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Analysis of Single Transmitter 3D Indoor Positioning based on Virtual Transmitter Concept

***Abstract**. The performance of indoor positioning systems is greatly affected by multipath error due to complexity of environment geometry. Other than mitigating the error, the nature of multipath wave propagation can be utilised to reduce the system's complexity and installation cost. This paper proposes the development of a single transmitter indoor positioning method based on virtual transmitter (VT) concept and TOA measurement. A 3-dimensional indoor space of 13.25m×12.25m×4m is modelled as the area of study. A ray tracing simulation tool is used to obtain the VTs' position and power delay profile (PDP) of the multipath channel at multiple receiver's position within the space. From the obtained PDP, three VTs with the highest received power are chosen to perform lateration using the linear least square (LLS) and nonlinear least square (NLLS). Analysis shows NLLS gives a far better estimation accuracy compared to LLS. The low z-plane estimation accuracy contributes to high RMSE of position estimation. The findings can be utilised as a baseline for indoor positioning estimation technique. With additional analysis, this method will be further improved for better accuracy.*

***Streszczenie.** Na wydajność wewnętrznych systemów pozycjonowania duży wpływ ma błąd wielościeżkowy ze względu na złożoność geometrii środowiska. Oprócz ograniczania błędów, natura propagacji fali wielościeżkowej może być wykorzystana do zmniejszenia złożoności systemu i kosztów instalacji. W artykule zaproponowano opracowanie metody pozycjonowania pojedynczego nadajnika w pomieszczeniach, opartej na koncepcji wirtualnego nadajnika (VT) i pomiarze TOA. Jako obszar badań modelowana jest trójwymiarowa przestrzeń wewnętrzna o wymiarach 13,25 m × 12,25 m × 4 m. Narzędzie do symulacji śledzenia promieni jest wykorzystywane do uzyskiwania pozycji VT i profilu opóźnienia mocy (PDP) kanału wielościeżkowego w pozycji wielu odbiorników w przestrzeni. Z otrzymanego PDP wybiera się trzy VT o najwyższej odbieranej mocy, aby przeprowadzić późniejszą metodę liniową najmniejszych kwadratów (LLS) i nieliniową metodę najmniejszych kwadratów (NLLS). Analiza pokazuje, że NLLS zapewnia znacznie lepszą dokładność oszacowania w porównaniu z LLS. Niska dokładność estymacji w płaszczyźnie Z przyczynia się do wysokiego RMSE estymacji pozycji. Wyniki można wykorzystać jako punkt odniesienia dla techniki szacowania pozycjonowania w pomieszczeniach. Dzięki dodatkowej analizie metoda ta zostanie udoskonalona w celu uzyskania większej dokładności. (**Analiza pozycjonowania 3D pojedynczego nadajnika w pomieszczeniach w oparciu o koncepcję wirtualnego nadajnika**)*

Keywords: Indoor positioning, Single transmitter, Virtual transmitter.
Słowa kluczowe: Pozycjonowanie w pomieszczeniach, Pojedynczy nadajnik, Wirtualny nadajnik.

Introduction

The demand for indoor positioning systems (IPS) has increased with the widely offered information access and wireless mobile communication technology. IPS provide the information of mobile devices' mobility in closed environment where Global Positioning Services (GPS) is not reliable due to weak signal penetration [1]. However, IPS necessitate higher accuracy with proportion to the area and the limitations in the environment. In current implementation, IPS relied on a standalone infrastructure that needs multiple transmitters to perform position estimation algorithms. However, multi-transmitter systems are more complex, require a high installation cost, and introduce synchronization error which commonly ignored in parameter measurements. On top of that, the major challenge in indoor environment is the nature of wireless wave multipath propagation which introduces multipath errors and lead to poor accuracy performance. Multipath errors are often considered as a threat and combated by using precise range estimation methods [2]. However, a new trend of manipulating multipath errors instead of combating them has been intensively investigated in recent years. The approach is associating multipath wave propagation with a single transmitter positioning systems has seen to solve multipath errors, as well as reduces the reliance on infrastructure and installation cost. Promising results have been explained in several works that propose the multipath-based single transmitter concept in outdoor [3–6], dense urban areas [7] and indoor environment [8–11]. For example, the implementation of single transmitter positioning concept has eliminated the use of multiple road-site unit (RSU) in VANET [3]. This overcomes the limitation of traditional sparsely distributed RSU where more than two RSUs are needed to perform trilateration or triangulation estimation. In the emerging 5G systems, the utilization of massive MIMO configurations in a single transmitter positioning system overcomes the synchronization issues between multiple transmitters [5,12–14]. Most of the current research consider 3D scenarios to resemble the real system implementation. Overall, 3D positioning is more complex than 2D positioning because it must concern the accuracy of elevation estimation apart from vertical accuracy. There are little investigations on the effect of estimation accuracy contributed by each of the planes in 3D environment architecture.

