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NLoS and LoS Link Identification For Improved Localisation

1 Introduction

Localisation is key to various applications such that annotating physical location of sensors with sensors data in wireless sensor network, localising personnel and objects for industrial automation, tracking personnel in working environments, contact tracing for maintaining social distance etc. Ultra-wide band is emerging as one of promising technology for localisation,it is a time-based localisation algorithm. UWB localisation is based on measuring the signal propagation time between a transmitter and a receiver.

Time-difference-of-arrival(TDOA) localisation algorithm requires precise clock synchronisation among all or reference nodes inside system but commonly TWR(Two-way ranging) method is used in UWB localisation as it doesn't require clock synchronisation and thus can be is resource-constrained wireless devices.

UWB pulse radios have ultra-wide bandwidth(typically more than 500MHz) and short transmit pulses offer high temporal and spatial resolutions and great multi-path fading immunity with result in high localisation accuracy and location update rate. However high multi path resolvability alone does not eliminate the effects of multi-path and NLoS (Non-Line of sight) propagation.

TWR based UWB localisation requires a UWB anchor (reference node) network to track tags(node with tracked). TWR is used to calculate range between anchor and tags and then triangulation can be done to have precise location of tag (with reference to anchors).The localisation algorithm will lead to erroneous results when there is large ranging errors between anchors and tag(s). Multi-path propagation and NLoS propagation are primary source of ranging algorithm inaccuracies.

NLoS identification can be used to detect NLoS nodes which can latter be eliminated (or weighted according) from the pool of nodes used of localisation. This is useful when we have a large number of anchor nodes available with many of them with an LoS link to the localized node(s). NLoS and LoS links can be identified based on channel impulse response (CIR) characteristics. A binary hypothesis test, using CIR characteristics, can be formulated to detect NLoS and LoS link.NLoS detection at localized node/localization engine can help eliminate or reduce ranging inaccuracies which can result in more precise and robust UWB based localization system.

2 Problem Statement

Overview of Localisation

A network consists of two types of nodes: *anchors* are nodes with known positions, while *tags* are nodes with unknown positions. Let there be a network with single tag with unknown 2D position $\mathbf{p(X,Y)}$ surrounded by N anchors with positions, $\mathbf{p_i(x_i,y_i)}$. The distance between the agent and anchor i is $d_i = \|\mathbf{p}-\mathbf{p_i}\|$.

The tag estimates the distance between itself and the anchors, using a ranging protocol such as Ultra-wide band based Two Way Ranging. Let $\hat{d}_i$ denotes the estimated distanced between the agent and anchor i and $\epsilon_i = \hat{d}_i - d_i$ is the ranging error. Given a set of at least three distance estimate, the tag will be able to determine its position using triangulation. Tag can solve below equation to compute $\mathbf{p(X,Y)}$.

