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Citation	2015 9th Asia Modelling Symposium (AMS): 132-136
Issue Date	2015
Type	Conference Paper
Text version	author
URL	http://hdl.handle.net/10119/14232
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Description	

A New Wireless Geolocation Technique Using Joint RSS-based Voronoi and Factor Graph

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***Abstract*—This paper proposes a new joint received signal strength (RSS)-based Voronoi and factor graph (RVFG) for wireless geolocation technique. The RSS-based Voronoi (RV) geolocation technique is used to select the appropriate four monitoring spots of RSS-based factor graph (RFG) covering the target. The RV technique is also used to provide the initial position of RFG technique. We modify the RV geolocation algorithm so that it can be performed in the fusion center. The performance of the proposed technique is compared in term of the root mean square (RMSE) to that of the conventional RV only technique. The results show that the accuracy of the proposed technique outperforms the conventional RV technique.**

Keywords–factor graph, Voronoi diagram, wireless geolocation, RSS

I. Introduction

Wireless geolocation with high accuracy is needed to provide location-related services in communications. The location-related service are playing crucial role in the society such as Emergency-911 (E-911), location-based billing service, intelligent transportation systems, car navigation, elderly people tracking, and precision agriculture [1]–[3]. This research field has gained considerable attention since past two decades. In 2013, one of wireless geolocation technique utilizing turbo (iterative) processing to perform location detection by using factor graph (FG) was introduced in [4], only a few years after the FG itself was introduced in [5]. The FG uses sum-product algorithm via message passing to compute the marginal function derived from global function, and hence the FG effectively coordinates all stochastic information to obtain high accuracy in geolocation. This global function, in the FG, factors to several simple local function that makes the FG has low complexity. The complexity reduction is achieved by the fact that only mean and variance are used as messages in the FG due to the Gaussianity assumption of the measurement error. [5], [6].

This paper proposes new scheme to select four appropriate monitoring spots[1] covering the target. The selected monitoring spots are used by received signal strength (RSS)[2]-based FG (RFG) geolocation technique as shown in Figs. 1 and 2. This RFG technique, which is introduced by [7], is using pattern-recognition technique to find four appropriate monitoring spots covering the target. However, this pattern-recognition technique is not explained in detailed in [7]. The conventional RSS-based Voronoi (RV) geolocation technique[3] [8] is used for selecting the monitoring spots, so-called RSS-based Voronoi FG (RVFG) technique.

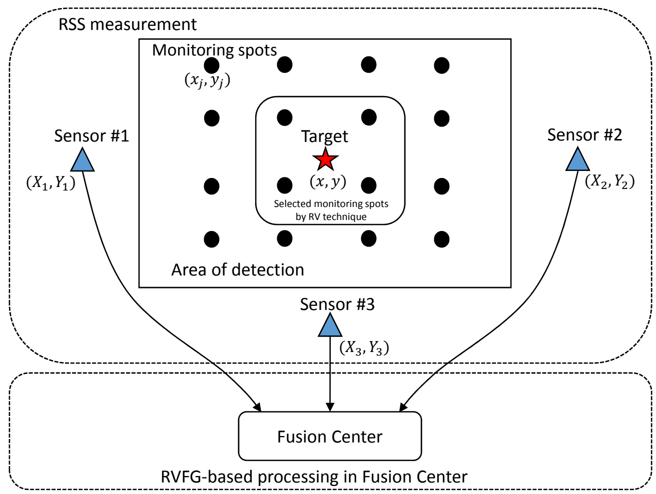

Figure 1. Basic structure of the RVFG-based geolocation technique describing sensors, target, monitoring spots, and fusion center.

A. Related Work

RFG geolocation technique detects the target position in indoor area of wireless networks. They assume that the environment is solely suffering from shadowing fading by averaging hundreds of RSS measurement from assumed each monitoring spot to eliminate the instantaneous fading. The state of the art of their technique lies in how close the

[1]We use the terminology of monitoring spot instead of training point mentioned in [7] for monitoring radio system.

