Model checking Indoor Positioning System with Triangulation Positioning Technology

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***Abstract*—Internet of things has been penetrated every corner of personal life. IPS (Indoor positioning system) is such an exact example which needs assistance of IoT technology. With the complicated architecture of IPS consisting with myriad components, the reliability of IPS appears essentially. However, besides the component limits the reliability of integral system reliability, there is one more restriction – TPT (Triangulation Positioning Technology). Therefore, in this paper, several experimental results are aimed at exploring the IPS reliability under TPT restriction.**

Keywords—Internet of things (IoT); Model Checking: PRISM; Indoor Positioning System; Triangulation Positioning Technology.

I. INTRODUCTION

Indoor positioning system has been popular in recent years with the maturity of Internet of Things (IoT). IPSs could be applied in a wide range of situations, for instance, searching the survivals in the ruins, tracing the path of patients in the hospital, locating players who are equipped with VR sensors in the playground room [1]. In addition to this, one commonality is proprietary positioning systems are supposed to connect and transmit data through PN (personal networks) [2, 3].

Typically three different systems topologies are used to function IPS on the strength of WLAN (Wireless-Local-Area-Network). The prevailing and commonest one is remote-positioning, which is based on collecting data from transmitters and computing all blocks of data in one station. The second approach is self-positioning, the operating principle is remote devices (receivers) could be capable of computing distance from known transmitters. The last topology is indirect positioning, according to the definition, it works under the guide of self-positioning principle while the data of self-positioning topology will be gathered together and finally send to the remote port [4, 5].

II. RELATED WORK

IoT extremely promotes indoor positioning technology, the idea of IoT is linking irrelevant objects together, changing objects more intelligent and coherent. It could be concluded technologies such as WLAN, Bluetooth, various protocols and applications are derivatives of IoT [6, 7]. With the help of the WLAN, signals could be transmitted from WLAN deployed determination model (such as 802.1 5GHZ router), returning the (2D/3D) digital position value by accurately evaluating the huge amount of signal data [8, 9]. Zerbra Technology has been designed an IPS named WhereNet [10]. Figure 1 presents the components of the whole system, it could be divided into three parts. Firstly, the tag made from the detectable material is able to coupe back signal. Antennas processed by location processors could be served as input sensors to send radio wave consistently. Serve is created to deal with input information which is reprocessed by location processor. Finally, the location information could be computed by the server with a sophisticated algorithm named DTOA (time difference of arrival) [4, 11, 12].

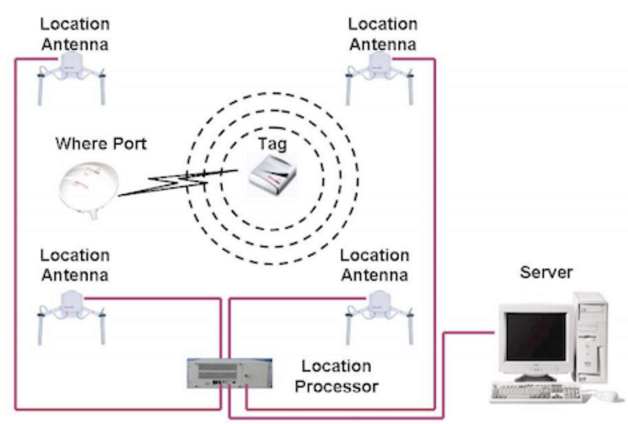

Fig 1. Zebra's WhereNEt realistic IPS model [2]

This paper makes following contributions:

- The findings in the experiments could display failure of main components on the reliability of integral IPS. Based on failure data it could be served as a component specification for researchers to design or modify their architectures.
- The experimental results will assist model designers to reflect the number factor of sensors under the restriction of TPT.
- Several frameworks will be compared in the next section, the consequence of comparisons would feedback a suggestive IPS model prototype under the influence of TPT.

III. MODEL CHECKING IPS

A. Framework

On the basis of WhereNet and TPT confinement, two IPS frameworks are devised in the Figure2 and 3. Both frameworks are supposed to contain the following parts: indoor positioning antenna, location processors, servers, main processor, dispatch radar, devices, BLE (Bluetooth low energy) transmission module. Within consideration of WhereNet's real model, it is advised to add a dispatch radar as the output port to dispatch processed data to the specific applications. BLE is treated as a module connecting dispatch radar and devices with high efficiency [13, 14].