In this paper, we realize the range-based technique utilizing virtual transmitter concept in an indoor environment. Firstly, we build a 3D indoor environment model as the platform to simulate multipath wave propagation. We study multipath propagation by using ray tracing technique and investigate the effect of x-, y- and z-plane estimation accuracy to the overall system's accuracy. RT simulation traces the transmission of wireless signal from a physical transmitter (PT) to the receiver located in the environment. The line of sight (LOS) ray and multipath rays' characteristics are captured at multiple grid points in terms of channel impulse response (CIR). Secondly, the power delay profile (PDP) of multipath channel is extracted and the coordinate of the best three virtual transmitters (VTs) are stored. We performed two basic estimation methods called linear least square (LLS) and non-linear least square (NLLS). The main contributions of this paper are as follows.

1. Simulating the multipath wave propagation in a single transmitter indoor positioning system.
2. Extracting power delay profile (PDP) from multipath channel and VT's parameters.

3. Analyzing the effect of estimation accuracy in x-, y- and z-plane.

The remainder of this paper is organized as follows: Section II provides the background study of single transmitter range based on indoor positioning technique. Section III briefly describes the RT together with linear least square (LLS) and nonlinear least square (NLLS) estimation schemes which are considered in this work. Then, we describe the simulation set up and discuss the results in Section IV. Finally, the findings are concluded in Section V.

Single Transmitter Positioning

There are two common methods proposed for single transmitter indoor positioning, which are fingerprinting [5,12–16], and range-based techniques [7,17–19]. Both techniques utilize the wireless channel parameters including TOA, received signal strength (RSS) and angle of arrival (AOA). The performance of fingerprinting-based positioning relies mainly on the accuracy and uniqueness of the recorded fingerprint database. Therefore, one of the challenges is that the database needs to be regularly updated and calibrated due to changes in the environment to maintain database accuracy. Moreover, signal fluctuations, especially in RSS-based methods, lead to unstable data measurements. On the other hand, range-based techniques are much simpler methods which take advantage of one of the channel parameters. In some works, TOA is combined with AOA and AOD to enhance positioning accuracy. These parameters are utilised either by manipulating the characteristics MIMO-OFDM signal or the virtual transmitter concept.

1) Multipath Channel Estimation

Basically, the realization of a single transmitter positioning system relies on the nature of wave propagation with respect to the environment geometry. In MIMO-OFDM systems [5,12,13], the behaviour of subcarriers propagating differently according to the environment is utilized to estimate the multipath channel characteristics. Similarly, in single omnidirectional antenna systems, the nature of the wave propagation and interaction with physical structures in the surrounding allows the channel characterization between transmitter and receiver. Other than focusing on the infrastructure and synchronization, the accuracy of elevation estimation is also important, especially in an indoor environment. Therefore, current research is mostly considering 3D scenarios, which give more accurate position estimation.

