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Indoor propagation investigation from a 2.4 GHz waist mounted beacon

James A. Kirkup*, David D. Rowlands, David V. Thiel

Centre for Wireless Monitoring and Applications, Griffith University, Brisbane, Qld 4111, Australia

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Abstract

Indoor positioning techniques are being considered for use within team sports where players are tracked and recorded providing coaching assistance. While Global Positioning System (GPS) is the de facto standard employed to estimate the location of players, this is unsuitable for accurate indoor positioning due to roof and wall signal obstruction. Over a dozen techniques have been suggested for wireless indoor positioning of static and/or moving objects with improved methods for limiting the position estimation errors. For those indoor techniques that rely on radio frequency (RF) signal propagation, propagation statistics are useful in determining path loss and signal degradation. This static indoor propagation knowledge is critical in the design of wireless indoor positioning systems and ultimately the accuracy of the position estimation. Signal path propagation losses and variations produced from shadowing, multipath, fading, scattering or diffraction from objects can hinder the designer's efforts to provide a reliable and accurate positioning system. However, sporting indoor environments generally have an open floor area where play is conducted free from objects apart from the players themselves. At the elite sporting level these indoor play areas are designed and constructed under international specifications. Consequently, static wireless RF signal propagation knowledge obtained from one of these commonly built play areas is applicable to hundreds of other venues around the world. Many of these indoor sporting areas are used for a variety of sports, for example, basketball, volleyball, indoor cricket, indoor soccer, netball and handball. A player positioning installation could potentially be used for all of these sports. This paper reports the wireless RF signal propagation of a 2.4GHz waist mounted beacon for an indoor sporting venue 'play area', which has been designed to international standards. A basketball court constructed of highly polished wood was chosen as the sample 'play area'. Propagation models are discussed and comparisons between predicted and measured results demonstrate the validity of the technique.

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Keywords: Basketball; positioning; propagation; wireless tracking; localisation

* Corresponding author. Tel.: 61-7-3735-5036; fax: +61-7-3735-5384.
E-mail address: james.kirkup@griffithuni.edu.au.

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1. Introduction

In this study propagation models based on the classical Free Space Loss and Two-Ray models have been developed using a basketball court as the sample play area with an area size of 15m x 28m, with an additional 2m of clearance to any obstructions such as team bench seating. These radio signal propagation models were determined using empirical methods and statistics and are founded on fitting mathematical models to on-site measurements. The potential benefits from this study to the design engineer of an indoor player positioning system is that expensive site measurement techniques can be avoided in favor of a low cost propagation model, which is also a simpler alternative.

2. Experimental setup and procedure

The indoor basketball court (play area) chosen for this study was constructed to international standards [1] with thin planks of hardwood laid side-by-side length ward across the court. A quarter of the court was used to undertake the measurements being representative of the other three quarters. The transmitting beacon [2] used was a modified wireless monitoring device, developed in-house by the Centre for Wireless Monitoring and Applications, which transmits a continuous carrier wave signal at 2.4GHz. The instrument used to record the received power (dBm) was a hand held spectrum analyzer with a resolution accuracy of 0.5dBm in amplitude. The receive antenna used was a vertically polarized commercially available directional patch antenna with approximately 9dBi gain at 2.4GHz. The transmit antenna consists of a grounded quarter wave monopole meander antenna printed on FR4 type circuit board used by the beacon. The transmit antenna was orientated to provide a vertically polarized omni-directional radiation pattern. Both transmit and receive antennas were mounted on custom built wooden test rigs (Figure 1). A series of straight paths traversing a quarter of the court floor (Figure 1) was chosen with 0.5m step distance measurements along each path giving a total of over 200 measurement sites.

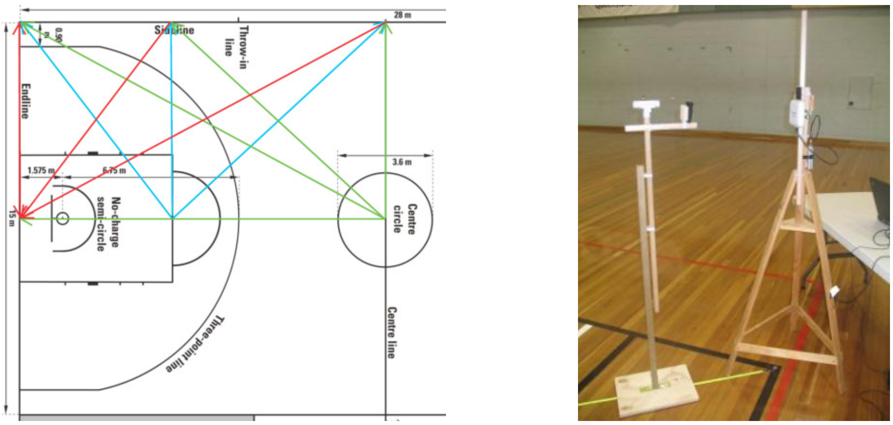

Fig. 1. (a) Measurement paths over quarter court; (b) custom built test rigs

Both the transmit and receive antenna heights were set to 1.45m above the court surface, representing the height of a beacon mounted under the chest (waist level) of an elite basketball player. The portable spectrum analyzer was taped to the test rig and connected to a laptop via a 3m USB data cable. All measurements were conducted in the far-field region of the transmitting antenna.

