Wireless Technology Agnostic Real-time Localization in Urban Areas

Mohamed Amine Abid
Department of Electrical and Computer Engineering
Université de Sherbrooke
Sherbrooke, Canada
Mohamed.Amine.Abid@usherbrooke.ca

Soumaya Cherkaoui
Department of Electrical and Computer Engineering
Université de Sherbrooke
Sherbrooke, Canada
Soumaya.Cherkaoui@usherbrooke.ca

Abstract— **Location estimation is a fundamental middleware for enabling location based services. Different Radio propagation models, customarily used in wireless networks planning, can be useful for localizing mobile nodes by estimating the transmitter-receiver distance from the Received Signal Strength (RSS). However, most of these localization methods need a prior knowledge of the Effective Isotropic Radiated Power (EIRP) to determine a target location and may suffer from imprecisions that can undermine the purpose of localization. In this paper, we propose a new technique called TR2S2 (Trilateration based on Ratio of Received Signal Strength). Though also based on RSS, the method improves location estimation accuracy compared to classical trilateration algorithms and does not need a knowledge of the EIRP. TR2S2 was applied using different deterministic and statistical radio propagation models in different settings. The results show that location estimation is every time more accurate than other compared methods.**

Keywords-component; Position estimation; Wireless networks; Received Signal Strength

I. INTRODUCTION

Precise location estimation is a fundamental building block for location aware applications. Real-Time Localization (RTL) and Real-Time Localization Systems (RTLS) are used to track and estimate the current location of objects and peoples [1]. One RTLS may perform well in a specific environment and respond to particular purposes while others may fail and vice-versa. For example, Global Positioning System (GPS) and Video based RTLS are not the most appropriate means for tracking and locating mobile targets in real time in highly dense urban areas, mainly due to costs or technical limitations [2-3]. Wireless Network (WN)-based RTLS are attracting considerable research interest in this sense. This is because they can take advantage of the existing infrastructure which is expected to grow even further with the pervasive wireless applications. Indeed, wireless devices such as feature-rich Personal Digital Assistants and Smartphone have become a fundamental tool in modern live, with a high penetration rate up to 100% in many societies [4]. Simultaneously, increasing efforts invested in ongoing research activities of radio wave propagation models and channel characterization act as leverage effect to improve WN based RTLS accuracy.

In this paper, a new technique called Trilateration based on Received Signal Strength Ratio (TR2S2) is illustrated. This method makes use of suitable radio propagation models to perform RTL. Multiple ongoing studies on radio propagation models and channel characterization for wireless systems now provide more accurate information about radio wave power law decay, which can increase the positioning performance significantly. With TR2S2, a target node has to be in the radio range of at least three non-collinear reference wireless nodes (RN) at known coordinates using omni-directional antennas. This assumption can be easily met in practical applications with the large and pervasive availability of wireless communications in highly dense urban area. TR2S2 is wireless technology-agnostic as it does not depend on the availability of a particular wireless technology.

The well-known trilateration [5] scheme combines RSS measuring and propagation models to firstly compute the transmitter-receiver (T-R) distance followed by geometric calculations to determine a node location. Most researches take this technique as basis and work on improving positioning accuracy either by using statistical heuristics or by working on propagation models. However, the proposed TR2S2 technique focuses on the improvement of trilateration technique itself as will be illustrated throughout the paper.

The contributions of this paper are as follows: (1) we present TR2S2, a new technique that uses RSS measurements that can be made by low-cost receivers. TR2S2 RTL does not require nodes synchronization or directional antennas and so can easily be deployed. (2) TR2S2 is loosely affected by variations in the environment as RSS measures are not used to determine T-R distance directly as will be illustrated later. Instead, TR2S2 uses RSS in a way that allows attenuating distance calculation errors made with particular propagation models should the environment change over time. (3) While other RSS-based methods, such as trilateration and relative localization [6] assume a known transmitter EIRP, TR2S2 allows estimating target nodes position even when the transmitted EIRP is unknown. (4) TR2S2 allows easily detecting and discarding measurements made by reference nodes hidden by obstacles and keep only measurements made by relevant nodes in the positioning process. (5) TR2S2 is independent of the used wireless technology (6) TR2S2 is independent of any particular propagation model, i.e., it is applicable with any radio wave propagation model allowing T-R distance recovery though RSS. Of course, TR2S2 localization accuracy is even bigger than the propagation model is detailed. (7) We show through simulations that TR2S2 location estimation is consistently more accurate than other compared models. The evaluation of TR2S2 was performed in terms of two important characteristics, including the average error and the failure rate of the location estimation. The aim of TR2S2 technique is to reduce localization error and eliminate failures cases.

