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Improving RF Transmit Power and Received Signal Strength in 2.4 GHz ZigBee Based Active RFID System with Embedded Method

F. A. Po'ad[1], W. Ismail[2], J. F. Jusoh[3]

[1]Department of Communication Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA.
[2]Auto ID Laboratory, School of Electrical and Electronic Engineering, Universiti Sains Malaysia, 14300 Seri Kembangan, Nibong Tebal, Pulau Pinang, MALAYSIA
[3]Department of Information Technology and Communication, Politeknik Sultan Abdul Halim Muadzam Shah, 06200 Bandar Baru Darulaman, Jitra, Kedah, MALAYSIA

Corresponding author: [1]farhana@uthm.edu.my, [2]eewidad@usm.my, [3]rizal79@polimas.edu.my

Abstract. This paper describes the experiments and analysis conducted on 2.4 GHz embedded active Radio Frequency Identification (RFID) – Wireless Sensor Network (WSN) based system that has been developed for the purposes of location tracking and monitoring in indoor and outdoor environments. Several experiments are conducted to test the effectiveness and performance of the developed system and two of them is by measuring the Radio Frequency (RF) transmitting power and Received Signal Strength (RSS) to prove that the embedded active RFID tag is capable to generate higher transmit power during data transmission and able to provide better RSS reading compared to standalone RFID tag. Experiments are carried out on two RFID tags which are active RFID tag embedded with GPS and GSM (ER2G); and standalone RFID tag communicating with the same active RFID reader. The developed ER2G contributes 12.26 % transmit power and 6.47 % RSS reading higher than standalone RFID tag. The results conclude that the ER2G gives better performance compared to standalone RFID tag and can be used as guidelines for future design improvements.

1. Introduction

Nowadays, there are a lot of technologies that can track and monitor locations are developed. A lot of researches have been done on the tracking such as logistics, buses, containers, humans, assets and automation industries either in indoor or outdoor environments [1-5]. Most of the developed systems are standalone and using single technology and only focussing on single environment either indoor or outdoor location. However, only a few works have been done on the tracking of both indoor and outdoor location simultaneously.

For outdoor tracking applications, the most widely used technology is the Global Positioning System (GPS), which is able to provide excellent performance in outdoor environments. However the GPS performance is degraded in indoor environments due to poor satellite reception. For indoor tracking applications, there are several numbers of standalone technologies that have been proposed for indoor tracking systems including Wi-Fi, ultrasound, Bluetooth, vision, infrared and RFID. According to Mainetti et al. [6], the RFID and Bluetooth technologies are the best solution for indoor tracking applications due low cost of implementation and less complexity of hardware development. However, the Bluetooth technology is unable to work in Non-Line of Sight (NLoS) environments and produce long latency approximately 10 s, which lead to the system drawbacks, thus make it unsuitable for real-time location tracking applications. RFID technology on the other hand, is more suitable for indoor environment, since it is able to work without direct Line of Sight (LoS) to perform the transmission and reception and having low latency less than 100 ms. In addition, the RFID technology provides high data rate, high security, cost effectiveness, and compactness [6]. Unlike GPS, RFID performance decreases in outdoor location due to multipath propagation and environmental factors, which can be a good reason to combine RFID technology with GPS technology in order to develop a system that can provide an automated switching between indoor and outdoor location tracking on the same platform.

