This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE Globecom 2010 proceedings.

Received Signal Compensation-Based Position Estimation of Outdoor RFID nodes

Mohamed Amine Abid and Soumaya Cherkaoui

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

***Abstract*— We propose a new algorithm for estimating the location of an outdoor RFID node, based on the received signal strength (RSS) of a transmitted message by a set of readers with known locations. The algorithm supposes omni-directional RFID readers that are prevalent for outdoor long range RFID systems. The method does not require knowledge of the Effective Isotropic Power (EIPR) of the transmitting tag, and bounds the position of the node within a small delimited candidate area. Our simulation results demonstrate that the Received Signal Compensation Based Localization (CBL) method outperforms other compared RSS-based methods in improving the precision of the bounded area.**

***Index Terms*—Localization, RFID, RSS**

I. Introduction

Radio Frequency Identification (RFID) technology is increasingly pervasive. Passive RFID tags are inexpensive and thus are the most prevalent form of RFID technology. Passive RFID poses, however, a number of limitations. The radio range of the reader does not exceed a few meters. Communication can be disturbed by materials such as metal, human body, walls, water, etc…Tags are parasitically powered by the energy from RFID readers, and usually employ linearly polarized antennas. If the angle between a reader and a tag is not within certain values, it may result in false negative readings. Most exiting works on RFID-based localization suppose a directional reader/tag antenna. But recently, omni-directional antennas for passive RFID are gaining much interest [1]. Active or semi-active RFID technology uses battery powered tags and can reach distances up to 200m. Typically, long-range active RFID technology uses omni-directional antennas and is targeted towards longer range indoors applications. For example, Montreal city has recently adopted an active RFID-based solution where RFID-tagged buses and RFID-enabled bus stops provide increased transit visibility [2]. Transit managers have a real-time view on bus dispositions and riders can wait sheltered from frigid weather temperatures while viewing real-time information about their bus expected time-of-arrival.

In this work we focused on network-based location estimation mechanisms for outdoor RFID nodes assuming omni-directional RFID readers. Given an RFID message emitted by a tag, the Received Signal Strength (RSS) collected at readers situated within the radio range of the tag is used to pinpoint the position of the emitter in a bounded zone with a certain confidence. The RSS value at each RFID reader is used to estimate a probable range of distances of the emitting tag from each reader. The new algorithm, called Compensation Based Localization (CBL) is based on distance ratios of a tag from two or more readers. The algorithm does not need assistance from the active tag in estimating its position. Neither does it require knowledge of the Effective Isotropic Power (EIRP) of the transmitting tag that may be affected, for example, with the state of its battery.

The rest of the paper is organized as follows: the next section discusses some related work. Section III presents the proposed approach. In section IV we present the simulation results and their analysis. Section V concludes the paper.

II. Related Works

Generally, radio frequency localization can be implemented by following one of two approaches. In the first one, most employed, the mobile node is the emitter and its location is computed at a central setup. In the second approach, the mobile is the receiver and its location is computed at its own level, like it is the case for GPS-equipped devices. Three methods are commonly used with RFID-based localization; Triangulation/Trilateration [3], Fingerprinting [4] and Landmark [5]. The majority of triangulation techniques use the first approach. Fingerprinting may use one or the other. However, most of RFID-based localization schemes presume a directional antenna model for the reader [6]. Ferret for example uses the location and directionality of RFID readers to infer the locations of nearby tags [7].

If we presume an omni-directional antenna model for RFID nodes, different works have been proposed to locate general wireless nodes based on some collected signal information. Time-of-Arrival based approaches such as in [8] need that all transmitters and receivers be precisely synchronized and have fast processors to eliminate the delay due to processing. This might not be feasible for RFID tags. Some relative RSS localization mechanisms were also described [9], [10] where a node collects the RSS values it receives to calculate its position. This again might not be practical in the case of RFID tags. RSS variations are taken into account in other works to construct a minimum and maximum distance annulus between the receiver and the emitter but the methods require knowledge of the emitter EIRP [11], [12] which might not be feasible if there are variations in the transmitting tag power.

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE Globecom 2010 proceedings.