The rest of the paper is structured as follow: related work in localization techniques in wireless networks is presented in section II together with a brief introduction of some main radio wave propagation models. In section III, we introduce TR2S2 and illustrate its usage with four different propagation models. In section IV, we describe the position estimation calculation technique in TR2S2. The simulations results for the evaluation of the TR2S2 method compared to others are given in section V. Section VI concludes the paper.

II. RELATED WORK

In literature, location estimation schemas making use of wireless network technologies can be classified into two categories, range-free and range-based [7]. Range-free schemes have been pursued as cost effective approaches that are easy to implement but they only provide coarse accuracy. Range-based schemes, regarded as more accurate, require collecting range information such as the Received Signal Strength Indicator (RSS), Angle of Arrival (AoA), Time of Arrival (ToA) or Time Difference of Arrival (TDoA). The latter two techniques require strict time synchronization between nodes in the network, making the schemes costly and quite difficult to implement. The AoA techniques use an array of antennas to measure the angle from which the signal arrives to the receiver. Such hardware is expensive, bulky and has high power consumption. RSS-based techniques involve measuring the energy received by receiver antenna to discern the attenuation amount caused by signal propagation, which is dependent on the T-R distance. RSS-based techniques require the simplest hardware which is usually already available in all standard wireless equipment. There are also systems based on RSS such as fingerprint localization [8]. This technique consists in creating a radio map based on RSS measurements as fingerprints at a large number of positions in an area during a training phase. This map is later used during the localization phase to find the closest points to the target node by matching its RSS measurements with data in the map.

RSS-range based location estimation methods involve the observation of multiple RSS of transmitted packets between the target node and at least three reference nodes with known positions. This process is usually referred to as multi-lateration. When the number of used observations is three, the process is referred to as trilateration or is also called triangulation because triangle geometric properties are used to estimate the target position. The approach involves finding intersections of circles with centers that correspond to reference node coordinates and with radiuses that correspond to the estimated T-R distances. Many methods with different complexities and restrictions have been proposed to determine the intersection points, such as analytical, least squares, Taylor series and approximate Maximum Likelihood methods [9]. Classical trilateration forms various patterns of circles that can be differentiated by the number possible solutions for the system of equations of circles involved. For example, if there are 3 to 6 intersection points, the estimated position is determined as the center of the smallest triangle formed by the three nearest intersection points as summits. If there are only two intersection points, the estimated position is obtained by computing the midpoint of the two point's line. Otherwise, when there is no intersection, the centers of the circles are taken as the summits of the triangle and the Centroid [10] of this triangle becomes the final location.

Many propagation models have been used with RSS-range based localization in order to estimate T-R distance from signals path loss in several propagation environments. These models are commonly classified into three categories; deterministic, empirical and semi-empirical models [11]. Deterministic models are based on fundamental physics laws of electromagnetic wave propagation to determine the received signal power at a particular location. Serving as reference models, their computation time is however relatively high and they require a complete map of the propagation environment. A well-known example of a deterministic model is ray-tracing [12]. Semi-empirical models combine an analytical formulation of physical phenomena (reflection, diffraction, scattering) with a statistical adjustment by using experimental measurements. They are fast, precise and robust but they require taking into account the environment conditions (topography, building outlines, street axis, land occupation, etc.). Empirical models are based on the analysis of many experimental measurements. These models predict the mean path loss as a function of various parameters such as frequency, T-R distance, antenna height, etc. They are robust, and fast. Several empirical propagation models have been proposed, for example Okumura, Hata and COST-231 [13] as large-scale propagation models, and Rayleigh and Rice distributions [14] as small-scale models.

In this work, we attached special importance to empirical models, because they are better suited to our goal of localization in an outdoor and dynamic environment. If distance between a mobile node and a set of RNs can be approximated from the propagation model, then it is possible to estimate the transmitter position with the TR2S2. In the next sections, the usage of TR2S2 method with various empirical models will be demonstrated. Besides, we will compare TR2S2 localization accuracy with classical trilateration algorithms.

III. THE TR2S2 THECHNIQUE

TR2S2 is a new generic technique that can be applied with any propagation model allowing to retrieving T-R distance from RSS values. We outline in this section the assumptions inherent in TR2S2 technique and present how to apply it using more than one propagation model (free space, Hata, Lognormal, etc). We also describe our scheme for estimating probabilistic minimal and maximal bounds of subsets of space that may contain the target node.