[2]We use the terminology of RSS instead of RSS indicator (RSSI) because we use dB as the unit for the measurement result.

[3]We use the shorter term, i.e., RV technique, in the rest part in this paper for simplicity.

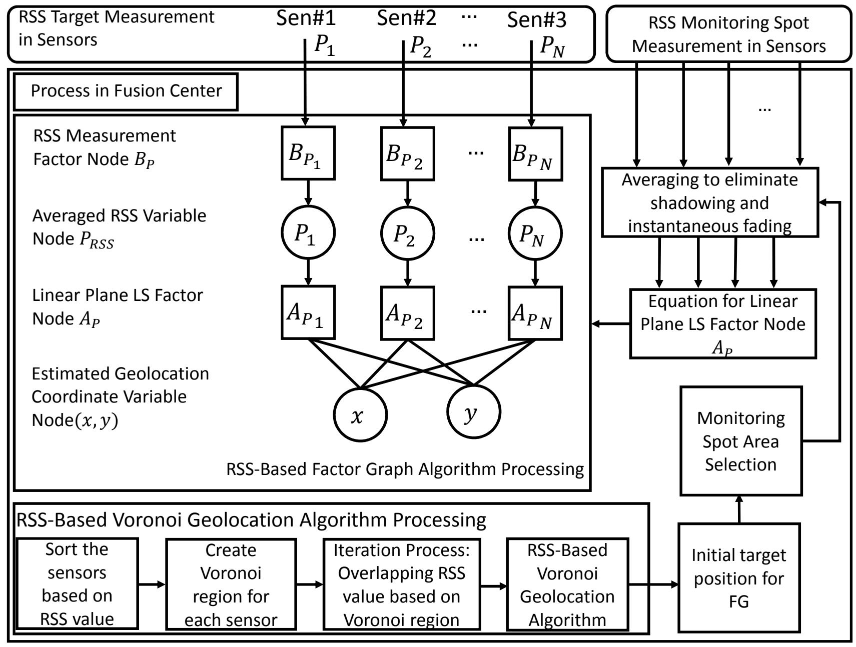

Figure 2. The proposed RVFG for Geolocation Technique

plane made by RSS information from monitoring spots to approximate the real RSS profile. Their technique uses least square (LS) to obtain the linear plane equation for the profile approximation.

In [9], we have investigated the RFG technique in outdoor environments, where solely path-loss taken into account. The shadowing and instantaneous fading components are eliminated by assuming a long enough averaging. We also find that the accuracy of the RFG geolocation technique depends on the width size of monitoring spot area[4] where the target is inside. Besides that, the monitoring spot number, more than four points, does not increase the accuracy.

The algorithm of RV technique [8] is briefly described in [10]. In [8], the target receives the RSS information from the beacons, hence the target processes the RSS informations to detect its own position estimate. The position estimate is obtained by accumulating the measured RSS belonging to each Voronoi region. After that, the algorithm is improved in [10] by employing the triangle algorithm between two sensors and the target to obtain the straight line. The several crossing points made by several straight lines are close to the target position. The measured RSS value is added to the expectation of the crossing points as weighting factor in calculating the position estimate. In RV technique, high accuracy is achieved with the large number of sensors.

[4]We use the term monitoring spot area instead of training cell mentioned in [7].

B. Contributions

The main contribution in this paper is combining the conventional RV technique and RFG technique, where the RV technique is used to select the appropriate four monitoring spots of RFG technique covering the target. The RV technique also provides the initial value for iteration in RFG technique. The RFG itself improves the accuracy of the RV technique. The main objectives of this paper are as follow: 1) We modify the conventional RV technique [8] with the opposite way, i.e., the sensors measure the RSS of the target and then forward it to fusion center, where the RV technique is performed in fusion center. 2) We combine the modified RV technique with the RFG technique to improve the accuracy, where the RV technique is used to select four monitoring spots of RFG technique, which are covering the target. 3) We compare the performance of the proposed technique with sensor numbers and signal to noise power ratio (SNR) as parameter. 4) The outdoor environment is assumed where long enough averaging is performed to eliminate the shadowing and instantaneous fading, hence the only path-loss still remains as in [9].

