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AN EMPIRICAL ANALYSIS OF A SIX RADIO CHANNEL PSEUDO GENERATOR FOR BETTER NOISE REDUCTION IN RANGING SYSTEMS

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Abstract

In this work, we have analysed a novel antenna array setup that will utilise frequency diversity to improve the performance of received signal strength (RSS) based geolocation techniques. Signal attenuation and fading properties are better mitigated when a communication channel is split into smaller sub carriers that exhibit orthogonality or independence. This analysis also includes the RSS range estimation in normal single carrier systems and multi carrier systems. This research can vastly improve current passive cell tower geolocation techniques that hinge on range estimation. This can vastly improve services like emergency rescue, tracking applications and location-based marketing where GPS is not available or applicable.

1. Introduction

Triangulation using RSS is the simplest and basic means by which we

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can find the position of a mobile user. This is due to the relative simplicity of the hardware and software that is needed to achieve this (filters, level detectors and equalizers). Various methods have been implemented for the use of the passive cell tower infrastructure to aid in location-based services [1-4]. Various research methods have looked at hybrid techniques to create better estimation models [5-7]. Mobile trilateration falls under four broad categories, i.e., network based, mobile based, network assisted and mobile assisted [8]. Fading in the wireless domain has two main variants:

(a) Large scale fading: This is due to shadowing and mean path loss. This loss increases with distance between the transmit antenna and the receive antenna. Shadowing is signal attenuation due to obstacles in the path of the electromagnetic wave [9].

(b) Small scale fading: This is responsible for the variation of RSS values by about 1%-2% of the actual value. Small scale fading is mainly due to factors like wave reflection, multi-path, Doppler effects, flat fading and frequency selective fading as shown in Figure 1 [10].

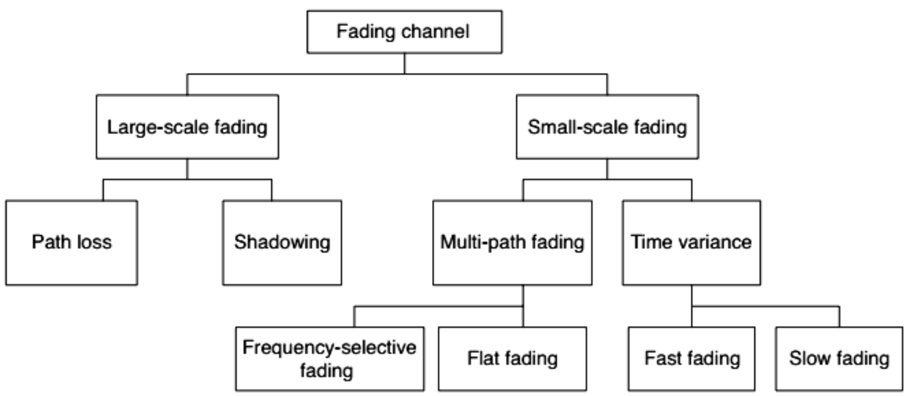

Figure 1. Classification of fading channels [10].

2. Channel Types

The basic assumption for signal strength in geolocation applications has been derived from the principles of applying a link budget approach to a wireless communication channel by taking into consideration antenna gains and power losses within the system. The Gaussian transmission channel can be described as the best-case scenario whereby the channel is only affected by adding white Gaussian noise at the receiver. Rayleigh channel is characterized by multi-path or scatter components that are received at the receiver. The Rician channel falls between the two extremes of an ideal Gaussian channel and the worst-case Rayleigh channel [11]. The Friis transmission equation does not give a clear representation of the actual link budget of a wireless system. The amplitude of an electromagnetic wave is not only related to the inverse of frequency of transmission but also the distance between transmitter and receiver. Different electromagnetic wave frequencies penetrate buildings and encounter fading uniquely [12]. Means, if we had two separate channels that are uncorrelated frequency wise, then shadowing and attenuation will be likewise uncorrelated. There are two possible ways to mitigate random and unexpected fading effects that will otherwise affect RSS distance estimation:

(a) Taking multiple RSS samples and finding the mean using the least squares regression method.

(b) Splitting the transmit channel into multiple frequency channels that are uncorrelated and running the RSS distance algorithm on each channel then use the least squares regression method on the values of distance obtained (frequency diversity).

Diversity allows the rapid reduction in distance estimation error in wireless communications by creating several unique and independent transmission channels. Each of these channels undergoes its own fade and retardation characteristic.