Table 1: Comparison between previous and proposed system

Title	Wireless Technology	WSN	Mobile	Mesh Network	GPS	Indoor and Outdoor Tracking	Real Time	Long Range	Integrated Platform
Combination RFID and GPS functionality on intelligent label [7]	Active RFID	No	No	No	Yes	No	Yes	No	Yes
Portable RFID reader having location determination [8]	Active RFID based on IEEE 802.11b (WLAN)	No	No	No	Yes	No (tag-reader) Yes (reader-work station)	Yes	No	Yes
Radio frequency identification sensor tag apparatus [9]	433 MHz active RFID	No	No	No	Yes	No	Yes	No	Yes
RFID tracker and locater [10]	Near Field Communication (NFC)	No	No	No	Yes	No	Yes	No	Yes
Hybrid tag includes active RFID, GPS, satellite and sensors [11]	433 MHz active RFID and Satellite Communication	No	No	No	Yes	No	Yes	No	No
Wireless sensor network for pilgrims tracking [12]	IEEE 802.16.4 that support 315/433/868/915 MHz ISM/SRD Band	Yes	No	No	Yes	No	Yes	No	Yes
Proposed system	2.4 GHz active RFID-ZigBee technology based on IEEE 802.15.4 and Mobile Communication	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Instead of embedding the GPS and RFID technologies, WSN technology is often integrated with RFID technology to increase the capabilities in terms of communication. Typically, RFID supports point to point and point to multipoint topology and the reading range is depending on the operating frequency and mostly up to 100 m distances. In addition, RFID technology only allows communication between reader and tags and does not provide information about the condition of the objects it detects, which contribute to the drawbacks of the technology. While WSN, not only provides information about the condition of the objects and environment but also enables multi-hop wireless communications, which can increases the reading range between tags and reader with variety and flexibility of network protocol. The WSN technology also allows communication between tag-tag, tag-router and tag-reader with some modifications. Alternatively, mobile communication such as GSM communication can be used as a backup communication for WSN network since it can provide wide coverage area over 203 countries throughout the world with cost effective hardware and service compared to satellite communication. Since, most of the previous work are focusing on single platform and standalone application, hence this research work focuses on integration and embedment of these four technologies for M2M indoor and outdoor location tracking and monitoring applications to expand their overall functionality and capacity and at the same time increase the performance of the embedded RFID system for real time applications. Table 1 shows a brief comparison between previous system and proposed system that are related to indoor and outdoor tracking and monitoring applications.

2. System Design

The active RFID system is designed and developed by combining four technologies on a single platform as illustrated in Figure 1. The technologies include 2.4 GHz active RFID, GPS, WSN ZigBee based IEEE 802.15.4 standard and GSM mobile communication that supports Tri-band frequencies 900/1800/1900 MHz. The system introduces automated switching mechanism between indoor and outdoor location and provides M2M communication between tags and reader and vice versa via WSN platform. The system implements multi protocols and multi modes configurations during operation. There are three types of nodes implemented in the network, which are ZigBee End Device (ZED), ZigBee Router (ZR) and ZigBee Coordinator (ZC) and are represented by tag, router and reader in the active RFID system.

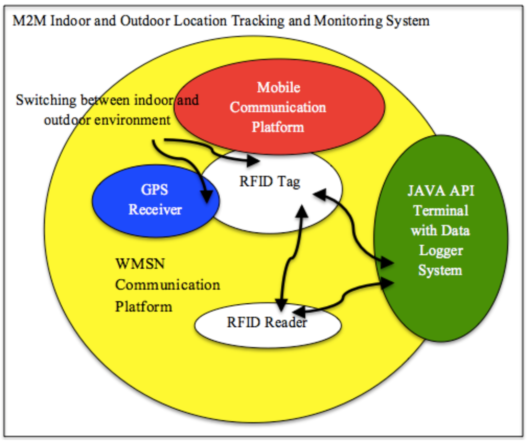

Figure 1: Overview of the System Architecture.

The proposed active RFID system can be used for many applications such as to track and monitor vehicles, humans, logistics and assets. The proposed active RFID tag can be attached to object or person to be tracked and monitored in both indoor and outdoor locations. All the information gathered from the tag will be relayed to the RFID reader connecting with the monitoring station via WSN platform that supports mesh network as shown in Figure 2. The RFID routers are utilized to route the data from tag to reader or vice versa. The proposed active RFID tag is battery powered and requires energy efficient hardware and software to minimize energy consumption. This can be achieved by optimizing the data volume and signal processing of the proposed embedded RFID tag. The RFID routers, and reader on the other hand, do not necessarily have strict restrictions on energy and processing power since it is powered by fixed supply. Figure 3 shows the architecture of the proposed active RFID tag and reader in terms of block diagram with all the technologies involved in the embedment.