II. SYSTEM MODEL OF JOINT RVFG GEOLOCATION TECHNIQUE

As stated before, only path-loss remains due to the long enough averaging. The RSS samples from monitoring spots and target are sent by sensors to the fusion center, where the joint RVFG geolocation algorithm processing is conducted. The RV technique is used to select four monitoring spots for RFG algorithm as shown in Fig. 2.

A. RV Geolocation Technique

The following modification processes on the RV technique are conducted in fusion center: 1) Creating the Voronoi diagram based on sensors position. 2) Sorting the sensors based on RSS value, where sensor with the highest RSS value is in the first position. 3) Adding plots having the highest RSS value to the first Voronoi region. 4) Removing the first sensor from the system. 5) Re-creating the Voronoi region based on the rest of sensors, where the second sensor is becoming the next first sensor. 6) Adding the plots having the second largest RSS value the new Voronoi region of the next first sensor. 7) Repeating the processes of 3) to 6) until the calculation of the last sensor completed. 8) Obtaining the target position by calculating the expectation of the coordinate positions with the highest accumulated RSS value.

Fig. 3 shows the Voronoi diagram with 23 sensors. One of the Voronoi region with the highest measured RSS value is assigned with its measured RSS value. After that, remove the sensor with highest measured RSS value, hence it remains only 22 sensors. The Voronoi region of the sensor, with highest measured RSS value among 22 sensors, is added with its own RSS value. Hence, there is accumulation and overlapping between the first Vornoi region and the second Voronoi region. After all sensors are removed with resulting the overlapping accumulation of RSS value from 23 sensors, as shown in Fig. 4, the coordinates having the highest accumulated RSS of target measured by 23 sensors are close to the true target position, which is at $(468, -838)$ m. The position estimate is obtained from the average of the coordinates having the highest accumulated RSS, which is at $(477, -840)$ m.

The computation complexity of RSS value overlapping accumulation in the RV technique depends on the resolution of Voronoi region. It is noted that the higher resolution requires heavier computation, for example, the resolution with grid 10 m^2 has lower complexity compare to higher resolution with grid 1 m^2. We tested the computation time of the RVFG, FRG, and RV techniques with parameter setting described in Section III. Table. I shows the computation time of RFVG, RFG, and RV techniques. The RFG technique which is using only 3 sensors has much lower computation time over RFVG and RV techniques. One of the schemes that can be used to solve the complexity issue is by using pre-computing of RV technique before using the technique

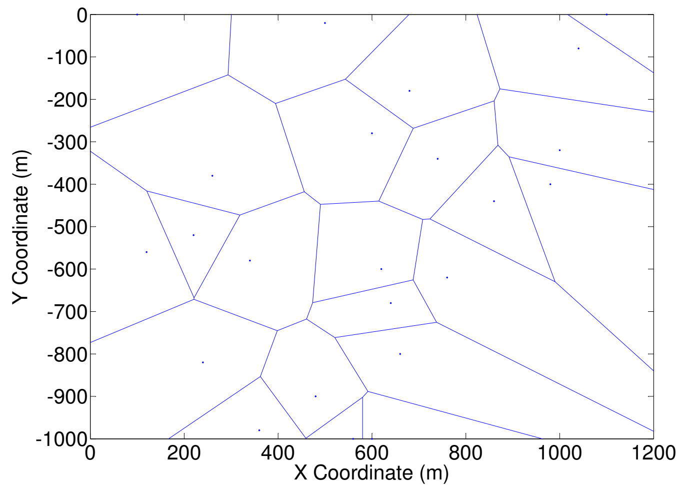

Figure 3. The Voronoi diagram with 23 sensors in $1,000 \times 1,000$ m^2.