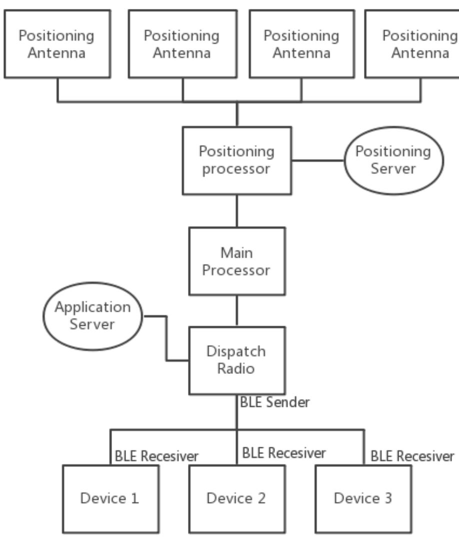

Fig 2. Framework-1

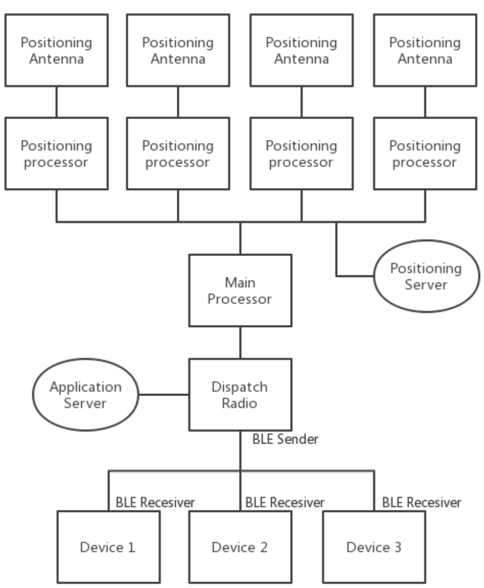

Fig 3. Framework-2

Beyond the construction of frameworks, the difference between framework-1 and framework-2 is the number variance of the positioning processors, it could be viewed framework-2 has 4 positioning processors while framework-1 only has one, this will produce a significant difference because of TPT.

B. Triangulation Positioning Technology

According to Thomas and Cliff, a critical positioning technic is applied in this system – TPT. Figure 2 illustrates how it works, only if at least 3 sensors existed this system has the possibility to detect the common one intersection point. Which means in this paper, IPS system must be kept safe under the promise of the number of input processors is bigger than three [11, 15].

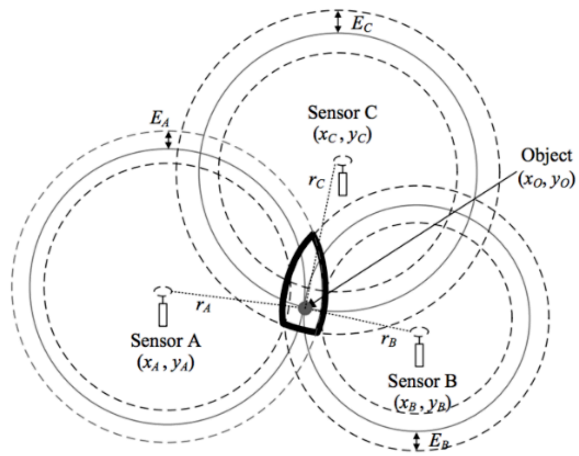

Fig 4. Triangulation Positioning Technique

C. Model Realization

After building blueprints, the prism is used to realize these models, the prism is a powerful tool to realize continuous-time Markov chains (CTMCs) and check the probabilistic model.

1) State Demonstrations

The whole system will shut down if any one of following conditions achieves.

- The number of the positioning antennas must smaller than 3.
- Positioning/Application server fails.
- In framework-2, smaller than 3 bundles (one bundle is a combination of one antenna and one processor which are in a line) fall down.
- BLE module is composed of 2 parts, sender and receivers, the sender is out of order, in the meantime, the number of the receivers is smaller than 1.
- Main processing breakdowns.