In our proposed scheme, we suppose at least three base stations (BS) at known positions as RNs in the read range of mobile node. Reference and target nodes are equipped with wireless adapters, which extract RSS each time a packet is received. In homogeneous networks, reference nodes send packets periodically with the same transmission power (EIRP). When environments change, even when the T-R distance is unchanged, the RSS still may change significantly. TR2S2 method is based on the ratios of RSS values as will be shown in the next sections. The ratio of RSS from a pair of RNs varies little with environment change as the RSS from either base stations increases or decreases simultaneously. As a result, unlike with proximity methods such as Fingerprint where it is necessary to reconstruct radio maps every time the environment changes, the TR2S2 technique determines a node location with comparable accuracy when the environment changes.

A. Free space propagation model and TR2S2

This deterministic model [15] is used to predict the received signal strength when the transmitter and receiver are in Line Of Sight (LOS) i.e., with an unobstructed communication path. The received power (P_r) is given by Friis equation as follow:

$$P_r = \frac{P_t\, G_t\, G_r\, \lambda^2}{(4\pi)^2\, d^n\, L} \quad (1)$$

Where P_t is the transmitted power, G_t and G_r are the gains of the transmitter and receiver antennas and λ is the wavelength. L is the system loss, not related to propagation. Often, G_t, G_r and L are set to 1 (matched antennas and lossless system). Path loss exponent n is the key parameter in RSS-based localization algorithms that define the rate at which RSS decreases with distance in a specific environment. Friis equation shows that the received power decreases inversely proportionally with the T-R distance. So we can presume that the ratio of distances separating one target node to two reference nodes is inversely proportionally to the ratio of RSS and function of path loss exponent n.

Let $P_{r_i} = \frac{P_t\, G_t\, G_r\, \lambda^2}{(4\pi)^2\, d_i^{\,n}\, L}$ and $P_{r_j} = \frac{P_t\, G_t\, G_r\, \lambda^2}{(4\pi)^2\, d_j^{\,n}\, L}$ be the received power values from the two identical transmitters BS_i and BS_j at distances d_i and d_j respectively from the target node. Now, admitting that path loss exponent n varies between two values $[n^-, n^+]$ depending on the environment dynamicity, the ratio of T-R distances d_i and d_j could have a minimum (2) and maximum (3) value respectively to minimum and maximum path loss exponent, where;

$$\left(\frac{d_i}{d_j}\right)^- = \sqrt[n^-]{\frac{Pr_j}{Pr_i}} \quad (2)$$

$$\left(\frac{d_i}{d_j}\right)^+ = \sqrt[n^+]{\frac{Pr_j}{Pr_i}} \quad (3)$$

B. Hata model and TR2S2

This large-scale model is a path loss formulation in urban environments based on experimental results. The mean path loss as a function of T-R distance, antenna heights and frequency is defined as follows:

$$L_{50}(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_t) - a(h_r) + (44.9 - 6.55\log(h_t))\log(d) \quad (4)$$

Where, L_{50} is the median path loss (in dB), f_c is the frequency in MHz, h_r and h_t are the effective heights above ground level of mobile node and base stations antennas. The parameter $a(h_r)$ is the correction factor for the effective antenna height of the mobile node based on the detection area size. For small to medium sized cities, the mobile antenna correction factor is given by:

$$a(h_r) = (1.1\log(f_c) - 0.7)h_r - (1.56\ \log(f_c) - 0.8) \quad (5)$$

This model is suitable for large ranges and its validity has been proved for frequencies between 150MHz and 1500MHz [16]. We admit that two BSs transmit signals with the same power P_t that will be received by the mobile node. P_{r1} and P_{r2} are the RSS from BS_1 and BS_2 respectively measured by the mobile node to localize, then;

$$PL(dB) = 10\log\left(\frac{P_t}{P_r}\right) \quad (6)$$

$$PL_1 + 10\log(P_{r1}) = PL_2 + 10\log(P_{r2}) \quad (7)$$

By replacing the PL with the median attenuation according to Hata model (4), the previous equality (7) is simplified as follow:

$$(44.9 - 6.55\log(h_t))\log(d_1) + 10\log(P_{r1}) = (44.9 - 6.55\log(h_t))\log(d_2) + 10\log(P_{r2}) \quad (8)$$

The relation between the ratio of distances separating the mobile node to each BS is defined as follows:

$$\frac{d_1}{d_2} = \left(\frac{P_{r2}}{P_{r1}}\right)^{\left(\frac{10}{44.9 - 6.55\log(h_t)}\right)} \quad (9)$$