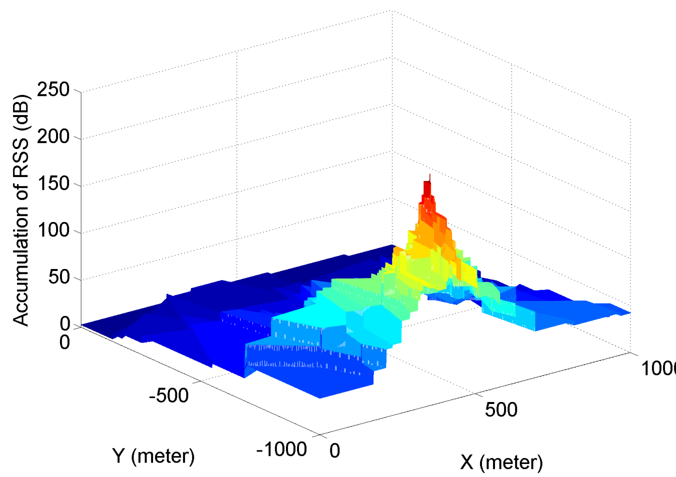

Figure 4. The RSS of target accumulation by the RV algorithm with 23 sensors, where the target is at $(468, -838)$ m.

for geolocation. The result of pre-computing of RSS is simply used by look-up table. However, pre-computing of RV technique is not in detail discussed in this paper because we leave out it to discuss as a future work.

TABLE I.
THE COMPUTATION TIME OF RFVF, RFG, AND RV TECHNIQUES.

Sensor Number	Time Processing (second)		
	RFVG	RFG	RV
3	1.2036	0.0086	1.195
23	25.9462	–	25.93755

B. RFG Geolocation Technique

The RFG technique in this sub-section is briefly described based on the technique introduced in [7]. We modify the environment from indoor area suffered from shadowing fading [7] to the outdoor area suffered from path-loss fading [9]. The first process in FG is conducted in *RSS measurement* *factor node* B_p to provide mean and variance massages extracted from RSS samples which is corrupted by zero-mean Gaussian measurement error. After that, the *averaged RSS variable node* P_{RSS} forwards the RSS messages of target from the *RSS measurement factor node* B_P to the *linear plane least square (LS) factor node* A_P.

The messages of the mean and variance of RSS samples as well as the x and y coordinate are exchanged iteratively between the *linear plane LS factor nodes* A_P and the *estimated geolocation coordinate variable node* (x, y) in FG as shown in Fig. 2. In the *linear plane LS factor node* A_P, the messages of mean and variance of RSS are converted to (x, y) coordinate as the target coordinate. The messages of mean and variance of (x, y) from each sensor are exchanged in *estimated geolocation coordinate variable node* (x, y), where sum-product algorithm is used to obtain the mean and variance during iteration process as well as while it converges. The mean value in the *estimated geolocation coordinate variable node* (x, y) is taken as the final estimation of target position.

The linear plane equation that is used to convert the messages of RSS from target to the coordinate is derived in [7], as

$$a_{x_i} \cdot x_j + a_{y_i} \cdot y_j + a_{p_i} \cdot p_{m_{i,j}} = c, \tag{1}$$

where $i = 1, 2, ..., N$ is the sensor number, $j = 1, 2, ..., M$ is the monitoring spot number, a_x is the coefficient of x coordinate variable, a_y is the coefficients of y coordinate variable, p_m is the RSS of monitoring spot, a_p is the coefficient of p variable, and c is a constant which is set as 1. The matrix equation from (1) is expressed as below

$$\mathbf{B} \cdot \mathbf{a} = \mathbf{c}, \tag{2}$$

where **b** is matrix of x_j, y_j, and $p_{m_{i,j}}$, **a** is vector of a_{x_i}, a_{y_i}, and a_{p_i}, and **c** is constant vector. The coefficient of the variables are obtained by employing the least square (LS) solution to (2), as

$$\mathbf{a} = \left(\mathbf{B}^T \cdot \mathbf{B}\right)^{-1} \cdot \mathbf{B}^T \cdot \mathbf{c}, \tag{3}$$