2) Model Constructions

Antenna modules: There are 4 positioning antennas in framework-1, each of them has failure rate "lambda_m" 1 / (30 * 24 * 60 * 60), which means one antenna will fail in a month. While in the framework-2 due to TPT restriction it keeps same failure rate for each antenna but each processor should be bigger than one. State transition of two model2 could be represented below:

Model1: []s > 1 -> s * lambda_m: (s'=s -1);

Model2: []s_i > 1 -> s_i* lambda_m: (s_i'=s_i -1);

i = {1, 2, 3, 4}

Positioning processors: positioning processors could reboot after transient malfunction. The transient failure rate is “lamda_tm” 1 / (2 * 30 * 24 * 60 * 60) which means every two months one positioning processor will be caught into transient failure. Moreover, the reboot success rate is “delta_d” 1/(24*60*60), it indicates positioning processor stuck into transient failure will revive in one day.

```
e : [0..2] init 2;
[] e > 0 & (s < MIN_SENSORS
| m < MIN_SERVER ) -> (e' = 0);
[] e  = 2 & s >= MIN_SENSORS
& m >= MIN_SERVER -> lambda_tm : (e' = e - 1);
[pos_pro_reboot] e = 1 & s > MIN_SENSORS
& m >= MIN_SERVER -> delta_d: (e' = 2);
```

Servers: servers could be positioning server or application server. Both of them are required to keep safe status to exchange data with input/output processor. The failure rate of these two servers is “lambda_y” 1 / (365*24*60*60) which denotes positioning server or application server will fail in a year.

Positioning server: [] m > 0 -> m * lambda_y : (m' = m - 1);

Application server: [] t > 0 -> t * lambda_y : (t' = t - 1);

BLE module: the failure rate of BLE sender is “lambda_tm”, furthermore, the failure rate of BLE receivers is “lambda_m”, they could be represented below:

BLE Sender: [] b > 0 -> b * lambda_tm : (b' = b - 1);

BLE Receiver: [] r > 1 -> r * lambda_m : (r' = r - 1);

3) Validating Frameworks

In the framework-1, 7 conditions could be possible to cause the failure of the integral system. “MIN_SERVER”, “MIN_BLESENDER”, “MIN_BLERECEIVER”, “MIN_DEVICE”, “MIN_SENSORS” are set to present minimum number of corresponded components. “MAX_COUNT” is defined as the maximum reboot times. “e” is the status of positioning processor module, the processor will fail when it is equal to 0. “x” is the status of dispatch radar, it only fails when x = 0. Therefore, the formula could be represented as below:

formula “down” = (m < MIN_SERVER) | (t < MIN_SERVER) | (b < MIN_BLESENDER) | (r < MIN_BLERECEIVER) | (d < MIN_DEVICE) | (s < MIN_SENSORS) | (count = MAX_COUNT + 1) | (e = 0) | (x = 0);

In model2, the failure conditions are almost the same as model1 but positioning processor number is different from before one. Hence, it needs to set pr1, pr2, pr3, pr4 to represent these four positioning processors. The formula is shown below:

label "down" = (m < MIN_SERVER) | (t < MIN_SERVER) | (b < MIN_BLESENDER) | (r < MIN_BLERECEIVER) | (d < MIN_DEVICE) | (pr1 = 0) | (pr2 = 0) | (pr3 = 0) | (pr4 = 0) | (x = 0) | (count = MAX_COUNT + 1);

In the following experiments, it will be tested within two groups of date duration, 24 hours or 30 days. As a result, the validation code statement could be presented like this:

“P = ?[true U<=24*3600 down]”

“P = ?[true U<=30*24*3600 down]”

These two equations mean IPS fails down will occur 24 hours and 1 day respectively.

IV. PERFORMANCE EVALUATION

Experimental results will be illustrated based on 4 main dominant factors that play a critical role in the whole IPS.

A. *Impact of positioning antennas*

The first experiment explores the number of antennas will make a difference to the reliability of the IPS. Since it has been stated positioning antennas are supposed to follow TPT rules. Following figures are proprietary on the basis of framework-1.