As the heights of BS antennas may not be exactly known, we suppose that h_t lies in interval $[h_t^-, h_t^+]$, knowing the upper and lower bound that the transmitter antenna height may have. So the ratio of T-R distances d_i and d_j could have a minimum (10) and maximum (11) value respectively to minimum and maximum highs of BS antennas.

$$\left(\frac{d_1}{d_2}\right)^- = \left(\frac{P_{r2}}{P_{r1}}\right)^{\left(\frac{10}{44.9 - 6.55\log(h_t^-)}\right)} \quad (10)$$

$$\left(\frac{d_1}{d_2}\right)^+ = \left(\frac{P_{r2}}{P_{r1}}\right)^{\left(\frac{10}{44.9 - 6.55\log(h_t^+)}\right)} \quad (11)$$

C. Probabilistic models and TR2S2

Probabilistic models offer computational simplicity and permit a more realistic modeling of radio wave propagation [13]. A probabilistic model uses a deterministic model as basis and introduces parameters in order to get the mean transmission range. Since the transmission between a base station and a mobile is rarely in line-of-sight in urban area, the received signal is subject to attenuation and non-deterministic distortion when traveling in the air. The distribution of these effects depends on deterministic models strengthened by probabilistic parameters.

1) Log-normal Shadowing model and TR2S2

Both determinist and empirical propagation models indicate that RSS decreases in logarithmic manner with T-R distance. According to Lognormal shadowing model [17], the path loss in term of distance follows the power law:

$$PL(d)\,[dB] = \overline{PL}\,(d_0)[dB] + 10n\,log\left(\frac{d}{d_0}\right) + X_\sigma[dB] \quad (12)$$

Where $\overline{PL}\,(d_0)$ represents the attenuation average at a reference distance d_0, n is the path loss exponent and X_σ is a Gaussian random variable of received power (in dB) with zero mean and standard deviation σ. With a confidence level C, the normality range of $X_\sigma \in [-z\sigma\text{ dB}, +z\sigma\text{ dB}]$ and the path loss at distance d is defined as:

$$PL(d)\,[dB] = \overline{PL}\,(d_0)[dB] + 10n\,log\left(\frac{d}{d_0}\right) \pm z\sigma\,[dB]$$

$$\text{With } z = Q_x^{-1}\left(\frac{c+1}{2}\right) \quad (13)$$

Since we cannot consider that the variation is equal for both sides of a mobile node, we consider two extreme situations.
In the first situation, the target node is closest to the BS_1 while being far away from BS_2, then:

$$\left(\frac{d_1}{d_2}\right)^+ = 10^{\left(\frac{P_{r2}+\overline{PL}(d_{02})-P_{r1}-\overline{PL}(d_{01})+2z\sigma}{10\,n}\right)} \quad (14)$$

Conversely, when the target node is farthest from the receiver BS_1 while being the closest possible to BS_2;

$$\left(\frac{d_1}{d_2}\right)^- = 10^{\left(\frac{P_{r2}+\overline{PL}(d_{02})-P_{r1}-\overline{PL}(d_{01})-2z\sigma}{10\,n}\right)} \quad (15)$$

2) Rayleigh distribution:

The Rayleigh distribution [11] models the situation when there is no LOS, and only multipath components exist. This model incorporates intensive variations in received signal power because multiple paths can either combine constructively or destructively. The Rayleigh distribution has a probability density function (PDF) given by:

$$P(r) = \begin{cases} \frac{r}{\sigma^2} exp\left[-\frac{r^2}{2\,\sigma^2}\right], & 0 \le r \le \infty \\ 0, & r < 0 \end{cases} \quad (16)$$

The probability that the envelope of the received signal does not exceed a specified value R, is given by the corresponding cumulative distribution function (CDF):

$$P(R) = \Pr(r \le R) = \int_0^R p(r)dr = 1 - \exp\left(-\frac{R^2}{2\,\sigma^2}\right) \quad (17)$$