III. RADIO PROPAGATION MODEL AND LOCALIZATION TECHNIQUE

An obvious RFID-based localization system requires the setting of a tag on the mobile node and two or more RFID readers at fixed locations. RFID tags may be attached to vehicles or carried by people. When a signal is received from a tag, some metrics are acquired and used for the distance estimation. CBL algorithm is based on the collection of RSS by a set of receivers. An RSS indicator eliminates the need for additional hardware in small receivers, and exhibits favorable properties with respect to power consumption, size and cost. Because of its attractiveness, the research community has extensively considered the use of radio signal strength. Since the attenuation of the emitted signal strength is function of the distance between the emitter and the receiver. The target can be localized with at least three receivers if the corresponding signal path losses due to propagation are known. RSS-based localization methods are appropriate for localized outdoor areas with no severe effects influencing propagation such as multipath, fading or shadowing. Several empirical and theoretical models [13], [14], [15] have been proposed in literature to correlate the difference between the transmitted and the received signal strength with distance. One main drawback of most RSS-based techniques is the need for a measurement-based training phase during which the radio map of the environment is created. The process of generating a radio map is not only costly and sensitive to changes from one area to another, but also unrealistic for application with a projected high deployment.

In the proposed Compensation Based Localization method, we rely on using an appropriate propagation model instead of generating a radio map of a zone. A few reference tags are placed in the area where targets localization is to take place. To determine the position of a target, CBL uses the propagation model and signal information collected by the readers from the reference tags and the target tag at a given time. The received signal strength decreases by a value of free space Path Loss (PL) proportionally to the distance to the sender as stated by [16].

$$P_r(d)[dBm] = P_t[dBm] - PL(d)[dB] + G_t[dB] + G_r[dB] \quad (1)$$

Where P_r And P_t are the power of the receiver and the transmitter, and G_r and G_t are the gains of the receiver and transmitter antennas respectively. $PL(d)$ is the path loss which is a function of distance d separating the emitter from the receiver, calculated as in the following equations:

$$PL(d)[dB] = \overline{PL}(d)[dB] + X_\sigma[dB] \quad (2)$$

$$\overline{PL}(d)[dB] = \overline{PL}(d_0)[dB] + 10n\, log\left(\frac{d}{d_0}\right) \quad (3)$$

Where n is the path loss exponent that indicates the rate, at which the path loss increases with distance, d_0 is the close-in reference distance which is determined from measurements close to the transmitter. The value of n depends on the specific propagation environment. In free space, n is equal to 2, and when obstructions are present, n will have a larger value.
The PL of the reference RFID tags is calculated using the free space path loss formula as follow:

$$PL(dB) = 10\log\left(\frac{P_t}{P_r}\right) = -10\log\left(\frac{G_t\, G_r\, \lambda^2}{(4\pi)^2\, d^2}\right) \quad (4)$$

According to Friis's free space transmission equation;

$$P_r = P_t\, G_t\, G_r \left(\frac{\lambda}{4\pi}\right)^2 \left(\frac{1}{d}\right)^n \quad (5)$$

Where λ is the wavelength. In practice, this method requires an accurate and continual determination of the value of n to mitigate the dynamic change in the environment. For this reason, n has to be calculated at each signal emission based on the reference RFID tags placed in specific coordinates in the detection area such as shown in Fig. 1.

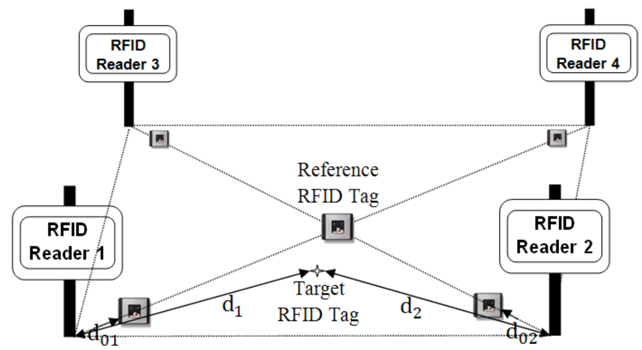

Fig. 1. Reference tags location.