Fig.1 depicts the basic concept of a 3D single transmitter positioning in a relatively small indoor scenario. Intuitively, the receiver receives a direct ray from the physical transmitter and three reflected rays due to reflection at three different points. Since the path taken by each ray is different, the time of arrival at the receiver is also different. If the total number of rays is denoted as R, the channel impulse response (CIR) that characterizes rays' propagation between transmitter and receiver can be expressed by equation (1).

$$h(t) = \sum_{r=0}^{R-1} a_r(t)\delta(t - t_d) \qquad (1)$$

where: $a_r(t)$ – complex gain of the r^{th} ray, $\delta(t - t_d)$ – shifted impulse at the delayed time of t_d.

CIR is employed as fingerprints in fingerprinting-based positioning [5,12,13]. On the other hand, channel parameters such as TOA, TDOA, AOA and RSS are extracted from CIR in range-based methods [7,17–19]. In this paper, we focus on range-based positioning algorithms.

Range-based methods rely on the implementation of the virtual transmitter concept to perform position estimation, as depicted in Fig.2. In the figure, two VTs are generated due to reflection by wall 1 and wall 2, while another VT is generated due to a scatterer (furniture). By implementing the virtual transmitter concept, the receiver's position can be estimated by finding the intersection of spheres circumference centered at the PT and VTs. Therefore, the existence of physical structures like vertical walls, floors, glass windows and ceilings, which were traditionally treated as obstacles, now become important to promote high numbers of virtual transmitters.

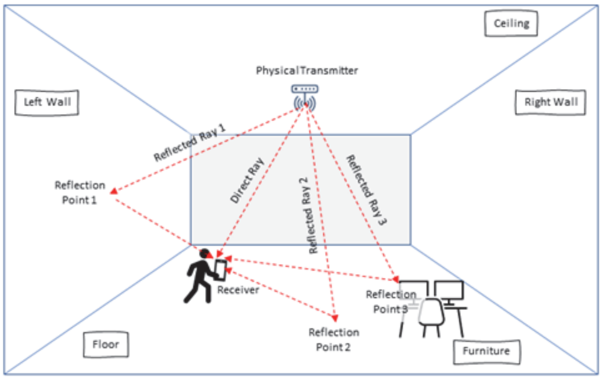

Fig.1. Illustration of multipath wave propagation in indoor environment.

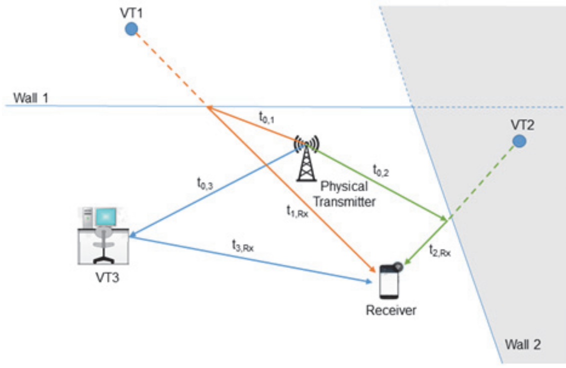

Fig.2. Generation of virtual transmitters.

Common techniques used to estimate CIR found in the literature are either using channel estimation algorithms [3,5,7,13,15,18], or scattering models [4,6,12]. However, time differences are extremely small for very short distances in an indoor environment, and minor errors may lead to a relatively significant error. Therefore, high precision channel estimation is necessary to provide high accuracy positioning. This can be done by using a deterministic modelling like RT technique, which works based on Maxwell's equations. With proper environment modelling and advanced CPU time reduction, RT provides accurate multipath channel characteristics.

2) Position Estimation Algorithm

In the range-based positioning methods, the receiver's position is estimated by either finding the intersection of reflection lines or using least square techniques. To use intersection approach, one needs to know the AOA. On the other hand, least square techniques can rely only on TOA. The researchers in [17] proposed a two-step weighted least squares to estimate the receiver's position in NLOS multipath environments. NLOS paths are converted into LOS paths using VT concept. The authors only consider a single reflection ray to generate VT.