3. Experimental results

The recorded measurements were entered into a computer program, developed in-house using the MATLAB® R2012a program, to produce scatter plots for distances up to 10m as shown in Figure 2.

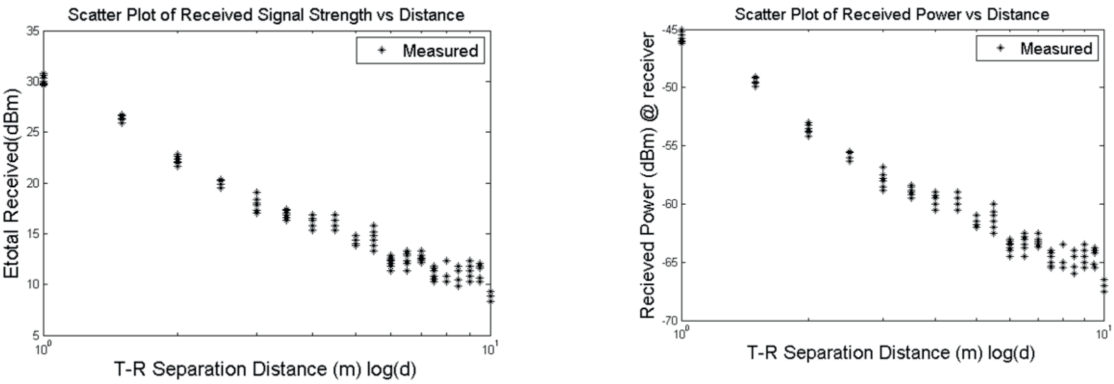

Fig. 2. Signal strength data recorded for all paths. a) Received field strength vs. Log-distance; b) Received power vs. Log-distance

4. Empirical path loss models

A Gaussian (or normal) distribution is commonly used in signal propagation prediction models to determine received signal strength where there is signal variation due to random shadowing, clutter, spatial or temporal movements. For this environment where there is a dominant stationary non-fading signal component (ie line-of-sight), the small-scale (fast) fading Gaussian spread generally follows a Ricean distribution [3, 4].

4.1. Free space path loss model

Both theoretical and measurement-based propagation models show that the average received signal power decreases logarithmically with distance. The Log-distance path loss model is given by

$$PL(dB, d \geq d_0) = PL(d_0) + 10n\log_{10}(d/d_0) \tag{1}$$

where n is the path loss exponent (slope index) that indicates the rate that path loss increases with distance, d_0 is a close in reference distance, $PL(d_0)$ is the average path loss measured or a free space calculation from the transmitter to d_0 and d is the separation distance in metres from the transmit antenna to the receive antenna. For the close in reference distance d_0, a distance of 1m was chosen and a reference power measurement was recorded within an anechoic chamber. Where there is surrounding clutter variation at different locations, measurements would be different to the average value predicted in equation (1). The path loss $PL(dB)$ at a given distance would be random and distributed log-normally about the mean distance value. In this case an additional random variable X_σ (dB) would need to be added to the equation, commonly known as log-normal shadowing [3]. X_σ is usually a zero-mean Gaussian (normal) distributed random variable with a standard deviation σ (dB).

A straight line linear regression and fit using the method of least square errors (MMSE) on the recorded measurements and those predicted by the free space path loss model resulted in a path loss exponent n of 2.05. A Gaussian random variable with zero mean and a calculated standard deviation σ of 1.03 dB could be added to account for a random shadowing variable. Plots of the estimated power (dBm) versus $\log_{10}(d)$ at the various measurement sites for the Free Space Path Loss model are shown in Figure 4 along with the straight line fit.

4.2. Two-ray path loss model

The simplest ray-tracing model applicable to indoor propagation is the "Two-Ray model", which is applicable when the ground reflection signal dominates the multipath signals. This model takes into account the direct signal path and one reflected path off the ground surface as shown in Figure 3.