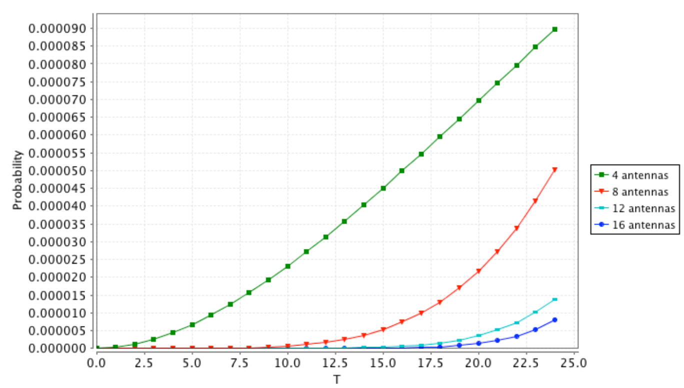

Fig 5. Different number antennas impact within 24 hours

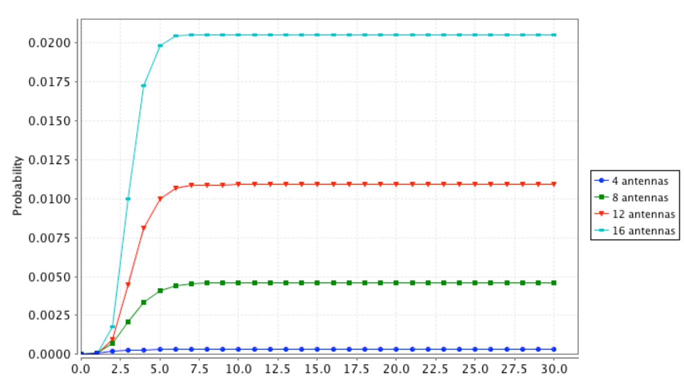

Fig 6. Different number antennas impact within 30 days

Finding. The result in Figure5 demonstrates that the incremental number of antennas decreases the failure probability of the entire system. However, if the duration is set to 30 days without changing the failure rate of antennas, the above finding is also alternated.

Finding. From the second graph in Figure 6, the different number of the antennas have the different failure rate. The failure rate will increase when the number of the antennas increase but the failure rate still keeps a low level.

Remark. The reason for this situation is that the entire system uses many antennas. When one of the antennas fails, there are still other antennas helping complete the work.

Furthermore, the failure rate of above experiments is set once a month, which means one antenna is bound to malfunctioning in a month. More findings would be obtained if the failure rate is changed homogeneously.

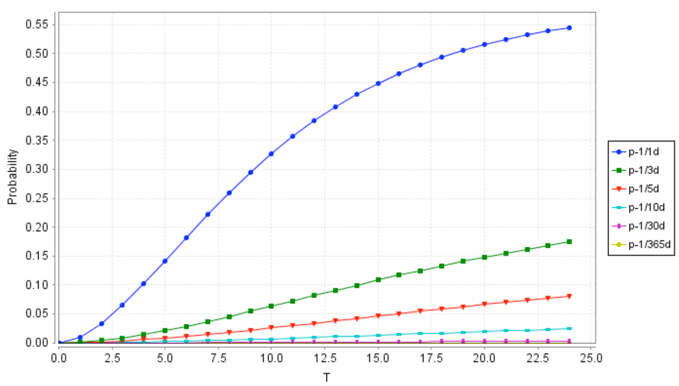

Fig 7. Antennas with different failure rate within 24 hours

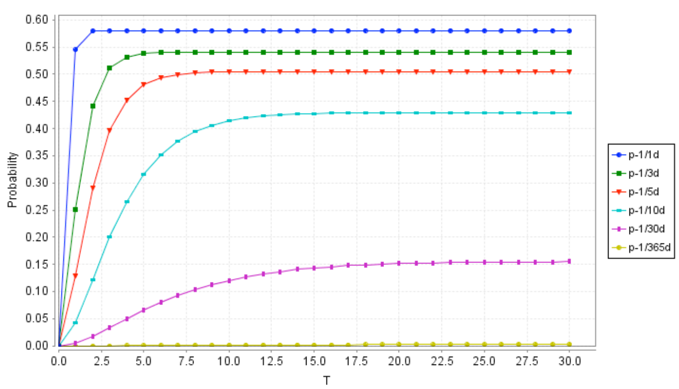

Fig 8. Figure 8 Antennas with different failure rate within 30 days

Finding. Figure 7 demonstrates that lower failure rate of the antenna could improve the reliability of the whole system in both the short-term experiment and long-term experiment if combining the two graphs.

Finding. In Figure 8, when the failure rate of the antenna is greater than 1/30 days, its influence on the reliability of the whole system becomes slight. After 15 days, the probabilities of the systems of all the curves become steady.

B. *Impact of positioning processors*

The second set of experiments show the result as graphs in Figure 9 and Figure 10, which focus on verifying the impact of the positioning processor on the reliability of the system.