The localization errors observed with this technique in real environments are quite large. They are due primarily to the random nature of the received power. Indeed, (2) shows that the received power is dependent of the random variable X_σ a zero-mean Gaussian distributed random variable (in dB) with standard derivation σ (also in dB). The variable X_σ considers the effects of propagation channel variability due to many factors such as fading, shadowing, reflection etc… Computations of probabilities that involve Gaussian processes require finding the area under the tail of the Gaussian (normal) probability density function as:

$$\varphi(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^2} \quad (6)$$

Where m and x are respectively the mean and the current value of PL (dB).
For a selected confidence level C, X_σ lies in the confidence interval [-zσ dB; +zσ dB], where $z = \Phi^{-1}\left(\frac{1+C}{2}\right)$ and can be obtained from a Normal distribution table. Reference tags are used to continuously calibrate the propagation parameters n and σ specific to the environment and can vary during the process of localization. To further reduce the effect of the error caused by variable X_σ, we consider the ratio $\frac{d_1}{d_2}$ where d_1 and d_2 are the distances between the transmitter target tag and readers R_1 and R_2 respectively. For a signal transmitted by the same source of power P_t two values of signal strength P_{r1} and P_{r2} are recorded by both readers. As we suppose all readers to be identical (same gains):

$$P_{r1} + \overline{PL}(d_{01}) + 10\, n \log\left(\frac{d_1}{d_{01}}\right) \pm z\sigma = P_{r2} + \overline{PL}(d_{02}) + 10\, n \log\left(\frac{d_2}{d_{02}}\right) \pm z\sigma \quad (7)$$

Knowing parameters of (5), we can deduce distance d separating the node from each reader with known coordinates.

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE Globecom 2010 proceedings.

A. Trilateration

The Trilateration method [3] is based on the fact that the location of an object can be determined if the distances to three references are known. It differs from triangulation, which is based on the measurement of the angles of the received signal. With three readers, the target can be approximately located in a given area as shown in Fig. 2. The dotted circles are constructed using the real distances between the target and three fixed readers (R_1, R_2 and R_3) and their intersection gives the actual position of the mobile RFID tag. Generally, the estimated distances (d_1 , d_2 and d_3) are larger than the real distances and their intersection gives rather a region of uncertainty (the shaded region) around the node. A variety of statistical direct or iterative techniques can be used to locate more precisely the target in this region of uncertainty. Note that in cases where at least one of the three estimated distances is less than the actual distance, the area cannot be determined because there would be no intersection. So to increase the accuracy of this technique, generally more than three receivers are used.

B. Compensation Based Localization

To remediate to errors of trilateration, CBL considers the ratio $\frac{d_1}{d_2}$ of distance to two given readers. Since we cannot assume that deviation can be canceled from one side to the other of the tag, we consider the two extreme situations to delimit the area where the target may be located. The first situation considers deviation in the R1 side at its minimum ($-z\sigma$), and at its maximum on the R2 side ($+z\sigma$), then;

$$\left(\frac{d_1}{d_2}\right)^+ = 10^{\left(\frac{P_{r2}+\overline{PL}(d_{02})-P_{r1}-\overline{PL}(d_{01})+2z\sigma}{10\,n}\right)} \quad (8)$$

And the second situation considers the deviation in the R1 side be at its maximum ($+z\sigma$) and at its minimum on R2 side ($-z\sigma$), then;

$$\left(\frac{d_1}{d_2}\right)^- = 10^{\left(\frac{P_{r2}+\overline{PL}(d_{02})-P_{r1}-\overline{PL}(d_{01})-2z\sigma}{10\,n}\right)} \quad (9)$$

Let's $\frac{d_1}{d_2} = K'$, d_i and d_j being the distance to RFID readers R_i et R_j, and L the distance between them (see Fig. 3) and $K = K'^2$. The target position relative to two readers represents a point with Cartesian coordinates x and y belonging to the set of points constituting the solution of the following second degree polynomial equation:

$$Ax^2 + By^2 + Cx + Dy + E = 0 \quad (10)$$

If both readers are at the same line parallel to x axe's, so $x_j = x_i + L$ and $y_i = y_j$, then;