Single transmitter indoor positioning relies on the room geometry to estimate reflection points. At least three reflection points are needed to perform trilateration. By using RT technique, TOA from each reflection point can be extracted from channel characteristics. In a 3D geometry, a TOA measured at one point describes a sphere around the reflection points. The radius of the sphere is distance between the point and the reflection point, which is calculated using the speed of light, $c = 3x10^8 ms^{-1}$. If the transmitter's location is known, the distance to the receiver is enough to estimate the circumference along which the receiver must be located. Measuring the distance to multiple transmitters allows the receiver to estimate multiple circumferences and determine its position by finding the intersection point between them. Fig.3 illustrates trilateration performed by three transmitters in 2-dimensional, for simplification.

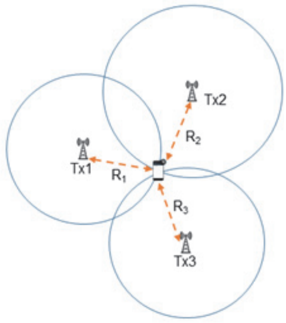

Fig.3. Receiver's position estimation in the TOA-based positioning.

Methodology

This paper uses the VT concept to realize a single transmitter indoor positioning. We built a 3D indoor environment and studied the nature of multipath propagation that occurs with respect to the environment's geometrical information. The RT technique was used to generate the CIR that characterizes the wireless channel between the physical transmitter (PT) and receiver. Then, we ran a post-process data extraction from the generated CIR using MATLAB. In this stage, the potential VTs are determined based on reflection points recorded in RT simulation. Also, the multipath channel's power delay profile (PDP) was extracted as the basis for the best three VTs selection. Finally, the collaboration of the PT and the selected VTs will estimate the receiver's position. In this paper, we performed two basic estimation methods which are linear least square (LLS) and non-linear least square (NLLS).

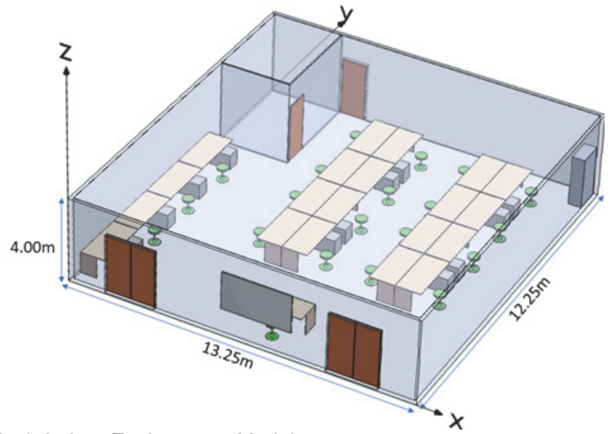

Fig.4. Indoor Environment Model.

1) Indoor Environment Model

A major concern about RT utilization is the need for a detailed and precise description of the environment [20,21]. Therefore, SketchUp was used to meticulously construct a laboratory room model with a dimension of 13.25m x 12.35m x 4m, as shown in Fig.4. The environment model was surrounded by four brick walls, three wooden doors, a ceiling board, and a concrete floor. There was an arrangement of furniture which are tables, chairs, pedestal cabinets, a stand cabinet and a whiteboard located in the room. There was a small room in the laboratory bounded by 2 plasterboard walls. The material's parameters that built up the room are based on the recommendation found in [22], and it is summarized in Table 1.

Table 1. The parameters of the materials that build up the environment.

Object	Material	Real Permittivity	Loss tangent
Ceiling	Ceiling board	1.500	0.0070914
Floor	Concrete	5.310	0.0907254
Partition	Plaster board	2.940	0.0525000
Walls	Brick	3.750	0.0651000
Tables	Chipboard	1.035	0.3345661
Door	Wood	1.198	0.0145666

2) RT Simulation

The RT simulation was run to calculate CIR using CloudRT platform developed by Beijing Jiao Tong University [21]. The platform was developed for academic purposes and can be accessed via http://www.raytracer.cloud/. The simulator can simulate ray propagation for the frequency range of 450MHz – 325GHz. For that purpose, a 3D coordinate system was established with the bottom left corner of the room as the origin (0,0,0), as shown in Fig. 5. The transmitter was hung to the ceiling at the coordinate of Tx (6.16, 6.63, 4), while the receiver's arbitrary position was denoted as Rx (x_i, y_i, z_i). The CIR were recorded at multiple grid points separated by 0.25m in x-plane and y-plane. In the z-plane, the receiver was fixed at 1m height.