$$\hat{d}_i = \|\mathbf{p}-\mathbf{p_i}\| \; for \, i = 1,2,3... \tag{1}$$

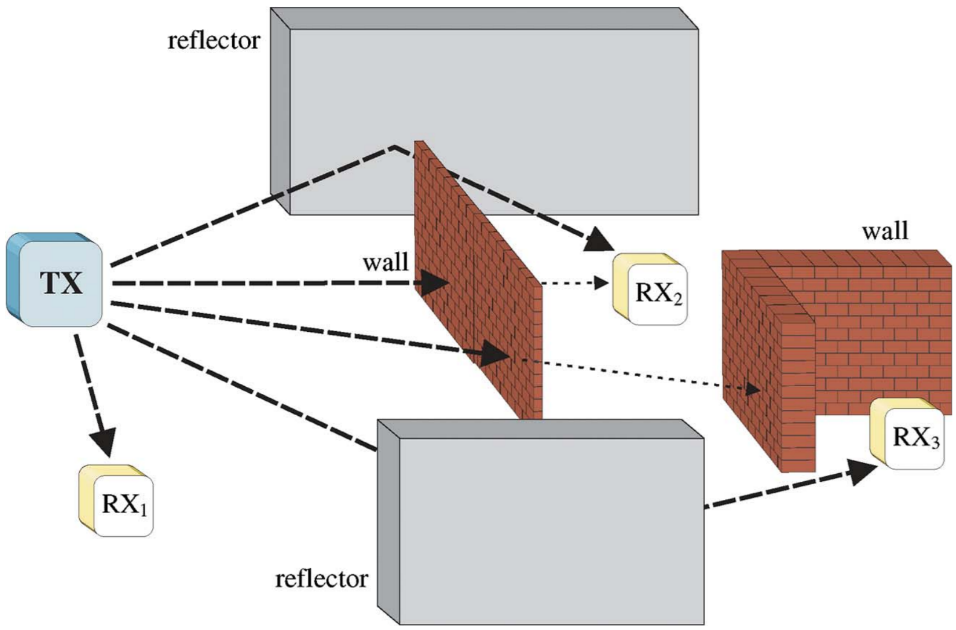

Figure 1: Possible LOS and NLOS conditions from transmitter TX to various receivers. RX1 is in LOS condition, RX2 and RX3 is in NLOS condition [4]

Ranging Error
The triangulation algorithm will lead to erroneous results when the ranging errors are large. In practice the estimated distances are not equal to the true distances, because of a number of effects including thermal noise, multi-path propagation, interference, and ranging algorithm inaccuracies. Additionally, the direct path between requester and responder may be obstructed, leading to NLOS propagation. In NLOS conditions, the direct path is either attenuated due to through material propagation (RX_2), or completely blocked (RX_3). In the former case, the distance estimates will be positively biased due to the reduced propagation speed (i.e., less than the expected speed of light, c). In the latter case the distance estimate is also positively biased, as it corresponds to a reflected path. In NLOS identification nodes (anchors) with NLOS characteristics are identified and distance estimates are not considered for triangulation. Figure 2 is the CDF plot of the ranging error for LOS and NLOS scenario based on the data collected as part of research in [4].In LOS conditions a ranging error below one meter occurs in more than 95% of the measurements. On the other hand, in NLOS conditions a ranging error below one meter occurs in less than 30% of the measurements.

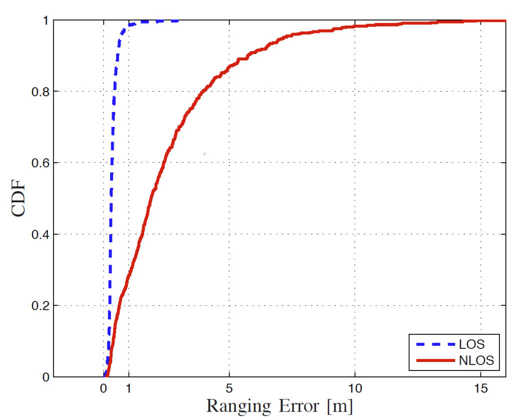

Figure 2: CDF of the ranging error for the LOS and NLOS condition[3]

Channel Impulse Response (CIR) and Channel Statistics

Determination direct path(DP) of arrival is essential requirement for accurate ranging. NLOS and LOS scenarios affect the propagation characteristics, which in turn affects the Channel Impulse Response. Thus, The amplitude and delay characteristics of CIR at receiver can be used to NLOS and LOS identification. UWB channels are able to capture a significant number of multipath components(MPCs). The Saleh-valenzuela model ,widely accepted and popular propagation model, for multipath propagation is given by [2]

$$h(t) = \sum_{l=0}^{\infty}\sum_{k=0}^{\infty} \beta_{kl} e^{j\theta_{kl}} \delta(t - T_l - \tau_{kl}) \tag{2}$$

where $beta_{kl}$ is the gain of the kth ray in lth cluster, θ_{kl} denotes the phase of the kth ray in lth cluster, T_l denotes the arrival time of the lth cluster τ_{kl} time delay of the kth ray in the lth cluster. A naive Hypothesis can be

$$\begin{aligned} H_0 &: d = cT_1 \\ H_1 &: d < cT_1 \end{aligned} \tag{3}$$

where H_0 is the LOS hypothesis, H_1 is the NLOS hypothesis c denotes speed of light, d denotes actual distance between transmitter and receiver.