$A = B = (1 - K)$
$C = 2\,K\,L - 2\,x_i(1 - K)$
$D = -2y_i(1 - K)$
$E = x_i^2(1 - K) + y_i^2(1 - K) - 2\,K\,L\,x_i - K\,L^2$

Otherwise, if both readers are in the same line parallel to y axe's, so $x_j = x_i$ and $y_i = y_j + L$, then;

$A = B = (1 - K)$
$C = -\,2x_i(1 - K)$
$D = 2\,K\,L - 2\,y_i(1 - K)$
$E = x_i^2(1 - K) + y_i^2(1 - K) - 2\,KL\,y_i - K\,L^2$

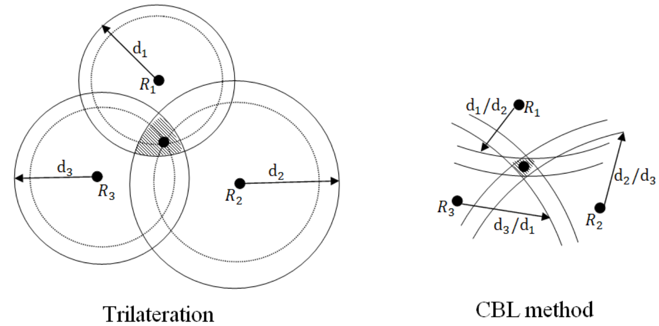

Fig. 2. Illustration of Trilateration and CBL methods.

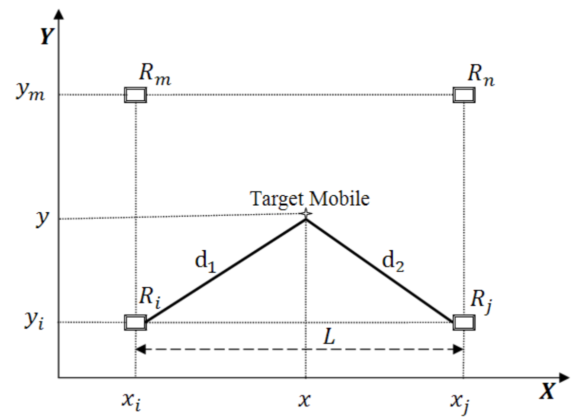

Fig. 3. Illustration of triangulation and CBL methods.

To accurately estimate the target position, it is necessary to determine the intersection area between two hyperbolas. Each hyperbola represents the estimate of distance separation from two readers by compensation. So to determine the position of a target, three readers at least are necessary. For example, with 3 readers, 6 hyperbolas can be plotted to minimize the region of uncertainty around the mobile tag. To ensure a solution in every case, annuli obtained by (8) and (9) are used by CBL. Each annulus delimits an area that can contain the target with a distance ratio calculated with respect to a pair of receivers R_i and R_j. The minimum bound of this area is the ratio between the nearest possible distances from the target to R_i still further from R_j. The maximum area bound is the ratio between the farthest possible distances from the target to R_i even closer to R_j. The target node is located in the area between the minimum and maximum distance range ratio to R_i and R_j called Δ_{ij}, as shown in Fig. 4.

In order to track the mobility of the target tag, CBL determines the successive bounded areas at successive times and proceeds iteratively. A regression line correlating best the points bounded by the areas calculated at each iteration, helps determine the trajectory of the target, as illustrated in Fig. 4. Along the iteration process, the number of calculated points increases and the trajectory becomes clearer. The position returned by CBL, at each iteration, will be situated on the regression straight line or nearest point. For the first iteration, the position of the closest reader (with the strongest RSS) is considered as a point of population.

978-1-4244-5638-3/10/$26.00 ©2010 IEEE

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE Globecom 2010 proceedings.