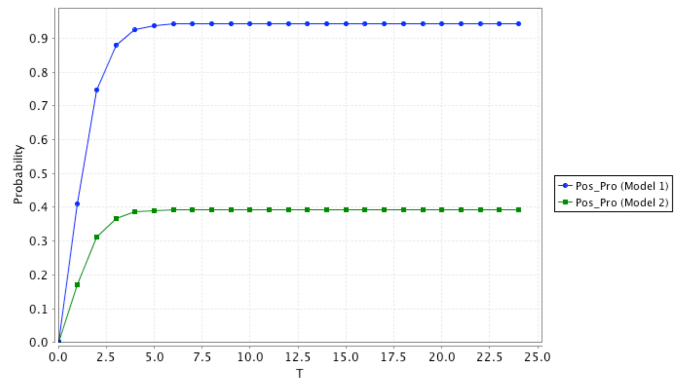

Fig 9. Different positioning processors fail within 24 hours

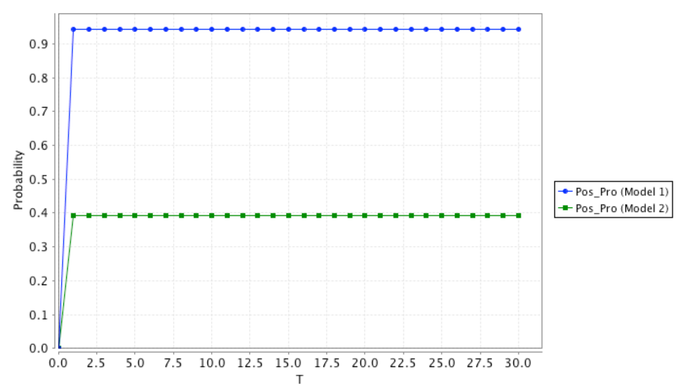

Fig 10. Different positioning processors fail within 30 days

Finding. From the first graph in Figure 9, it shows the probability in 24 hours. In the 6^{th} hour, the probability of the positioning processor failure has stabilized between 0.9 and 1.0.

Finding. The second graph in Figure 10 shows the probability in 30 days. Since the probability does not change from the 6^{th} hour in one day, the probability of 30 days does not change from 0.9 to 1.0 from the first day.

Remark. This propensity occurs because the failure of positioning processors depends on servers and antennas. Positioning processors fail permanently only servers and antennas totally breakdown.

C. *Comparison Of Two Frameworks*

This section is for contrasting integral IPSs of two frameworks in 24 hours and 30 days.

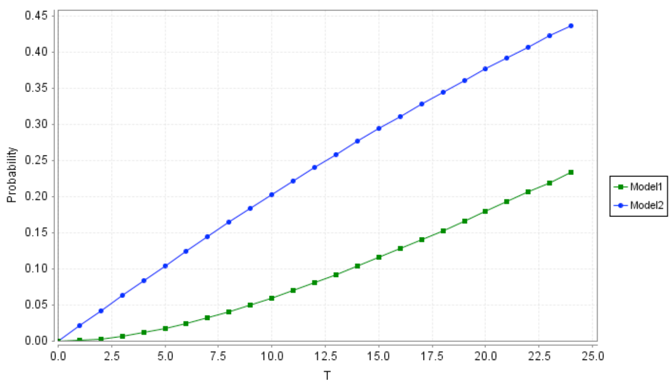

Fig 11. The failure rate of two frameworks in 24 hours

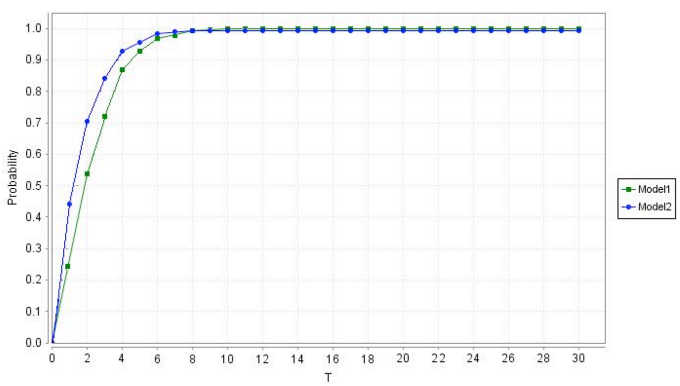

Fig 12. The figure 12. Failure rate of two frameworks in 30 days

Finding. Figure 11 testifies that with the same parameters setting of, framework-1 has higher reliability result. The failure rate of framework-1 is approximately half of framework-2, thus, framework-1 is more reliable.

Finding. After 8 days, the failure rates of both two frameworks are approximately approaching to. However, framework-1 has better performance from day 0 to day 7.