Where r is the envelop amplitude of the received signal and $2\sigma^2$ is the predicted mean power of the received multipath signal. Similar to Lognormal shadowing model, Rayleigh model depends on a deterministic model to which a certain variation is applied:

$$P_{r_{Rayleigh}}(d) = Rayleigh(P_{r_{determinist}}(d)) \quad (18)$$

From the CDF of Rayleigh distribution, we can determine with confidence level C that the received power variation is included in the interval $[z_{min}\sigma, +z_{max}\sigma]$, where;

$$z_{min} = \sqrt{2\ln\left({}^{2}/_{2-\alpha}\right)} \quad (19)$$

$$z_{max} = \sqrt{2\ln\left({}^{2}/_{\alpha}\right)} \quad (20)$$

And $\Pr(z_{min}\sigma \le x \le z_{max}\sigma) = 1 - \alpha = C, 0 \le C \le 1$ (21)

As shown in the Fig.1, for $\Pr(a < x \le b) = C$, the area in each tail of the curve is equal to (1-C)/2. For confidence interval of 95%, the area in each tail is equal to 0.05/2 = 0.025.

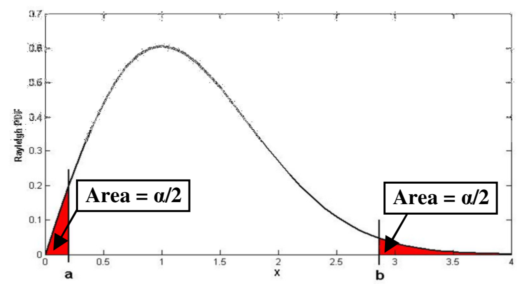

Figure 1. Example of Rayleigh distribution PDF.

IV. LOCALISATION BASED ON TR2S2

In this section, we present how to apply TR2S2 to determine the area that may contain the receiver as an intersection of rings. Each ring marks the probable position of a mobile node in relation to two RNs based on distances ratio. Eventually, we explain how to detect the presence of obstacles and eliminate erroneous receivers from the localization process.

A. Position estimation from ratio of distances

In order to localize the mobile node, we use the ratio of distance extracted from propagation models. Let us assume that $\left(\frac{d_i}{d_j}\right)^2 = K$ with d_i and d_j are the distances of target node with coordinates (x, y) to BS_i with coordinates (x_i, y_i) and BS_j with coordinates (x_j, y_j), where;

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (22)$$

$$d_j = \sqrt{(x - x_j)^2 + (y - y_j)^2} \quad (23)$$

Then the position of target node belongs to the solution of the following equation in second order form:

$$A\,x^2 + B\,y^2 + Cx + Dy + E = 0 \quad (24)$$

Where: $A = (1 - K), B = (1 - K), C = 2(Kx_j - x_i)$
$D = 2(Ky_j - y_i)$ and $E = x_i^2 - Kx_j^2 + y_i^2 - Ky_j^2$

For any polynomial equation of second order, where A = B with A and B nonzero real, as in our case, the solution is a circle. Then, with TR2S2 method, the target node position by reference to two RNs form the set of points whose (x, y) coordinates belong to a circle with center Cx and radius R defined as follow:

$$Cx = \left(-\frac{C}{2A}; -\frac{D}{2A}\right)$$

$$R = \sqrt{\frac{C^2+D^2-4AE}{4A^2}}$$

Where $A = B = (1 - K)$, $C = 2\left(Kx_j - x_i\right)$,

$$D = 2\left(Ky_j - y_i\right) \text{ and } E = x_i^2 - Kx_j^2 + y_i^2 - Ky_j^2 \qquad (25)$$

To accurately estimate the mobile position, it is necessary to calculate the coordinates of the points forming the intersection area of two annuluses. Each annulus is estimated according to one pair of reference nodes. To obtain a solution at every shot we use maximum and minimum equations. By replacing K parameter by its value inferred by the propagation model, e.g. (14) and (15) with lognormal model, we calculate the minimum and maximum limits of area that contains the target node with respect to a pair of reference points BS_i and BS_j. The minimum bound of this zone is the ratio between the closest distance to BS_i and farther distance from BS_j. In turn, the maximum area bound is the ratio between the farthest distances from BS_i and the one closer to BS_j. For example, the mobile node position per reference to BS_i and BS_j may only lies either on the perimeter or inside the circle Cir_{max} with the following coordinates;

$$Cir_{max} = \left(\left(-\frac{C_{max}}{2A_{max}}; -\frac{D_{max}}{2A_{max}}\right), \sqrt{\frac{{C_{max}}^2+{D_{max}}^2-4A_{max}E_{max}}{4{A_{max}}^2}}\right)$$

Where A, B, C, D *and* E computed with K equals to $\left(\left(\frac{d_i}{d_j}\right)^+\right)^2$.

The domain that defines the transmitter location also called area of uncertainty emerges as the intersection of several rings; each defines an area between two circles, as illustrated by the gray area in Fig.2.