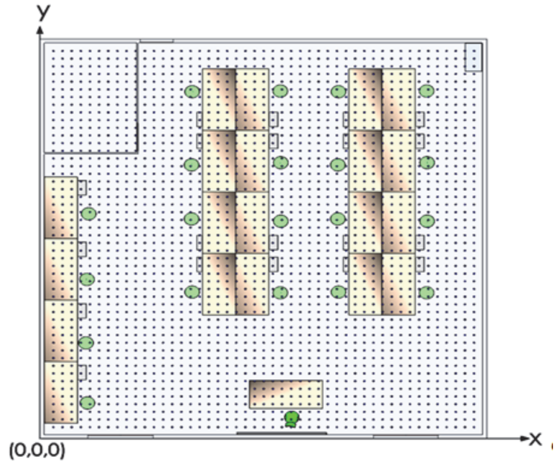

Fig.5. Measurement grid points with 0.25m separation on x- and y-plane, and z = 1m.

Table 2. The parameters of simulation setup.

Parameter	Value
Frequency	2.8GHz
Bandwidth	200MHz
LOS	Yes
Reflection order	2
Propagation mechanism	Reflection

The signal transmitted from the transmitter are illustrated as rays that are emitted at certain degrees apart from one to another. Each emitted ray travels in a straight line and may impinge the object surfaces at a particular incident angle. We treated the point where the rays reflected as a seconder transmitter or VT. Table 2 summarizes the simulation parameters used. This work only considers the reflection mechanism while ignoring the transmission (penetration) and diffraction mechanisms. The simulation only accounts for the first and second reflections.

Fig.6 shows an example of the wave propagation of the transmitted signal when the receiver is located on the front desk. The red line represents the LOS ray, while blue dashed lines depict multipath rays. Each of the multipath lines is reflected at its respective reflection point.

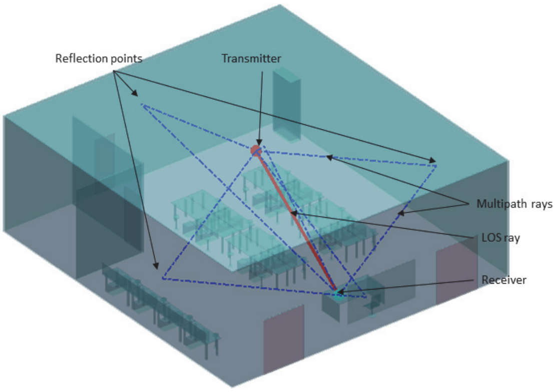

Fig.6. RT simulation for one receiver's location.

As explained in [9,23,24], the reflection points can be considered as VTs. In the example scenario of Fig.6, there are five reflection points which correspond to 5 VTs. Since only three VTs were needed for the position estimation process, we compared the PDP of the rays. Three VTs with the highest received power rays were selected as the working VTs. The information of the selected VTs was stored in a tuple of VTs' coordinates and its corresponding TOA.

3) Position Estimation

In this paper, we use simple position estimation based on TOA measurements. The TOA calculated at a specific receiver's location corresponds to the distance between the transmitters and the receiver. Conceptually, the receiver's position is the intersection between four spheres, centered at the transmitter's coordinate with a radius corresponding to TOA. However, the direct calculation of spheres' intersection involves a high degree of non-linear solution [25], leading to complex computational complexity. Therefore, we use two linearization techniques to estimate the receiver's position. The first technique is the linear least square (LLS), as described by equation (2) through (5).

