**Situation Assisted Indoor Localization Using Signals of Opportunity**

Karthick Nanmaran  
Research Associate, Department of Computer Science and Engineering, SRM University, Chennai, India  
karthicknanmaran@gmail.com

B. Amutha  
Professor, Department of Computer Science and Engineering, SRM University, Chennai, India  
bamutha62@gmail.com

**Abstract**—Development of an accurate, less-complexity indoor positioning system using Smartphone is the scope of this research. In an indoor environment, a Smartphone can communicate with the signals of opportunity. The signals for experimentation include Wi-Fi, Bluetooth, GSM and optical signals which will almost be available in all the buildings and a Smartphone can communicate with all these signals based on the facilities provided in modern day mobile phones. The problems associated with indoor scenario are the architectural styles of the buildings which obstruct the Line of Sight [LOS] between the Smartphone and the signals of opportunity. In Non-Line of Sight [NLOS] scenario, it is difficult to estimate the position accurately. It is really a challenging task to deal with the indoor environment with walls and corridors because the ranging error in LOS and NLOS conditions is different. To avoid this problem, a communication system is modeled as a frequency selective channel model that uses LOS and NLOS signals in the available frequencies. The signal which has the highest Signal to Noise [SNR] ratio, low Bit Error Rate [BER] and maximum throughput parameters is chosen by the parameter selection algorithm based on statistical analysis, as these three parameters are essential to estimate the location accuracy. The communication system which satisfies these three parameters for the particular indoor environment at a particular frequency is chosen as the site specific path loss model. The indoor environment is completely covered with site specific path loss models with applicable frequencies. Empirical measurements were done for single user and multi user path loss models in first floor of our University Building based on the available frequencies. The experimental results showed that our communication system is applicable to Wi-Fi, Bluetooth, GSM and Optical signals in LOS and NLOS conditions providing site specific indoor positional accuracy.

**Keywords**—Indoor position, localization, signals of opportunity

**I. INTRODUCTION**

There are lots of opportunities for people to find their way in indoors. As people spend 70% of their time in indoors, it is quite essential to know their locations in indoors and as they want to move from one location to other location, they need to know their path with the device they use to have always in hand which is a smartphone. For blind people and for children it is quite necessary to track them as they do not put themselves in trouble. Like very big buildings, shopping malls, airport, museum and other clumsy indoor environments, indoor positioning is required with tracking and navigation as well. As location based services are much useful to humans and the constructions of buildings in the real world are getting bigger and bigger, indoor location based services are highly demanded. The research in indoor location based service started in 1990s and lot of techniques have been developed for the known environments whereas no universally acceptable efficient indoor location based scheme is currently available and this render to be one of the hottest current research issues.

The features of smart phones, its computing power, the equipped battery and the sensor devices equipped on it and it is a device without which people hesitate to live now a days is the most ideal device on which indoor location based systems could be executed. The Smartphone positioning technology is used to create new business in the navigation and mobile location-based services (LBS) industries. This research is intended to provide a smartphone indoor positioning engine named Situation Assisted Indoor Localization [SAIL] which can be easily integrated with mobile Location Based Services. SAIL is a hybrid solution that fuses measurements of smartphone sensors with the opportunistic wireless signals with the required signal strength.

The purpose of this research is twofold. To analyze the signals of opportunity with various parameters based on the internal structural models of the building. This involves LOS and NLOS signals. In different paths, the opportunistic signal’s parameters are investigated with a data fusion algorithm. According to our knowledge, there is no such methodology which fuses the signals of opportunity with combined optimal parameters exist in the earlier literature.

**II. LITERATURE SURVEY**

Propagation of Radio Frequency (RF) waves in indoor buildings and complex structured corridors is very complex and diverse as the propagation effects in the indoor scenarios will change over fractions of wavelength. Therefore, analyzing the RF propagation characteristics is vital for such complex indoor environments and estimation of propagation losses is very much needed for wireless networks. This lead us to choose the available frequencies as the test bed in the chosen...
indoor environment and provide a site specific path loss model pertaining to a particular frequency. In this research work, smartphone based short-range, RF propagation path loss measurements with wireless access points kept on top of the floor walls at a height of 5 meters from the floor were made in typical wide straight indoor floors and narrow corridors at 915/1800/2400/5000 MHz in our multi-storied University building using a smartphone shown in Fig 1.1. Comparisons between measured and simulated path loss values were done using Matlab simulations.

![Smart Phone with Signals of opportunity](image)

Log distance path loss model, free space and ITU-R path loss models were analyzed with the developed OWIL model experimented with 900/1800/2400/5000 MHz frequency ranges. The average path loss exponent values were deduced from the observed empirical data. The research is predominately geared towards characterizing the propagation effects on different situational frequencies and their effect on indoor positioning accuracy.