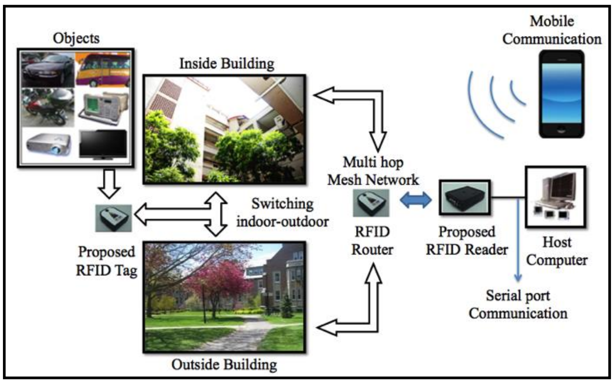

Figure 2: Overview of the System Architecture.

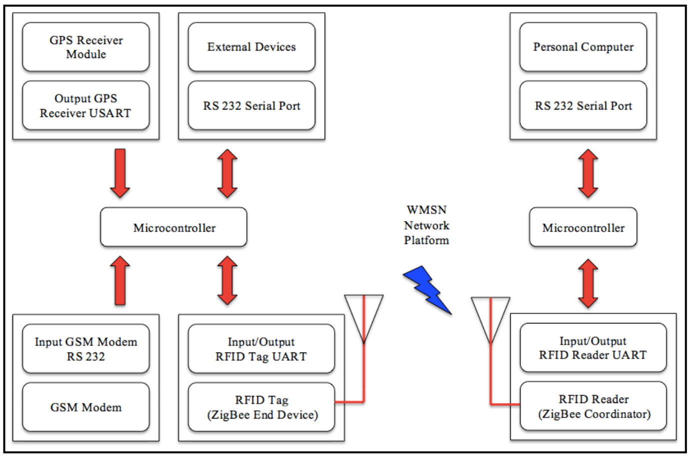

Figure 3: Block Diagram of Embedded Hardware Architecture

The development of tag and reader are based on the embedded method with Tag Talk First (TTF) and Reader Talk First (RTF) protocols. All the technologies are integrated as part of a complete device including hardware and mechanical parts that is controlled by single microcontroller on the same platform with real time computing. The following subsections elaborate on the proposed method of embedment in the active RFID tag and reader, power management module, communication protocol and algorithm and sensor network configurations involved in the development of active RFID system for tracking and monitoring applications.

2.1. Active RFID Tag

The main novelty of the proposed embedded active RFID tag is the implementation of an automated switching protocol for indoor and outdoor location tracking and monitoring. The tag is capable to communicate with active RFID reader for M2M communication and able to control the process in mesh network with the aid of RFID routers. The system includes a standalone active RFID tag that consists of a microcontroller embedded with a RF module as shown in Figure 4. The design is adopted from [9], which invents a RFID device for determining the location of objects that are tagged with RFID tag.

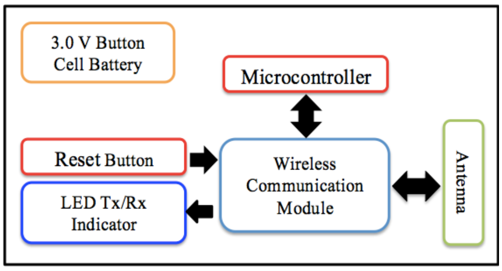

Figure 4: Standalone active RFID tag

The standalone RFID tag is further enhanced by adding external connection that allows the tag to communicate and control the process between RFID tag, real time clock (RTC) and external devices such as GPS receiver, GSM modem and personal computer (PC) as illustrated in Figure 5. The embedded active RFID tag communicates with the RFID reader at 2.4 GHz ISM band frenquency with the ability to transmit location data to active RFID reader up to 120 m indoor, 300 m outdoor and can be extended via RFID routers in multi hops communication using WSN platform [13-15]. Furthermore, the embedded RFID tag has an additional function, which able to transmit location data via mobile communication when the embedded RFID tag is not within WSN coverage area.