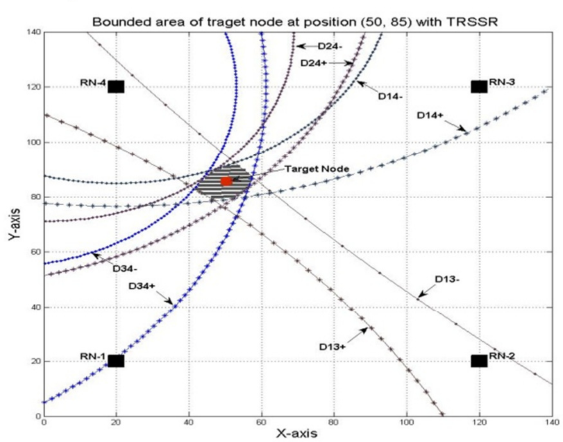

Figure 2. Example of annuluses intersection area

B. *Obstructed reference node detection:*

In TR2S2 method each circle is computed with reference to a pair of fixed nodes. If there is no intersection between two circles that involve the same receiver, thus this latter is obstructed by an obstacle. If one circle is very far from the reference nodes, even further than the coverage area, then one of them is obstructed. To determine which one, we must verify with one-third reference node. The third case, most likely to occur, is when two rings with very small radiuses are close to two reference nodes, then the third is obstructed and then eliminated from the localization process. Generally more than three reference nodes are recommended for more accuracy; thereby more annulus can be obtained, with 3, 4 and 5 reference nodes we obtain respectively 3, 6 and 9 different pairs. As well, if one reference node is obstructed, there remain enough nodes to perform TR2S2 localization.

V. SIMULATIONS RESULTS

In this section we outline the results obtained by simulating TR2S2 algorithm, using Matlab, with the four aforementioned propagation models. We also compare TR2S2 performance with classical the trilateration method used in the same conditions. Results for all propagation models, except for Hata model, are presented for same configuration with four fixed nodes deployed at (20, 20), (120, 20), (120, 120) and (20, 120) in meter when the intersection of their respective coverage ranges delimit the detection area as a 230x230 meter grid. With TR2S2, minimum and maximum bound circles are constructed between each pair of reference nodes, when they are centered on each reference node in the case of the classical trilateration. The target node is located in the overlap region of all annuluses. Then, the chosen estimated position is the center of the bounded area and the location error considered is the longer distance between the center of bounded area and the farther point belonging to the edge of this area.

A. *Performance of TR2S2 with Free space path loss model:*

Free space model is the perfect model to emphasize the improvement of TR2S2. As shown in Fig.3, TR2S2 always performs better than trilateration and it is much less sensitive to the variation of path loss exponent n, whatever the value of EIRP. When n varies only by ±0.05, the location error values returned by TR2S2 and classical trilateration are equals to 0.4m and 3.37m respectively. When n varies by ±1, the location error with TR2S2 and trilateration grow to 9m and 32.8m respectively.

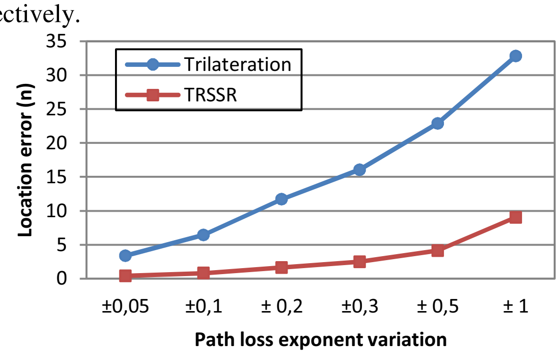

Figure 3. Location error obtained by TR2S2 and Trilateration based on free space model, with different values of path loss exponent variation.

B. Performance of TR2S2 with Hata model:

For the simulation of TR2S2 with Hata model, we assume a frequency of 1500 MHz and four fixed base stations deployed at (2, 2), (12, 2), (12, 12) and (2, 12) in Km forming a detection areas of 23x23 Km grid. As the heights of nodes antennas are unknown, we define different ranges of antennas heights variation in meter for BS (hBS) and Mobile Station (hMS). For example the value ±5m and ±60m in the x-axis of Fig.4 mean that hBS varies in the intervals [95, 105] and [40, 160] (in meter) respectively. Similarly for hMS, the annotation “Tri hMS ±0,1m” in the legend of the same graphic means that hMS varies between 4.9m and 5.1m. The variation of hMS is taken into consideration only with Trilateration method, as this variable not used in TR2S2 calculation (5). For the same values of hBS variation TR2S2 performs slightly better than classical Trilateration when the height of MS antenna is exactly known. For example with hBS variation equals to ±5m the location error is equal to 0.155Km and 0.211Km with TR2S2 and Trilateration respectively. On the other side, when the hMS value is unknown, and an interval of variation is used to estimate the location, TR2S2 perform much better than Trilateration. As shown in the Fig.4, with hBS and hMS variation equal to ±20m and ±0.8m respectively, TR2S2 returns a location error equals to 0.623Km while classical trilateration return a location error equals to 1.953Km.