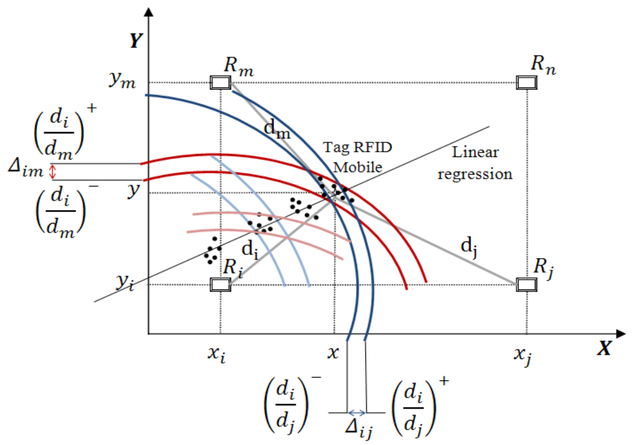

Fig. 4. Target Tracking Approach.

The line of least squares also called regression y function of x represents the trajectory:

$$y = a\,x + b \qquad (11)$$

Where:

$$a = \frac{\sum_{i=1}^{N}(x_i - \overline{x}) * (y_i - \overline{y})}{\sum_{i=1}^{N}(x_i - \overline{x})^2} \quad \text{And} \quad b = \overline{y} - a\,\overline{x}$$

N is total number of points, $\overline{x} = \sum_{i=1}^{N} x_i$ and $\overline{y} = \sum_{i=1}^{N} y_i$

A simple linear correlation coefficient | R | close to 1 means a good fit between all points and a better identification of the target trajectory.

$$R = \frac{\sum_{i=1}^{N}(x_i - \overline{x}).(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \overline{x})^2}.\sqrt{\sum_{i=1}^{N}(y_i - \overline{y})^2}} \qquad (12)$$

IV. Simulation Results

In order to validate the features of the CBL, a set of simulations were performed in MATLAB environment. The scenario illustrated in the figures depicts an example where an RFID tag is attached to a person or a vehicle moving within the zone of a road intersection. Localization in this scenario is performed with four receivers, located on a 10 m × 10 m grid. The transmitter location is simulated randomly inside the grid. The simulation assumes a frequency of 915 MHz, a reference distance d_0 of 1 m, with a path loss exponent n of 2.69 and a shadowing standard deviation σ of 3.43 both determined experimentally in an outdoor setting. An EIRP of 50 dBm determined experimentally is assumed for computing the simulated RSS values at each receiver. For each execution, the minimum and maximum amount of signal shadowing is added to the RSS values along a Normal distribution, with mean zero and standard deviation σ. The minimum and maximum bound hyperbolas are then traced between each pair of receivers. The RFID tag localization is performed for confidence values C = 0.92, 0.95 and 0.99. The area (z) of the bounded zone calculated by CBL is shown in Table1.

TABLE 1
Relationship between intersection area and C values.

Z (C %)	1.66 (C=92%)	1.96 (C=95%)	2.44 (C=99%)
Intersection zone area (m^2)	9.544	13.7732	23.1642
Intersection zone vs. total zone	9.55%	13.77%	23.16%

In the second part of the set of simulations, CBL method is compared first to the Trilateration method and second to the the RSS Localization method described in [17].

For the Trilateration method, the layout is depicted in Fig. 5. Let (x, y) represent the coordinates of the real target T, and (D_1, D_2, D_3 and D_4) distances estimated from (R_1, R_2, R_3 and R_4) based on Friis's equation with the same value of standard deviation σ. For each estimated position, one circle is plotted with the reader coordinates as center and the estimated separation distance value as radius. The grey area shown in Fig. 5 measures the gap between the distance estimated via the RSS Localization and the real target position.

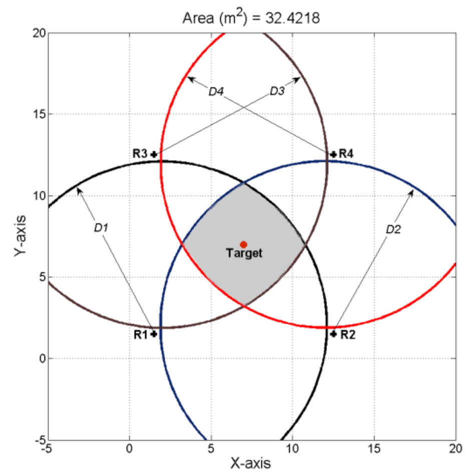

Fig. 5. Intersection area with the Trilateration based localization method.