where $(.)^{-1}$ is the inverse matrix of its argument, and $(.)^T$ is the transpose matrix. The coefficients in **a** from (3) are taken for the final linear plane equation to convert target RSS to the target coordinate (x, y) as expressed below

$$a_{x_i}.x + a_{y_i}.y + a_{p_i}.p_{t_i} = c, \tag{4}$$

where p_t is the RSS of target. The *linear plane LS factor node* A_p uses (4) to convert the target RSS message to the pairing target coordinate position. The detail process as well as the mean and variance function in each node of RFG geolocation can be found in [7].

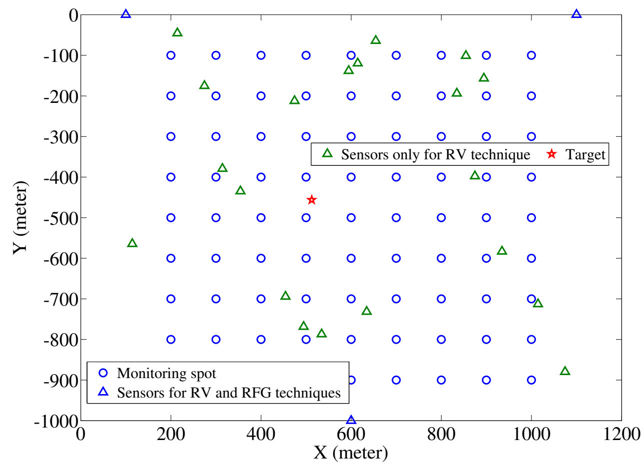

Figure 5. The simulation setup describing monitoring spots with grid 100×100 m^2, 23 sensors, 1 targets in total outdoor area of $1,000 \times 1,000$ m^2.

III. Simulation Results

The computer simulations were conducted to verify the performance of the proposed technique. The simulation round consists of 100 trials, each having one target randomly chosen from the area of 800×800 m^2. 3 sensors used by RFG technique are set fixed at the positions of $(100, 0), (100, 1000), (600, -1000)$ m in $(X-Y)$ coordinate as shown in Fig. 5. Each trial has also additional numbers of sensors, i.e, 0 to 20 sensors, randomly chosen from the area of $1,000 \times 1,000$ m^2, where all of the sensors in total are used by RV technique.

The monitoring spot positions are set in square area of $1,000 \times 1,000$ m^2 with grid step in 100×100 m^2 as suggested in [9]. The RV technique is used to select one cell of 4 monitoring spots covering the target position. The results are followed by the RFG technique to obtain the accurate position estimate of the target by using the selected 4 monitoring spots and initial value provided by RV technique. The RFG technique also uses only 3 sensors which are set a fixed positions.

The RSS values of target measured in sensors are made by Path-loss exponent model because of the long enough averaging assumption to eliminate the shadowing and instantaneous fading as in [9]. We set the path-loss exponent $n = 3$, reference distance $d_0 = 100$ m, and frequency carrier $f = 1$ GHz.

The following parameters were used to evaluate the accuracy of the proposed technique: a) 30 times of iterations for each trial, b) 100 samples, c) 3 to 23 sensors. The values of the measurement error is in SNR, i.e., 0 to 30 dB. We assume that the measurements are corrupted by the measurement error having the same variance in each sensor for simplicity.

Figs. 6 and 7 show the trajectory of the proposed technique with 23 sensors. The initial value provided by RV technique is close to the target position at $(498, -463)$ m be-