(2) $$A\vec{x} = \vec{b}$$

(3) $$A = \begin{pmatrix} x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \\ \vdots & \vdots & \vdots \\ x_n - x_1 & y_n - y_1 & z_3 - z_1 \end{pmatrix}$$

(4) $$\vec{x} = \begin{pmatrix} x - x_1 \\ y - y_1 \\ z - z_1 \end{pmatrix}$$

(5) $$\vec{b} = \begin{pmatrix} b_{21} \\ b_{31} \\ b_{41} \\ \vdots \\ b_{n1} \end{pmatrix}$$

The second estimation technique is non-linear least square (NLLS) which is based on the Newton iteration as described by equation (6).

(6) $$\vec{R}_{\{k+1\}} = \vec{R}_{\{k\}} - \left(\mathcal{J}_{\{k\}}^{T}\mathcal{J}_{\{k\}}\right)^{-1}\mathcal{J}_{\{k\}}^{T}\vec{f}_{\{k\}}$$

$\vec{R}_{\{k+1\}}$ is the approximate solution at iteration k+1 and $\vec{R}_{\{k\}}$ is the kth approximate solution. The terms related to Jacobian matrix, $\mathcal{J}$ are given by equation (7) and (8).

(7) $$\mathcal{J}^T\mathcal{J} = \begin{pmatrix} \sum_{i=1}^{n}\frac{(x-x_i)^2}{(f_i+r_i)^2} & \sum_{i=1}^{n}\frac{(x-x_i)(y-y_i)}{(f_i+r_i)^2} & \sum_{i=1}^{n}\frac{(x-x_i)(z-z_i)}{(f_i+r_i)^2} \\ \sum_{i=1}^{n}\frac{(x-x_i)(y-y_i)}{(f_i+r_i)^2} & \sum_{i=1}^{n}\frac{(y-y_i)^2}{(f_i+r_i)^2} & \sum_{i=1}^{n}\frac{(y-y_i)(z-z_i)}{(f_i+r_i)^2} \\ \sum_{i=1}^{n}\frac{(x-x_i)(z-z_i)}{(f_i+r_i)^2} & \sum_{i=1}^{n}\frac{(y-y_i)(z-z_i)}{(f_i+r_i)^2} & \sum_{i=1}^{n}\frac{(z-z_i)^2}{(f_i+r_i)^2} \end{pmatrix}$$

(8) $$\mathcal{J}^T\vec{f} = \begin{pmatrix} \sum_{i=1}^{n}\frac{(x-x_i)f_i}{(f_i+r_i)^2} \\ \sum_{i=1}^{n}\frac{(y-y_i)f_i}{(f_i+r_i)^2} \\ \sum_{i=1}^{n}\frac{(z-z_i)f_i}{(f_i+r_i)^2} \end{pmatrix}$$

The final approximation is given by equation (9).

(9) $$\vec{R} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

Result and Performance Analysis

In this section the simulation results are presented to show the realization of single transmitter site-specific positioning in indoor area. We investigate the root cause of insufficient positioning accuracy by calculating the error contributed by x-, y-, and z-plane. The overall root-mean square error (RMSE) for estimation using LLS and NLLS are also presented.

Table 3. Symbolic location of the five test points.

Measurement Points	Location	Plane		
		x	y	z
Point 1	Front	0.25	9.00	1.00
Point 2	Centre	6.00	6.00	1.00
Point 3	Back	8.50	6.00	1.00
Point 4	Left	6.25	0.25	1.00
Point 5	Right	6.25	13.0	1.00

Table 4. VTs' parameters extracted from the RT simulation.