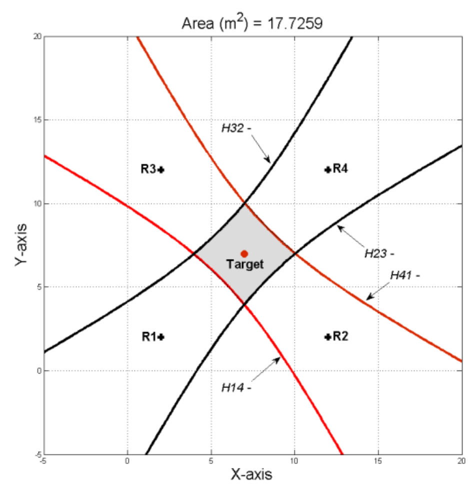

Fig. 6. Intersection area with a RSS Based Localization method.

For the RSS Localization method, two candidates' hyperbolic bounds $H_{14-}$and H_{41-} are plotted to limit the location of a target T between two readers R_1 and $R_2$with the same confidence level C and the same standard deviation σ. Two other hyperbolic bounds $H_{23-}$and H_{32-} for the pair of receivers R_2 and R_3 are computed in the same way to get the intersection area colored in grey shown in Fig. 6.

Finally, the CBL method is used for each pair of receivers (R_i, R_j) with $D_{ij-}$and D_{ij+} defined as the minimum and maximum bounds, respectively, of the compensated distance difference range between R_i and R_j with the same confidence level C as shown in Fig. 7.

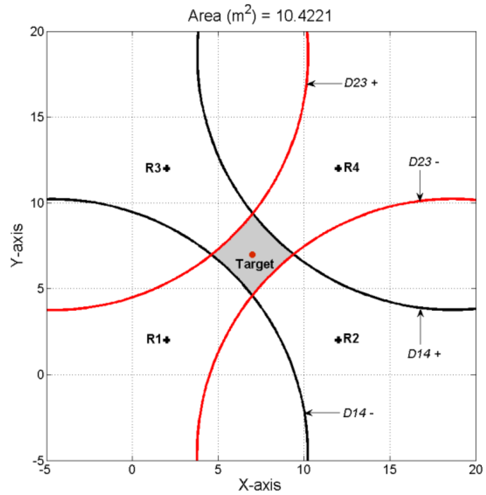

Fig. 7. Intersection area with CBL.

In all simulation sets performed, the proposed RSS Compensation Based Localization method improves localization accuracy over the other two methods. As we can see in the graphs of the illustrated scenario, the three methods succeed in bounding the real target position. Also, they illustrate that the bounded area computed by CBL is smaller than that of the compared RSS-based method, and that the latter is smaller than the area determined by the Trilateration method. For an overall area of 100 m^2, the bounded area computed for each method with a confidence level C = 93% is: 32.42 m^2 for Trilateration, 17.72 m^2 for the Relative Signal Strengh method and 10.42 m^2 for CBL. This corresponds to the localization improvement ratios shown in Table 2. The Global Improvement Ratio being the difference in the calculated areas versus the total area. The Relative Improvement Ratio is the difference between the calculated areas versus the area calculated by the method compared to CBL.

TABLE II
Localization Improvement.

	CBL Global Improvement Ratio	CBL Relative Improvement Ratio
Trilateration	22%	67.85%
Relative SS	7.3%	40.11%

V. Conclusion

The proposed localization scheme succeeds in bounding, with a confidence coefficient, the location of an RFID tag with an unknown EIRP, within an area size consistently smaller than that of other compared methods. Further experiments are required to test CBL in different outdoors settings and with additional receivers. Although the empirical values used in simulations performed were collected for RFID active technology, CBL can be used to estimate the position of a nodes using other wireless technologies, assuming omni-directional antennas at the receivers and that the receivers have known global positions and can aggregate information about the received RSS from the target node.