In recent technological pushes, second generation communications (2G) have been superseded by 3G and 4G, however in developing nations like Africa and Asia (2G) is the widest terrestrial network available. This has driven the research in the legacy technology. In the Global System for Mobile (GSM) communications, frequency diversity is implemented using frequency hopping (FH). The most common type of frequency hopping employed is slow frequency hopping (SFH) whereby each carrier channel cycles through 64 predetermined frequencies. With each new symbol or burst, the logical channel changes for every 4.615 ms [13].

3. Model

Starting from an elementary single carrier system model, where we have a transmitted symbol $\{s_m\}$ and the symbol period is *T*. This symbol is transmitted through a channel $h(t)$ after going through a transmit filter $g_T(t)$, where additive noise will be introduced $n(t)$. Antenna at the receiver will take the received symbol through a receive filter $g_R(t)$ and equalizer $h^{-1}(t)$. The signal recovered at the receiver $y(t)$ is

$$y(t) = \sum_{m}^{\infty} s_m g(t - mT) + n(t), \tag{1}$$

where $g(t) = g_T(t) * h(t) * g_R(t) * h^{-1}(t)$. To ensure that this channel is indeed frequency non-selective, the symbol period $T >> 10$ times the delay spread of S_m at the receiver. At the detector side, a path loss algorithm is run that includes shadowing, random power noise and the frequency component of fading to create the RSS receive matrix where each row is an independent frequency channel. The radio channel is an extremely difficult channel to model due to the random nature of noise. Modelling of a radio channel is done using statistical methods. The best model to use here is the Friis transmission equation. This model is used in telecommunication engineering to estimate the received signal power P_r by a receive antenna with receiver gain G_r separated by distance *R* from a transmit antenna with gain G_t, transmit frequency *f* and transmit power of P_t under ideal conditions. The RSS value derived from the Friis transmission equation P_r is given as:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right). \tag{2}$$

Equation (3) is a modified log path loss model where a noise component has been incorporated into the equation. The signal to noise ratio (SNR) will be varied in each sample of measurements, the noise component is modelled as white Gaussian random noise that is normally distributed with a mean of zero (multi-path effects and interference). Equation (3) is transposed into a function in MATLAB and the noise component added using the inbuilt noise generator

$$P_r = P_t + G_t + G_r + 20\log_{10}\left(\frac{c}{4\pi f R}\right) + n(0, N) - P_s. \tag{3}$$

A reception matrix of P_r values with dimensions $(n \times m)$ stores incoming RSS values as shown in equation (4). The rows, n represent the number of transmit frequencies and m is the RSS value at each sample period. Figure 2 shows the logical block diagram of the diversity technique

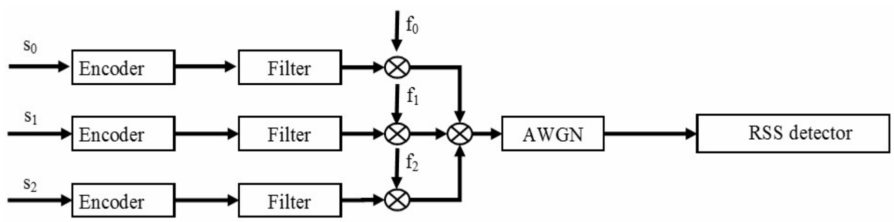

Figure 2. Model for multi-channel RSS trilateration with advantage of frequency non-selective fade.

Let $\dot{F}$ be an array populated with transmit frequencies represented by $\dot{F} = [f_1, f_2, f_3, ..., f_n]$. The $\dot{F}$ array will be iterated through the range estimating equation and each iteration will be multiplied by a scaling constant k that is dependent on the frequency [14],

$$P_r = \begin{pmatrix} Rss_{11} & \cdots & Rss_{1m} \\ \vdots & \ddots & \vdots \\ Rss_{1n} & \cdots & Rss_{nm} \end{pmatrix}. \tag{4}$$

Equation (3) can be rearranged to give equation (5) where R is the distance between the transmitters, a constant of proportionality k is added for each value of frequency. The constant k is discussed in [14],

$$R = \frac{c}{4\pi k\overline{F}\left(\sqrt[20]{10^{(P_r - P_t - G_t - G_r + n(0,\ N) - P_s)}}\right)}. \tag{5}$$

Effectiveness of this new ranging technique has been measured by comparing the root mean square error (RMSE) values for the combined diverse channel and the single channel:

$$RMSE_{(1,\,m)} = \sqrt{\frac{\sum (P_{r(1,\,m)} - \mu)^2}{m}}, \tag{6}$$

where $\mu = \frac{\sum \left(P_{r(1,1)} + P_{r(1,\,2)} + P_{r(1,\,3)} + \cdots + P_{r(1,\,m)}\right)}{m}$.