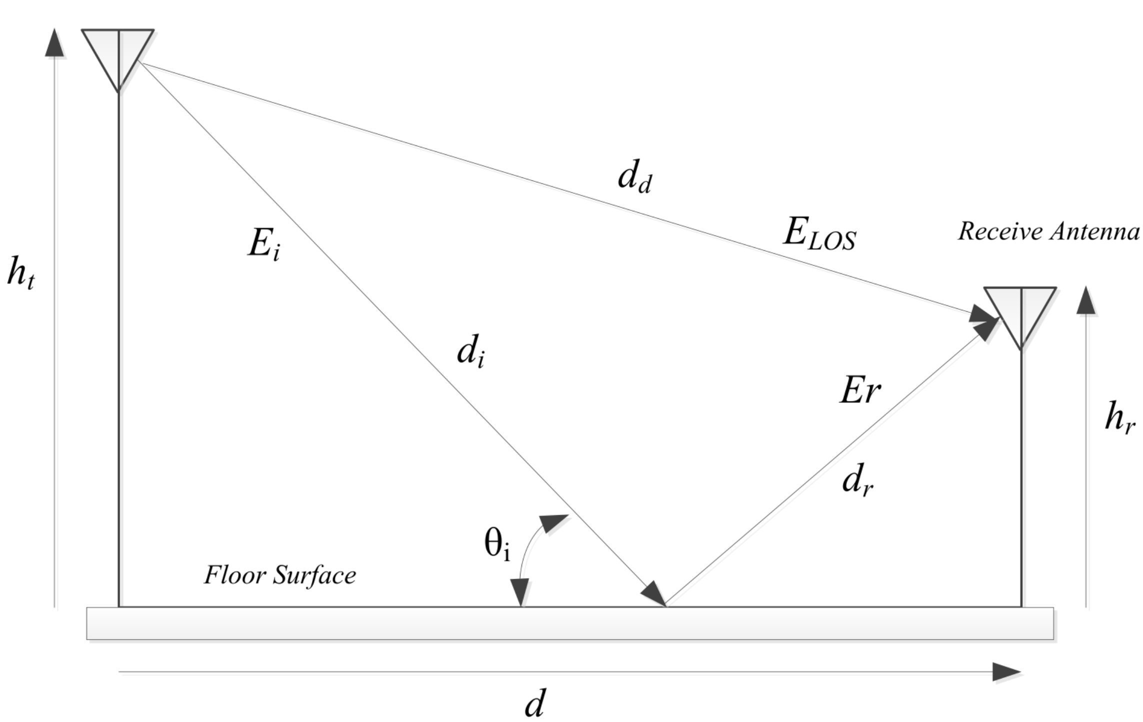

Fig. 3. Two-ray model representation

Comparison of ray-tracing methods with empirical data in literature has shown that it can accurately model the received signal within indoor environments with appropriately adjusted diffraction and reflection coefficients [5].

The two ray path loss model at any given frequency is given by

$$PL(dB, f) = PL(d_0) + 10n\log_{10}(P_d/PL(d_0)) \qquad (2)$$

where n is again the path loss exponent (slope index) that indicates the rate that path loss increases with distance, $PL(d_0)$ is the average path loss measured or a free space calculation from the transmitter to a close in reference distance d_0 and P_d is the average power received at distance d in metres from the transmit antenna to the receive antenna. The average power received at the receiver is made up of the combined line-of-sight E_{LOS} signal, or direct ray, travelling a distance d_d and a reflected E_R signal traveling a total distance of d_i plus d_r as represented in Figure 3. At any given frequency the total received field strength (mV/m) is given by $|E_{TOTAL}| = |E_{LOS} + E_R|$ and was calculated using the following equation

$$|E_{TOTAL}| = \left| \left({E_0}/{d_d} \right) e^{-jkd_d} + \Gamma \left({E_0}/{d'} \right) e^{-jkd'} \right| \tag{3}$$

Where E_0 measured field strength (mV/m) at a close in reference distance d_0 in metres;
d_d line-of-sight distance from transmitting to receiving antennas in metres;
d' the total distance travelled by the reflected signal in metres (ie $d_i + d_r$);
k is the wave number (phase constant) and is determined by $2\pi f / c$, where f is the frequency (2.4GHz) and c is the speed of light;
Γ reflection coefficient [3], which depends on the angle of incidence θ_i, the wave polarisation and frequency. It is also dependent on the relative dielectric constant and conductivity of the reflecting surface, which were taken to be 1.99 and 0.012 S/m respectively [11].

A linear regression using MMSE on the recorded measurements resulted in a path loss exponent n of 12.8. Plots of the estimated received field power (dBm) versus $\log_{10}(d)$ for the Two-Ray Path Loss model are shown in Figure 4.