Acknowledgment

This work has been performed within the project “Wireless Sensor Networks for Communicative and Adaptive Cars”, which is funded by the Canadian AUTO21 Network of Centers of Excellence.

References

[1] S.-L. Chen, 1 K.-H. Lin, and R. Mittra, “Miniature and near-3D omnidirectional radiation pattern RFID tag antenna design,” Electronic Letters Volume 45, Issue 18, p.923–924, 2009.
[2] White paper: “*Montreal Transit Authority (AMT) relies on Motorola RFID*,” Last accessed March 25 2010. http://www.motorola.com.
[3] Zheng Yang, Yunhao Liu, “Quality of trilateration: confidence-based iterative localization,” *IEEE Transactions on Parallel and Distributed Systems*, 29 May 2009.
[4] Guang-yao Jin; Xiao-yi Lu; Myong-Soon Park, “An indoor localization mechanism using active RFID tag,” Sensor Networks, Ubiquitous, and Trustworthy Computing, 2006. IEEE International Conference on Volume 1, 5-7 June 2006.
[5] J.S. Choi, H. Lee, R. Elmasri, D.W. Engels, “Localization systems using passive UHF RFID,” Fifth International Joint Conference on INC, IMS and IDC, 2009, pp.1727-1732.
[6] Hahnel, W. Burgard, D. Fox, K. Fishkin, and M. Philipose, “Mapping and localization with RFID technology,” Intel Research Institute, Seattle, WA, Tech. Rep. IRS-TR-03-014, December 2003.
[7] Xiaotao Liu, Mark Corner, Prashant Shenoy, “Ferret: RFID Localization for pervasive multimedia,” *UbiComp 2006*: Ubiquitous Computing (2006), pp. 422-440.
[8] N. Sastry, U. Shankar, and D. Wagner, “Secure verification of location claims,” in Proceedings of the 2nd ACM Workshop on Wireless Security (WiSe), September 2003, pp. 1–10.
[9] T. He, C. Huang, B. M. Blum, J. A. Stankovic, and T. Abdelzaher, “Range-free localization schemes for large scale sensor networks,” in Proceedings of the 9th Annual International Conference on Mobile Computing and Networking (*MobiCom*), September 2003, pp. 81–95.
[10] C. Liu, K. Wu, and T. He, “Sensor localization with ring overlapping based on comparison of received signal strength indicator,” in Proceedings of the IEEE International Conference on Mobile Ad-hoc and Sensor Systems, October 2004, pp. 516–518.
[11] M. Barbeau and J.-M. Robert, “Rogue-base station detection in WiMax/802.16 wireless access networks,” Annals of Telecom-munications, vol. 61, no. 11–12, pp. 1300–1313, November–December 2006.
[12] B.-C. Liu, K.-H. Lin, and J.-C. Wu, “Analysis of hyperbolic and circular positioning algorithms using stationary signal-strength-difference measurements in wireless communications,” IEEE Transactions on Vehicular Technology, vol. 55, no. 2, pp. 499–509, March 2006.
[13] R. Janaswamy, “Path loss predictions in the presence of buildings on flat terrain: A 3-D vector parabolic equation approach,” *IEEE Transactions on Antennas and Propagation*, August 2003.
[14] V.S. Abhayawardhana, I.J. Wassell, D. Crosby, M.P. Sellars and M.G. Brown, “Comparison of empirical propagation path loss models for fixed wireless access systems,” Vehicular Technology Conference, 2005 IEEE 61st 30 May-1 June 2005, V-1; 73 – 77.
[15] Seung-Hyun Kong, “TOA and AOD statistics for down link Gaussian scatterer distribution model,” Wireless Communications, IEEE Transactions on Volume 8-5, May 2009,2609 – 2617.
[16] T. S. Rappaport, “*Wireless communications: principles and practice*,” Second Edition 2002, *Prentice Hall PTR*.
[17] C. Laurendeau and M. Barbeau, “Hyperbolic location sstimation of malicious nodes in mobile WiFi/802.11 networks,” in the Proceedings of the 2nd IEEE LCN Workshop On User MObility and VEhicular Networks (ON-MOVE), October 2008.