If there are interference risks, the most direct mitigation measure is to reserve a guard band between two wireless communication networks. This can minimize interference, but it may also waste frequency resources. The actual width of a guard band depends on the anti-interference capability of equipment and the amount of interference from existing networks.

III. MEASUREMENT PARADIGM

A. Measurement Specifications

The diagram of the measurement paradigm used for frequency selective characterization based on parametric values of indoor path loss channel is shown in fig 3.1

A smart plane is used to sweep continuous signals non-uniformly distributed from 900 MHz to 5000 MHz, with 900/1800/2400/5000 MHz operable access points situated in a specific indoor environment. The signal received by the smartphone is analyzed by the parametric selection algorithm based on high SNR, low BER and improved throughput. The parameters SNR, BER and Throughput of a wireless channel form the basis for the position estimation algorithm.

B. Parametric Selection Algorithm based on Channel State Information

The two levels of Channel State Information (CSI) are considered namely instantaneous CSI and statistical CSI.

1. Instantaneous CSI: It is a short term CSI that works on the current channel conditions. If the current channel conditions are known, from the transmitted signal, the received signal can be optimized using spatial multiplexing to achieve low BER.

2. Statistical CSI: It is a long term CSI based on statistical characterization of the channel. It depends on

   - the type of fading distribution
   - the average channel gain
   - LOS component and,
   - the spatial correlation

To analyze CSI acquisition, a practical test of how fast the channel conditions are changing was considered. In fast fading systems, the channel conditions vary rapidly. Under the transmission of a single information channel, statistical CSI is applicable. For slow fading systems, Instantaneous CSI can be estimated with reasonable accuracy.

As this test is conducted with a situation aware indoor localization principle and based on assumption that the smartphone user is also moving in a random manner, the current or instantaneous channel state estimation is combined with the user’s availability as single user or multi-user scenario.

C. Estimation of CSI with 900/1800/2400/5000 MHz

As the user awaits for situational frequencies, the instantaneous CSI has to be estimated for a short term basis based on the availability of the frequency signal. The pilot sequence signal is transmitted from the access point from where the channel matrix M is estimated using the combined knowledge of the transmitted and received signal strength.

The pilot sequence of signals be $P_1, P_2, \ldots, P_n$, where $P_i$ as a

$$Y_i = M P_i + n_i$$  \hspace{1cm} (1)

where Y is the received signal for the pilot sequence where i varies from 1 … n.

$$Y = Y_1 \ldots Y_n$$

$$P = P_1 \ldots P_n$$

$$N = n_1 \ldots n_n$$

Therefore, $Y = M P + N$  \hspace{1cm} (2)

Channel estimation M from Y (rx) and P (tx) denotes that the signal strength at the receiver is termed to be Y and the signal strength at the transmitter is termed as P. The equation
specifies the channel matrix associated with both transmit and receive signal of the relevant antenna.

Figure 3.1. An Indoor Measurement Scenario

According to Shannon’s capacity theorem, the capacity of the channels in the maximum data rate \( R \), at which the transmitter (Tx) and the receiver (Rx) can communicate is determined by the channel’s Bandwidth (BW) and SNR.

\[ \text{SNR} = \frac{S}{N} \]

Shannon Hartley theorem established that
\[ R = B \log_2(1 + \rho) \]  

The Signal to Noise Interference Ratio is SNIR, as the interfering source of power \( I \) and another source of noise,
\[ \rho I = \frac{S}{I+N} \]

\[ \rho \]

D. Channel Effect

1. Apart from straight path loss, the multipath natures of indoor environments affect the positional accuracy thereby limiting channel capacity. At 2400 / 5000 MHz, RF signals are bounced due to metal / glass surfaces. Due to this multipath scattering occur which leads to improvement of channel gain or a complete channel loss.

2. Phase angle variation of the received signal is affected between frequency and space. For a given distance, \( d \), travelled, the phase change is \( \frac{2\pi d}{\lambda} \).

\[ Q - Q' = \frac{2\pi d}{\lambda} \]

Therefore, the receiver accepting different received power leads to different frequencies, Therefore a study of frequency selective channels based on Ricean / Rayleigh fading mechanisms is required.

E. Frequency Selective Fading Channels

1. Rayleigh Fading

Rayleigh fading is the specialised model for stochastic fading when there is no line of sight signal, and is termed a special case of the more generalised concept of Ricean fading. In Rayleigh fading, the amplitude gain is characterized by a Rayleigh distribution.

2. Rician fading

Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by several different paths such as exhibiting multipath interference, and at least one of the paths is changing with lengthening or shortening. Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. It is proposed to have LOS using Rician fading. In Rician fading, the amplitude gain is characterized by a Rician distribution.

IV. SPATIAL VARIATION

The spatial variation depends on the statistical estimation of the fast fading channels. If the mobile user moves, the receiver receives multipath signals with rapid changes and the channel is affected by multipath effects.