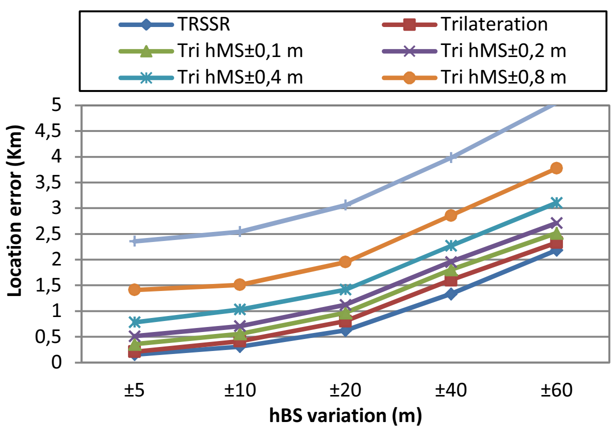

Figure 4. Location error obtained by TR2S2 and Trilateration based on Hata model for different heights of BS and MS antennas variation.

C. Performance of TR2S2 with lognormal model:

The simulations for TR2S2 with Lognormal model assumes a frequency of 2.4 GHz, path loss exponent of equals to 3 and shadowing standard deviation σ equals to 3.43 determined for this frequency in an outdoor environment. A transmitter EIRP of 17 dBm (≃50mW) is assumed for computing simulated RSS values at the target node. For each execution, a random amount of signal shadowing is added to the RSS values along a normal distribution, with zero mean and $[-Z\sigma, +Z\sigma]$ shadowing deviation. From tables of probabilities for normal distribution, we can make these statements for Z equals to 1.56, 1.96 and 2.58 to determine the confidence level of 90%, 95% and 99% respectively.

With TR2S2 method, the transmitted power value is removed from (10) and (11), unlike classical trilateration, where an EIRP range must be considered. In Fig.5, we observe that the error increases as the confidence level increases for both methods and in all simulations. The location error for TR2S2 do not exceed 17m with confidence level of 90% and 27m for C=99% in a detection area size of 230x230m. With classical trilateration, the intersection of annuluses expands as considered EIRP interval is larger. When the EIRP range is set to ±2mW, the maximum location error is equal to 21.62m with C=90% and attains 30m for C=99%.

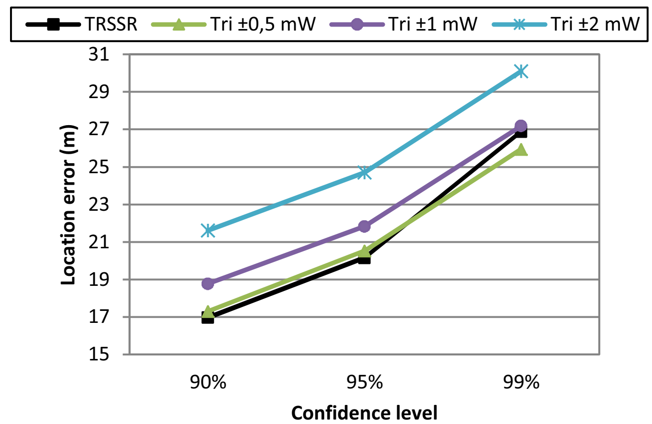

Figure 5. Location error obtained by TR2S2 and Trilateration based on lognormal model with different transmit power variation for different confidence levels

D. Performance of TR2S2 with Rayleigh distribution:

The simulation for TR2S2 with Rayleigh distribution assumes a frequency of 2.4 GHz, as well as the values for detection area size, transmitter EIRP, path loss exponent and shadowing standard deviation used with lognormal model. The main difference is the way to compute Z_{min} and $Z_{\max}$ according to (15) and (16). The values of Z_{min} and $Z_{\max}$ and the location error of TR2S2 method corresponding to confidence levels 90%, 95% and 99% are listed in Table I.