V. Conclusion

It has been fully illustrated two frameworks of IPSs with TPT in the paper. Four experiments have been conducted thoroughly, which includes different quantity of positioning antennas, different failure rate of positioning antennas. In addition, positioning processors failure is also considered in this paper. The last experiment is a comparison of two frameworks within common duration.

After analysis of these experiments, it could be concluded IPS reliability keeps the same direct proportion to the number of antennas. While this tendency changed when the duration is extended to 30 days because of TPT. Furthermore, IPS will become more vulnerable when failure rate is modified a higher value, but inclination does not effect after 15 days. When mentioned the impact positioning processors, it is decided by servers and antennas, therefore, the reliability is limited when time more lasts than 6 hours. After a comprehensive contrast of these two frameworks, it is concluded the first framework is much more reliable and robust than the second one.

Due to research conditions and time limits. It is hoped to realize these two frameworks in the actual world and thus the experimental data would be more accurate and reliable. In addition, in this paper, it does not conduct the experiments about the failure of BLE module, while this module is served to connect application servers and output port to devices, which also plays a decisive role in the whole IPS.

REFERENCE

[1] J. Egger, M. Gall, J. Wallner, P. Boechat, A. Hann, X. Li, X. Chen and D. Schmalstieg, "HTC Vive MeVisLab integration via OpenVR for medical applications," PLoS ONE, GERMANY, 2017.

[2] D. Madigan, E. Einahrawy, R. Martin, W.-H. Ju, P. Krishnan and A. Krishnakumar, "Bayesian indoor positioning systems," in *INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies*, Miami, FL, USA, 2005.

[3] M. Rainer, "Overview of current indoor positioning systems," *Geodesy and Cartography,* vol. 35, no. 1, pp. 18-22 , 23 Dec 2008.

[4] Y. Gu, A. Lo and I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," *IEEE Communications Surveys & Tutorials,* vol. 11, no. 1, pp. 13 - 32, 4 March 2009.

[5] H. Liu, H. Darabi, P. Banerjee and J. Liu, "Survey of Wireless Indoor Positioning Techniques and Systems," *IEEE Transactions on Systems, Man, and Cybernetics,* vol. 37, no. 6, pp. 1067 - 1080, 6 Nov 2007.

[6] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys & Tutorials,* vol. 17, no. 4, pp. 2347 - 2376, 2015.

[7] B. v. d. V. G. N. W. W. D. W. &. L. F. Jun Hu, "Designing the Internet of Things for learning environmentally responsible behaviour," in *EDUTAINMENT 2011 CONFERENCE*, 2012.

[8] Z. Xiang, S. Song, J. Chen, H. Wang, J. Huang and X. Gao, "A wireless LAN-based indoor positioning technology," *IBM Journal of Research and Development,* vol. 48 , no. 5, pp. 617 - 626, 6 Sep 2004.

[9] O. Baala, Y. Zheng and A. Caminada, "The Impact of AP Placement in WLAN-Based Indoor Positioning System," in *Eighth International Conference*, Gosier, Guadeloupe, 2009.

[10] K. J. Dyke, N. Schofield and M. Barnes, "The Impact of Transport Electrification on Electrical Networks," *IEEE Transactions on Industrial Electronics,* vol. 57, no. 12, pp. 3917 - 3926, Dec 2010.

[11] D. Niculescu and B. Nath, "Ad hoc positioning system

(APS)," in *Global Telecommunications Conference*, San Antonio, TX, USA, 2001.

[12] R. Ardoino, F. Capriati and A. Zaccaron, "Performances of a DTOA estimation algorithm based on Cross-Correlation Technique," in *IEEE Conference* , Krakow, Poland, 2007.

[13] C. Gomez, J. Oller and J. Paradells, "Overview and Evaluation of Bluetooth Low Energy: An Emerging Low-Power Wireless Technology," MDPI AG, Switzerland, 2012.

[14] M. Siekkinen, M. Hiienkari, J. K. Nurminen and J. Nieminen, "How low energy is bluetooth low energy? Comparative measurements with ZigBee/802.15.4," in *Wireless Communications and Networking Conference Workshops*, Paris, France, 2012.

[15] J. P. Y. G. J. T. Y. H. W. a. R. C. H. Chih Yung Chen, "An Indoor Positioning Technique Based on Fuzzy Logic," in *International MultiConference of Engineers and Computer Scientists*, Hong Kong, 2010.