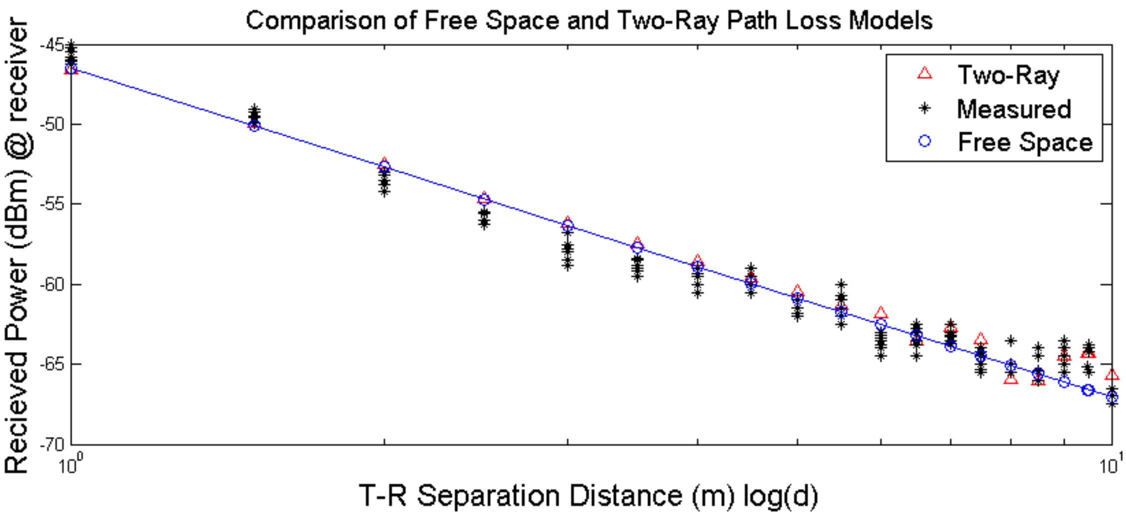

Fig. 4. Measured and estimated received powers for free space and two-ray models.

The results shown in Figures 2 and 4 indicates that for distances less than 10m there is very little interference from the ground reflection or other multipath signals. This confirms an environment of a Ricean distribution type under static conditions with a dominant line-of-sight signal component. The measured and calculated results also show that the measurements concur closely with the maxima and minima trend observed in the Two-Ray model predicted values. It is observed that the value for the path loss exponent n of 2.05 is very close to the value of 2.0 which is typical for a free space indoor environment. The value of n will have a larger value when obstructions are present.

5. Discussion and conclusion

Positioning systems for the tracking of players in indoor team sports have matured in the last decade prompting a growing interest by researchers in this area. The main motivation for these systems is the valuable information they provide to coaches and educators for improving the players' performance and ultimately the teams' offensive and defensive plays. Although outdoor positioning systems for sport have been around for some time, potential systems for implementation in indoor player tracking systems were only recently introduced in the mid 2000's [7].

Indoor wireless positioning systems that are based on radio frequency (RF) signal propagation are reliant on the underlying transmission channel propagation knowledge and the characteristics of the indoor environment. The need for static and non-static signal propagation knowledge in these environments is still important today and highly valued. There have been surveys and studies conducted on wireless indoor positioning techniques and propagation models [8, 9] that assist the design engineers, unfortunately, there is no one empirical model or positioning technique suitable for every indoor environment. This is mainly due to the variation in position and shape of the inanimate objects and surfaces between one environment to the next. This unknown variation in multipath, scattering or shadowing interference to the transmission signal hinders the mathematics used by researchers to produce a universal model. However, the playing area used by some elite indoor team sports is mainly free from these interfering and varying objects, except for the players and referees themselves. As the play area layout follows international specifications and is replicated at hundreds of venues around the world, scope exists to produce a general propagation model.

A sufficient number of field strength measurements were recorded over a typical indoor play area used by the sport of basketball to be a representative sample for this study. Free Space and Two-Ray path loss propagation models were successfully produced from these measurements for distances less than 10m. The prediction models showed that margin errors of less than 1dB are feasible where the accuracy of this value is constrained by the resolution limits of the hand held spectrum analyzer.

For a play area of 28m x 14m, using data from previous beam width experiments [10], it is feasible to provide full static coverage for determining the position with only two receive beacons per quarter court. Using the estimated path loss exponent for the free space path loss model it is possible to obtain conservative static positional accuracies of less than 0.5m.

By understanding the static signal propagation characteristics of the play area, further study can now be undertaken to include the effects of a moveable transmitting beacon mounted on a player and its impact on the accuracy of the position estimation. The measurements showed that the direct LOS signal was dominant and therefore the measurement sample follows a typical Ricean distribution. It is expected that this will change to a Raleigh type distribution when movement is introduced to the beacon and when other players and referees are considered within the play area. Values used for the reflection coefficient in the Two-Ray prediction model were derived from a ITU-R study [11]. Further investigation into the material reflection properties of the court surface could be undertaken to improve on the accuracy of these values.

The first step in considering the validity of an indoor wireless positioning system, for the tracking of players, is a high level of confidence in position predictability and accuracy under static conditions. This study has met this criterion and provides an opportunity for further research work in indoor wireless player positioning systems based on received signal strength or similar techniques.

Acknowledgements

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