The amplitude and delay characteristics of CIR can be captured using the kurtosis, the mean excess delay, and the rms delay spread of the CIR.

- Kurtosis(k) - The kurtosis of a certain data is defined as the ratio of the fourth-order moment of the data to the square of the second-order moment(variance) of the data.Kurtosis provides information about the amplitude statistics of the received MPCs, It indicates how "peaky" data is. Thus for a CIR with high kurtosis values, it is more likely that the received signal is under LOS. It is given by[5]

$$k = \frac{E[(|h(t)| - \mu_{|h|})^4]}{\sigma_{|h|}^4} \tag{4}$$

  $\mu_{|h|})$ and $\sigma_{|h|}$ are the mean and standard deviation of the $|h(t)|$

- Mean excess delay (τ_m) - Mean excess delay characterize delay information of the multipath channel. It is define as the time delay during which multipath energy falls to X dB below the maximum. It is given by[5]

$$\tau_m = \frac{\int_{-\infty}^{\infty} t|h(t)|^2 dt}{\int_{-\infty}^{\infty} |h(t)|^2 dt} \tag{5}$$

- RMS delay spread(τ_{rms}) - RMS delay characterize delay information of the multipath channel. The RMS delay spread serves as an indicator of the time dispersion of the received signal's energy. It is given by[5]

$$\tau_{rms} = \frac{\int_{-\infty}^{\infty} (t - \tau_m)|h(t)|^2 dt}{\int_{-\infty}^{\infty} t|h(t)|^2 dt} \tag{6}$$

In [2] B.Silva and G.P. Hancke also mentioned other metrics to characterize CIR and can be used of NLOS and LOS identification.

- Skewness(S) - Skewness is an indicator of the asymmetry of a distribution. It is given by[2]

$$S = \frac{E[(|h(t)| - \mu_{|h|})^3]}{\sigma_{|h|}^3} \tag{7}$$

  $\mu_{|h|})$ and $\sigma_{|h|}$ are the mean and standard deviation of the $|h(t)|$

- Peak-to-lead delay:(PLD) - The PLD is the time difference(in nanoseconds) between the first(τ_f) and strongest(τ_s) MPCs. Typically the larger the difference, the more severe the NLOS condition. It is given by[2]

$$PLD = \tau_f - \tau_s \tag{8}$$

- Power difference(PD) - It is define as the difference between total power P_T and the power of the first path P_{FP} in the CIR.

$$PD = P_T - P_{FP} \tag{9}$$

- Power ratio(P_R) - It is define as the ratio the power of the first path P_{FP} in the CIR to of total power P_T .

$$P_R = \frac{P_{FP}}{P_T} \tag{10}$$

To determine whether a certain measurement is either LOS or NLOS, a binary hypothesis test based on the probability distribution(PDFs) for both hypotheses can be employed. Let H_0 denotes the LOS hypothesis and H_1 denotes the NLOS hypothesis. A binary hypothesis test can be formulated as follows.

$$L = \frac{p_\xi(\xi|H_0)}{p_\xi(\xi|H_1)} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\gtrless}} \lambda \tag{11}$$

where ξ is denotes any metrics previously defined, p_ξ is the conditional PDF for said metric, λ is a threshold, and L is the computed Likelihood ratio.

3 Likelihood Ratio and Distributions

From the literature I have collected information regarding distribution of various metrics>. I have to tabulate them and explain them in report

4 Simulation and Mitigation Techniques

Still working on a way to figure out simulation in this context

5 Learning's and Takeaway

6 References

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3. S. Marano et al., “NLOS identification and mitigation for localization based on UWB experimental data,” IEEE J. Sel. Areas Commun., vol. 28, no. 7, pp. 1026-1035, Sep. 2010.

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5. Ismail Güvenç, Chia-Chin Chong, Fujio Watanabe, and Hiroshi Inamura. 2008. NLOS identification and weighted least-squares localization for UWB systems using multipath channel statistics. EURASIP J. Adv. Signal Process 2008, Article 36 (January 2008), 14 pages. DOI:https://doi.org/10.1155/2008/271984

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