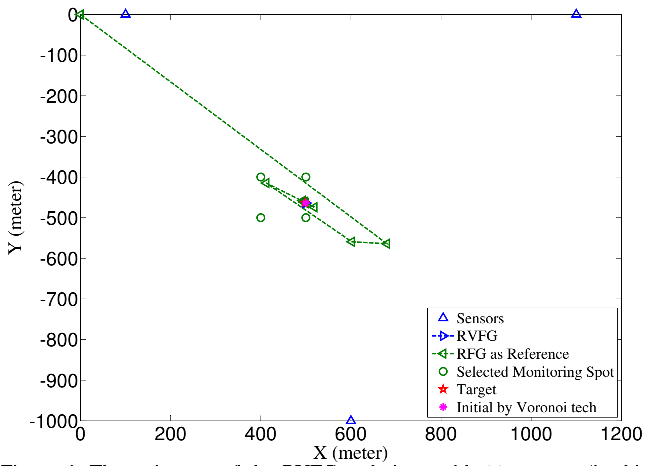

Figure 6. The trajectory of the RVFG technique with 23 sensors (in this figure only shown 3 sensors used by FG-based for simplicity in analysis) and target at $(498, -463)$m.

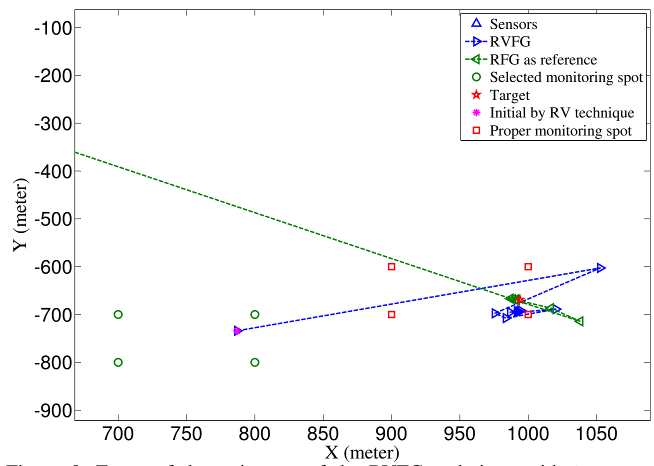

Figure 8. Zoom of the trajectory of the RVFG technique with 3 sensors (the sensors are now shown because of the zoom of the figure) and target at $(994, -669)$m.

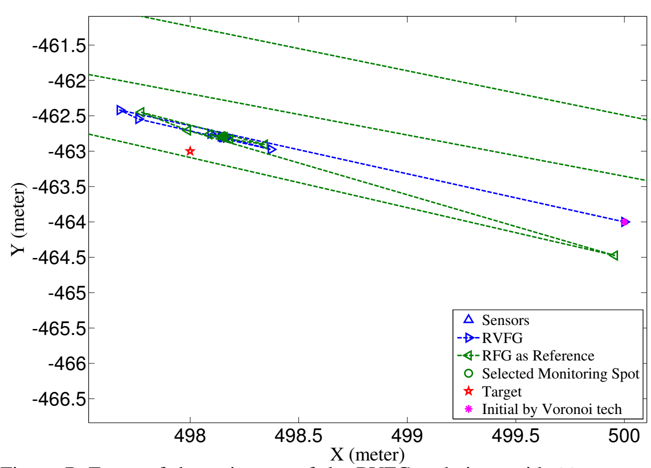

Figure 7. Zoom of the trajectory of the RVFG technique with 23 sensors (in this figure only shown 3 sensors used by FG-based for simplicity in analysis) and target at $(498, -463)$m.

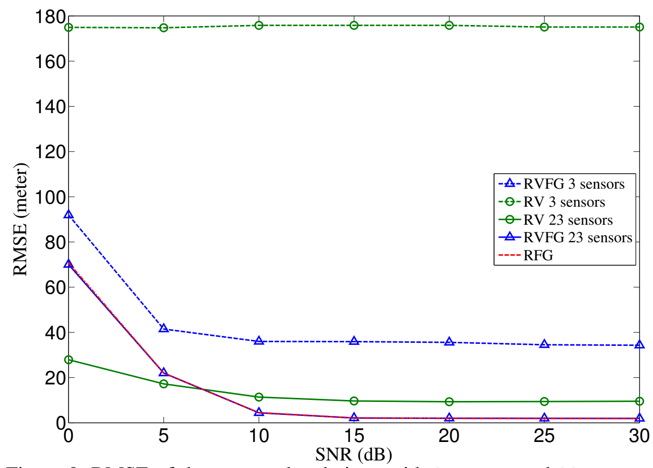

Figure 9. RMSE of the proposed technique with 3 sensors and 23 sensors.