Receiver's Location	Parameters	VT1	VT2	VT3
Point 1	Coordinate (x, y, z)	0.05, 8.93, 1.09	0.44, 9.08, 1.09	3.66, 0.05, 2.73
	TOA (ns)	0.17069	9.1267	0.56465
Point 2	Coordinate (x, y, z)	0.50, 6.31, 2.48	12.27, 6.31, 2.52	6.07, 0.05, 2.42
	TOA (ns)	0.17069	8.1090	0.43087
Point 3	Coordinate (x, y, z)	12.26, 6.24, 2.14	7.38, 0.05, 2.42	7.27, 13.20, 2.56
	TOA (ns)	0.44177	8.5904	0.47836
Point 4	Coordinate (x, y, z)	12.26, 3.41, 2.48	0.05, 3.46, 2.50	6.19, 13.20, 2.98
	TOA (ns)	0.44177	9.9993	0.66110
Point 5	Coordinate (x, y, z)	6.24, 13.20, 1.09	12.26, 9.83, 2.48	6.19, 0.05, 2.98
	TOA (ns)	17.069	9.9976	0.66077

1) Estimation of Virtual Transmitter's Position

We take five measurement points at different part of the room as example to explain the results, as summarized in Table 3. The best three VTs' coordinates and their corresponding TOA are extracted from the CIR using MATLAB. From the simulation, it is found that, about 4 to 8 reflection points were generated by the multipath rays at each point of receiver.

Table 4 summarizes the coordinate and TOA of the best three VTs selected based on the received power. From the results in Table 4, we can see that the VT's locations are scattered arbitrarily within the room in all three directions of x, y, and z.

2) Position Estimation using Linear Least Square

Applying equation (3) and (5) to the TOA extracted in previous part, matrix A and b for point 1 are:

$$A = \begin{bmatrix} -6.1090 & 2.2952 & -2.9054 \\ -5.7233 & 2.4499 & -2.9052 \\ -2.5040 & -6.5790 & -1.2711 \end{bmatrix}$$

$$b = \begin{bmatrix} 23.0835 \\ 23.2077 \\ -92.1655 \end{bmatrix}$$

Table 5 summarizes the estimated coordinate in x-, y- and z-plane obtained by using LLS. The results show a relatively high RMSE for all five points. It is observed from the error calculated for each plane (x, y, and z), the high value of RMSE is contributed mainly by the z-plane estimation. For the five selected points, the z-plane error may reach up to 64 m.

Table 5. Estimated Position by using LLS.

Plane	Receiver Location	Estimated Position	Error	RMSE
x	0.25	1.11	0.8600	19.6330
y	9.00	20.0	11	
z	1.00	17.2	16.2300	
x	6.00	5.72	0.2825	39.6030
y	6.00	6.29	0.2905	
z	1.00	40.6	39.6009	
x	8.50	17.2	8.7287	54.3230
y	6.00	4.88	1.1156	
z	1.00	54.6	53.6056	
x	6.25	6.41	0.1652	64.5209
y	0.25	-6.53	6.7804	
z	1.00	65.2	64.1634	
x	6.25	-3.22	9.4732	37.6409
y	13.0	24.3	11.2557	
z	1.00	35.7	34.6469	

Fig.7 shows the CDF of position accuracy in x-, y-, and z-plane for LLS estimation. It is observed that 90% of the testing points estimated with 11.6m and 17.95m in x- and y-direction, respectively. It is even severe in the z-plane where 90% of the testing points estimated with 63.83m of error. This range of error is too large and not acceptable in indoor positioning.

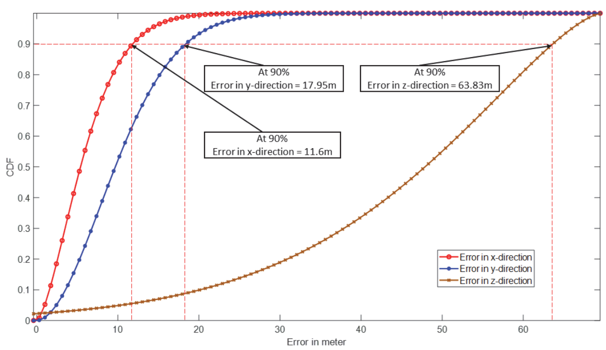

Fig.7. CDF of estimated position errors in x-, y- and z-direction using LLS.

3) Position Estimation using Non-Linear Least Square

Table 6 summarizes the estimated position in x-, y- and z-plane obtained by using NLLS. In comparison with the results shown in Table 5, it is found that NLLS estimates the position with much lower error. The overall RMSE obtained is less than 2m for all five points. However, it is observed that the main contribution of the error comes from the z-plane estimation.

