and 7b both illustrate that when a mobile device is close to a stationary device a lower interference effect is experienced and the received signal is also weak. However, as the device moves away (e.g., 100m-200m) the received signals get stronger as the SIRs increase, and much faster for a mobile Bluetooth on stationary WLAN because the overlapping regions disappear quickly.

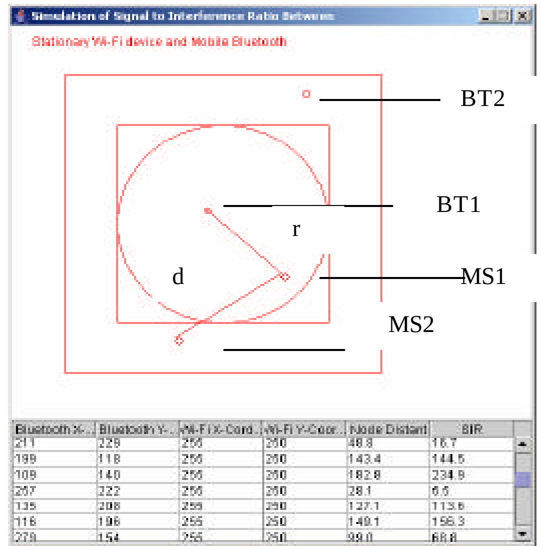

Figure 6a: Simulation Setup of the Bluetooth interference on IEEE 802.11b

6. Conclusion and future work

From the Java simulation and analysis of the Bluetooth and IEEE 802.11interference in the free space, the range of interference of Bluetooth in the WLAN environment is much shorter than that of IEEE 802.11 interference in the Bluetooth piconet.

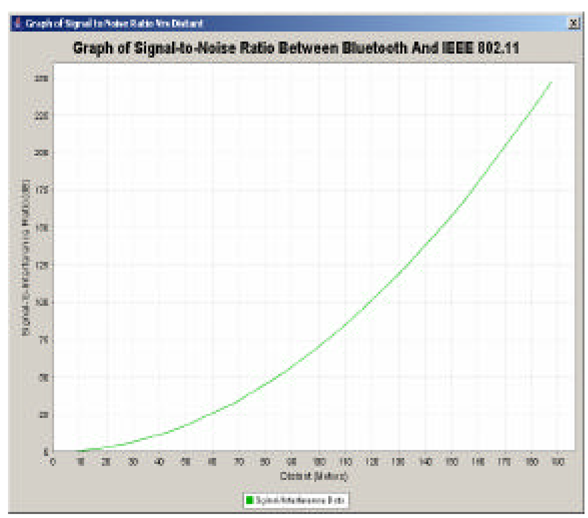

Figure 6b: Graph of signal-to-interference ratio between a stationary packet-receiving IEEE 802.11 device and a mobile Bluetooth device

We conclude from the simulation that the range of interference of Bluetooth on IEEE 802.11 device is far less than the range of interference of IEEE 802.11 device on the Bluetooth device. Hence, a Bluetooth device has to be very close to the WLAN device before it can cause a significant interference to the WLAN device.

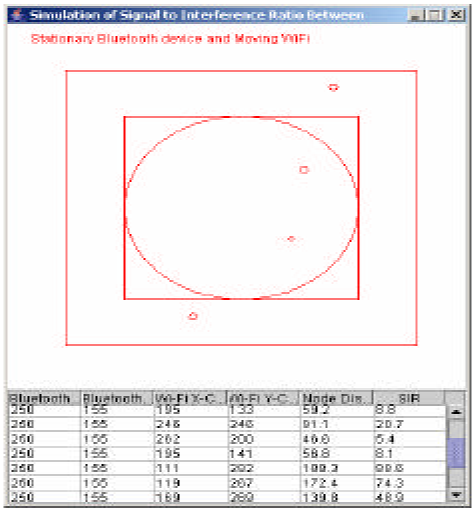

Figure 7a: Simulation setup for the IEEE 802.11 interference on Bluetooth

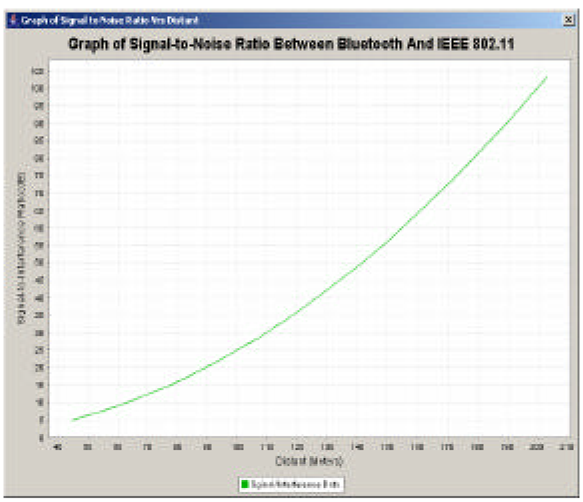

Figure 7b: Graph of signal-to-interference ratio and separation distance of mobile IEEE 802.11device and a stationary Bluetooth device

The reason is based on the fact that, IEEE 802.11 devices cover a longer coverage area than Bluetooth, hence a larger transmitting power. The higher the power of transmitted signal the higher the probability of the interference.

The results of the simulation also indicate that for a path loss index of 2, the SIR is related to the ratio of the distance of separation, r and d. Thus, for known α-values the corresponding SIRs can be used by wireless device designers to calibrate such devices and address the range of interference problem. We are currently investigating the path loss index for various free spaces such as indoor environment, outdoor environment, line-of-sight indoors, and indoor obstructions. Consequently, we plan to extend the investigation to cover the ranges of interference for various wireless protocols.

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