cause of many sensors involved, hence the accumulation of the measured RSS value concentrated at averaged coordinate at $(500, -464)$ m, near to the target position. The trajectory of proposed technique is compared to the trajectory of the idealistic of RFG curve where correct monitoring spots are always selected. The initial value is set at $(0, 0)$ m. The RV technique with small number of sensors selects the wrong monitoring spots area as shown in Fig. 8, with the sensor numbers of 3. Therefore, the proposed technique can not reach close to the true target position.

Fig. 9 shows the accuracy of proposed technique in term of RMSE with sensor numbers as a parameter. It is shown that the accuracy with 23 sensors outperforms of the accuracy with 3 sensors, because with higher sensor numbers, the RV technique provides more accurate initial value to select monitoring spot for FG technique. The proposed technique outperforms the conventional RV technique for SNR more than 7 dB with 23 sensors. The improvement of achieved accuracy of the proposed technique over the conventional RV technique is approximately 7.5 m at the SNR of 15 dB.

IV. Conclusion

We have proposed a new wireless geolocation technique using joint RSS-based Voronoi and factor graph (RVFG). The RV geolocation is used to select the area of monitoring spots for RFG geolocation algorithm, as well as to provide inital value. The simulation results confirmed that our proposed technique provides higher accuracy compared to the conventional RV technique. This technique suitable is for outdoor environment in the future location based applications. The future work is to solve the complexity of RV technique by using pre-computing processing.

References

[1] J. James J. Caffery and G. L. Stuber, “Overview of radiolocation in CDMA cellular systems,” *IEEE Communications Magazine*, vol. 36, no. 4, pp. 38–45, April 1998.

[2] K. Pahlavan, X. Li, and J.-P. Makela, "Indoor geolocation science and technology," *IEEE Communication Magazine*, vol. 40, pp. 112–118, February 2002.

[3] Y. Zhao, "Standardization of mobile phone positioning for 3G systems," *IEEE Communication Magazine*, vol. 40, pp. 108–116, July 2002.

[4] J.-C. Chen, C.-S. Maa, and J.-T. Chen, "Factor graphs for mobile position location," in *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP) 2003*, vol. 2, April 2003, pp. 393–396.

[5] F. R. Kschischang, B. J. Frey, and H.-A. Loeliger, "Factor graphs and the sum-product algorithm," *IEEE Trans. on Information Theory*, vol. 47, no. 2, pp. 498–519, February 2001.

[6] J.-C. Chen, Y.-C. Wang, C.-S. Maa, and J.-T. Chen, "Network side mobile position location using factor graphs," *IEEE Trans. on Wireless Comm.*, vol. 5, no. 10, pp. 2696–2704, October 2006.

[7] C.-T. Huang, C.-H. Wu, Y.-N. Lee, and J.-T. Chen, "A novel indoor RSS-based position location algorithm using factor graphs," *IEEE Trans. on Wireless Comm.*, vol. 8, no. 6, pp. 3050–3058, June 2009.

[8] J. C. Wang, L. S. Huang, H. L. Xu, B. Xu, and S. L. Li, "A novel range free localization scheme based on voronoi diagrams in wireless sensor networks," *Journal of Computer Research and Development*, vol. 45, no. 1, pp. 119–125, 2008.

[9] M. R. K. Aziz, K. Anwar, and T. Matsumoto, "Monitoring spot configuration of RSS-based factor graph geolocation technique in outdoor WSN environment," in *IEICE General Conference 2015*, March 2015, (Submitted).

[10] S. Cai, H. Pan, Z. Gao, N. Yao, and Z. Sun, "Research of localization algorithm based on weighted voronoi diagrams for wireless sensor network," *EURASIP Journal on Wireless Communications and Networking*, 2014.