<table>
<thead>
<tr>
<th>Channel Frequency</th>
<th>Throughput</th>
<th>Positioning Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 MHz</td>
<td>95</td>
<td>95%</td>
</tr>
<tr>
<td>1800 MHz</td>
<td>90</td>
<td>90%</td>
</tr>
<tr>
<td>2400 MHz</td>
<td>92</td>
<td>92%</td>
</tr>
<tr>
<td>5000 MHz</td>
<td>92</td>
<td>92%</td>
</tr>
<tr>
<td>( 10^{12} - 10^{15} ) THz</td>
<td>80</td>
<td>80%</td>
</tr>
</tbody>
</table>
A. Positioning Algorithm

Start

Input = SNR, CNR, BER, Throughput

Lookup table for SNR, CNR, BER, Throughput for positional accuracy

IF SNR, BER, Throughput provides required accuracy

No

yes

Keep the channel

Apply trilateration to calculate position

Stop

B. Lookup Table Formation

Start

Study the channel parameters – SNR, BER, Throughput

Optimal SNR – Assign Channel with the highest SNR value

Optimal BER – Optimal Bitrate Adaption Technique

Optimal Throughput – Assign channel with max. Throughput

Stop

C. Relationship between SNR, BER, Throughput

1. At any SNR, BER is continuously increasing function of the bit rate.
2. Within the allowable BER range, the bit rate is usable. (BER < 10^{-2})
3. BER at a given SNR = 10 + next lower bit rate.
4. Throughput depends on the BER. If BER increases, throughput decreases at the same rate.

BER \rightarrow B_b \quad SNR \rightarrow S_b \quad Throughput \rightarrow T_i

SNR = 10 \times \log_{10}(S/N) \text{ db} \quad (6)

Using Nyquist–Shannon theorem, if changes of differing magnitudes are associated with separate bit, the reply of information can be increased.

At each time the signal frequency changes, say n which is the rate of information.

R = 2B \times \log_2(n) \text{ bits/second} \quad (7)

where R is the rate of Information. B is the bandwidth and n is the level.

The error free signal over the channel is

C = B \times \log_2(1+S/N) \text{ bits/second} \quad (8)

This is the maximum independent sample rate the channel can carry and \log_2(S/N) bits denotes average level of signal voltage levels.

D. Measurement Environment and Data Connection

Measurements were carried out inside the Tech Park Building of SRM University. In the office rooms optical signals were
used for position estimation of a smart phone. The building has a complex indoor structure, architectural style, layout, and size. However, the sizes of class rooms are all within 20 by 20 m² under a short-range environment. In the corridors and the verandah 23 locations were selected for line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios, respectively. In NLOS scenario, the waves were obstructed by the architectural style of the building and the partitioning by over 2 m height partition due to its style. The transmitter-receiver (T-R) separation is ranging from 30 cm to 12 m. In each floor, the access points were kept fixed in a given position which is the best place for signal coverage in the verandah but not the corridors. The receive antenna is nothing but a smart phone was moved throughout the preprepared 23 locations. In each location, measurements were made at 10 points. Transmit and receive antennas during all the measurements were in the same position as it is the horizontal plane, while the height of antennas was about 2 m.

III. DATA ANALYSIS

The path-loss model is derived based on Rayleigh fading and Ricean fading mechanism of the observed RF channel which includes reflection, diffraction, and scattering for both LOS and NLOS scenarios. The path loss exponent along with a frequency based site specific factor is identified due to the random variation of signals based on the shadowing effects. Thus, the path-loss model for a T-R separation at the frequency is given with a 1 meter separate distance comparison with other distances in terms of 1 meter variation in between consecutive measurements at each frequency point through measurement data.

The scatter plots are drawn for the path loss computed in the locations of the verandah and the corridor in LOS and NLOS scenarios between 900-5000 MHz are depicted. The lines are least squares linear regression lines through the scatter of path loss in locations estimated by the path loss models due to Rayleigh and Ricean fading.

IV. CONCLUSION

In this paper, a novel situational aware frequency selection signals are chosen for a site specific indoor environment. The statistical prediction path-loss model for short-distance indoor with a verandah and corridors in a floor environment at 0.9 – 5.0 GHz is presented. A complete characterization of the model parameters was described with empirical validations and dependencies between parameters. The distinctions of the site specific model with the given range of different frequencies are significant as the experimental data shows the difference of path-loss value at different frequencies is obvious.

The above research work shows the parametric validation of SNR, BER and throughput which make a point in positional accuracy and minimizing the complexity. This research also explains the relationship between the path-loss exponent and the working frequency together produces a new framework about describing the path loss specific to a given indoor scenario. It provides a certain basis for the realization of wireless communication with the available frequencies under complex indoor environment effectively utilizing the spectrum resource for a smartphone based indoor positioning system.

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REFERENCES