Equation (5) shows the RMSE of the first channel with *m* samples.

4. Results and Analysis

Analysis of RSS values on all the independent transmission channels gives rise to values as shown in Figure 3. Fifteen delay periods have been used to calculate the distance between transmitter and receiver. The theoretical distance was 2500 m, but each channel estimate fluctuated with variances as high as 60 m. The mean distance factoring all the channels has been found to be 2497 m. Each of these channels were simulated under extreme conditions, AWGN with SNR of 60 dB were used in the simulation.

An analysis of simulated varied SNR and the resulting root mean square errors is portrayed by Figure 4. In the simulation, five independent electromagnetic channels were modelled using equation (5). The signal to noise ratio was varied between 30 and 60 for the single channel and the multi-channel carrier. RMSE drops drastically for the multi-orthogonal carrier setup as compared to the dedicated frequency channel thus proving the effectiveness of frequency diversity to mitigate ranging error.

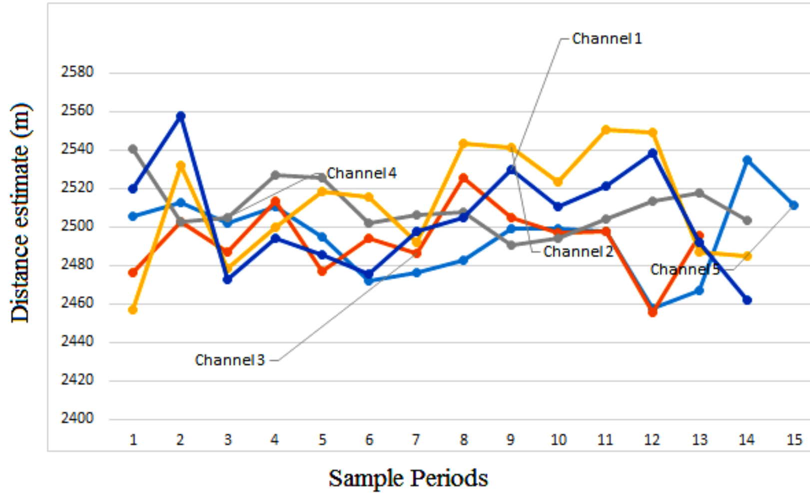

Figure 3. Distance estimate values of each channel sampled at various periods.

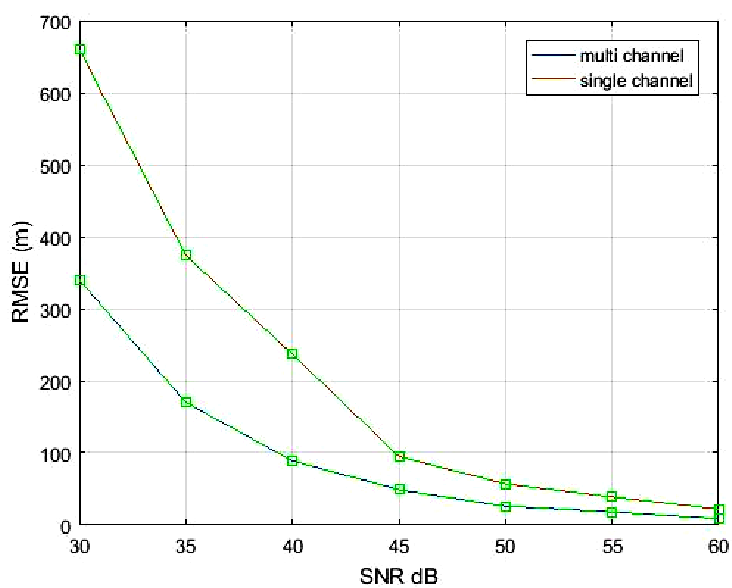

Figure 4. RMSE vs SNR for multi-channel and single channel.

5. Conclusion

Using statistically independent channels for trilateration purposes, enhancement in the effective accuracy of range measurement can be seen by the curves in Figure 4. Error estimates for the multi-channel calculation offer better SNR vs RMSE curves compared to a single channel. Further development could be the design of an android application (APK) package on an android that can utilize this trilateration scheme and run multiple scenarios and prove this technique in real world environment.

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