Table 6. Estimated Position by using NLLS.

Plane	Receiver Location	Estimated Position	Error	RMSE
x	0.25	1.21	0.9600	1.8185
y	9.00	9.98	0.98	
z	1.00	2.18	1.1800	
x	6	7.0003	1.0003	1.8309
y	6	6.9890	0.9890	
z	1	2.1719	1.1719	
x	8.5	9.5183	1.0183	1.8492
y	6	7.0141	1.0141	
z	1	2.1636	1.1636	
x	6.25	7.2646	1.0146	1.8812
y	0.25	1.2540	1.0040	
z	1	2.2254	1.2254	
x	6.25	7.1899	0.9399	1.7653
y	13	13.9930	0.9930	
z	1	2.1166	1.1166	

Fig.8 shows the CDF of position accuracy in x-, y-, and z-plane for NLLS estimation. It is observed that 90% of the testing points estimated with 1.98m and 3.16m in x- and y-plane, respectively. This range of error is much lower compared to the result shown in Fig.7. However, in the z-plane, 90% of the testing points estimated with 9.98m of error. Even though it shows an improvement when compared to LLS estimation, this range of error is still not acceptable in indoor positioning.

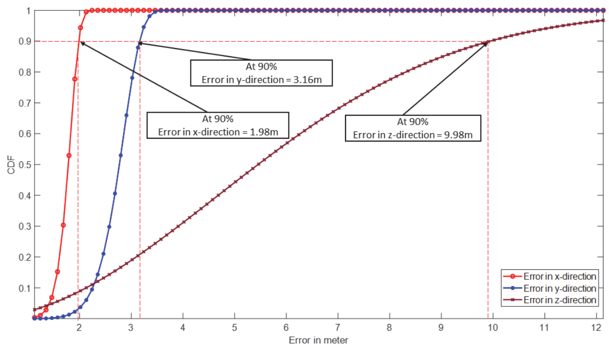

Fig.8. CDF of estimated position errors in x-, y- and z-direction using NLLS.

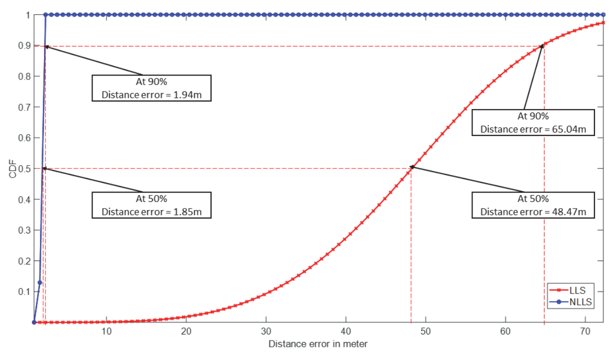

Fig.9. CDF of RMSE of estimated position errors using LLS and NLLS.

Fig. 9 shows the CDF of RMSE of estimated position errors using LLS and NLLS. It is observed that NLLS gives an estimation error of 1.85m and 1.94m for 50% and 90% of the time, respectively. While NLLS gives an estimation error of 48.47m and 65.04m for 50% and 90% of the time, respectively. It is obvious that using NLLS estimation method gives higher positioning accuracy. However, the performance is still insufficient relative to area and complexity of indoor environments.

Conclusion

In this paper, we use the virtual transmitter concept to realize a single transmitter positioning system in a multipath indoor environment. The nature of multipath wave propagation is utilized to determine the VT's positions with respect to the environment geometry by using RT technique. In addition, the TOA of every received ray corresponding to the VT are also extracted from the channel properties. With the coordinates of at least three VTs are known and its corresponding TOA, the receiver's position is estimated using LLS and NLLS estimation methods. Simulation results show that this NLLS gives a much better accuracy compared to LLS. The finding can be used as the basis for further enhancement in single transmitter indoor positioning in future works.

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