TABLE I. CONFIDENCE LEVEL AND LOCATION ERROR WITH RAYLEIGHT DISTRIBUTION

Confidence	**90%**	**95%**	**99%**
Z_{min}	0.3847	0.2703	0.1203
$Z_{\max}$	2.94	3.2625	3.91
Location error	13m	15.3481m	19.6583m

VI. CONCLUSION

In this paper, we presented TR2S2, a new method based on RSS for RTL of a mobile nodes that is wireless technology agnostic, and can be applied with different radio propagation models. We showed that TS2R2, used in combination with different radio propagation models, achieved consistently smaller localization error than the classical triangulation method. TR2S2 location error decreases to less than 1m in ideal conditions and to values around 15 m with multipath phenomena within a detection area size of 230x230m. These results were obtained without the need of time and memory consuming operations for radio map building or specialized equipment to measure time or angle of arrival of signals. TR2S2 is a good candidate to implement simple, cost effective and energy efficient RTLS in urban areas based on existing deployed wireless infrastructure.

REFERENCES

[1] J. Hightower and G. Borriello, "Location systems for ubiquitous computing," IEEE Computer, vol. 34, no. 8, pp. 57-66, Aug. 2001.

[2] M. Lu, W. Chen, X. Shen, , H. Lam, J. Liu, "Positioning and tracking construction vehicles in highly dense urban areas and building construction sites," Journal of Automation in Construction, 2006.

[3] M. S. Shehata, and all, "Video-based automatic incident detection for smart roads: The outdoor environmental challenges regarding false alarms," IEEE Trans. Intell. Transp. Syst., vol. 9, no. 2, pp. 349-360, Jun. 2008.

[4] News Technology, Over 5 billion mobile phone connections worldwide, http://www.bbc.co.uk/news/10569081, July 2010.

[5] D. Munoz, F. Bouchereau, C. Vargas, and R. Enriquez-Caldera, Position Location Techniques and Applications. Academic Press, 2009.

[6] C. Laurendeau and M. Barbeau, "Rogue Attribution Using Relative Signal Strength Based Location Estimation," Carleton University, Technical Report TR-08-01, January 2008.

[7] G. Sun, J. Chen, W. Guo, and K.J.R. Liu, "Signal processing techniques in network-aided positioning," IEEE Signal Processing Mag., vol. 22, no. 4, pp. 12–23, July 2005.

[8] H. Liu, H. Darabi, P. Benrjee, and J. Liu, "Survey of wireless indoor positioning techniques and systems," IEEE Trans. Syst., Man, Cybern. C, Appl. Rev., vol. 37, no. 6, pp. 1067–1080, Nov. 2007.

[9] G. Shen, R. Zetik, and R. S. Thoma, "Performance comparison of TOA and TDoA based location estimation algorithms in los environment," in Proc. WPNC, 2008, pp. 71–78.

[10] N. Bulusu, J. Heidemann and D. Estrin, "GPS-Less Low-Cost Outdoor Localization for Very Small Devices," IEEE Personal Communications, Vol. 7, No. 5, October 2000, pp. 28-34.

[11] T. K. Sarkar, Z. Ji, K. Kim, A. Medour, and M. Salazar-Palma, "A survey of various propagation models for mobile communication," IEEE Antennas Propag. Mag., vol. 45, no. 3, pp. 51–82, Jun. 2003.

[12] G. E. Athanasiadou, A. R. Nix, and J. P. McGeehan, "A microcellular ray-tracing propagation model and evaluation of its narrow-band and wide-band predictions," IEEE J. Select Areas Commun., vol. 18, pp. 322–335, Mar. 2000.

[13] Abhayawardhana, V.S., Wassell, I.J., Crosby, D., Sellars, M.P., and Brown, M.G., "Comparison of Empirical Propagation Path Loss Models for Fixed Wireless Access Systems", VTC 2005.

[14] H. Suzuki, "A statistical model for urban radio propagation," IEEE Trans. Commun., vol. 25, pp. 673–680, July 1977.

[15] H. T. Friis, "A Note on a Simple Transmission Formula," in Proceedings of the I.R.E., vol. 34, no. 5, May 1946, pp. 254–256.

[16] M. Hata, "Empirical formula for propagation loss in land mobile radio services," IEEE Transactions on Vehicular Technology, vol. vol. VT-29, pp. 317–325, September 1981.

[17] T. S. Rappaport, Wireless Communications: Principles and Practice, 2nd ed. Prentice-Hall, 2002.