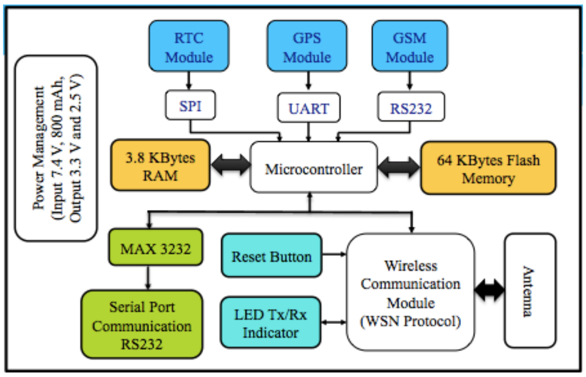

Figure 5: Embedded active RFID tag

The embedded RFID tag is powered up by 7.4 V 800 mAh Lithium Polymer rechargeable battery with the support of power management module as shown in Figure 6 to supply a proper voltage to each component reside in the RFID tag. The data volume to be transmitted in the embedded RFID tag also should be kept minimal and the elements of the protocols and algorithms residing in the NETWORK, MAC, and PHY layers are designed to maximize energy efficiency and limit signal interference [12]. To achieve these, the embedded RFID tag is programmed to operate in cyclic sleep mode and wakeup periodically based on predefined interval. The API mode is used to minimize the amount of signal processing, data volume and delay between transmission and reception. The embedded RFID tag is implemented with multi protocols that can automatically change from TTF to RTF or vice versa. An automated switching between indoor and outdoor location is activated based on data received from the GPS receiver. If the data is valid, thus the embedded RFID tag is woken up and TTF protocol is activated. Otherwise, the embedded RFID tag will turn to cyclic sleep mode and waiting for assertion of an interrupt line from wireless communication module. The RSSI reading and RFID tag ID programmed inside tag are extracted after the interruption. The designed further includes the steps of filtering data of a received data packet and demodulating a received RF signal by the wireless communication module.

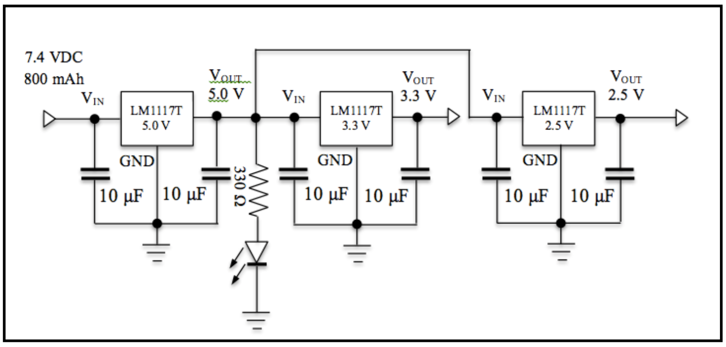

Figure 6: Power Management Module

2.2. Active RFID Reader

The active RFID reader introduced by Abdulla [16] consist of a wireless communication module connected to an antenna and a USB/RS232 serial communication port that is powered by the fixed supply as shown in Figure 7.

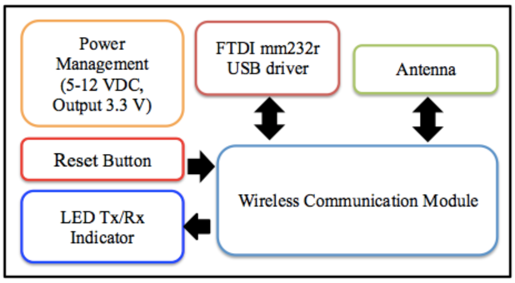

Figure 7: Basic RFID reader

The reader is further modified and has similar circuit as embedded active RFID tag except that the reader has been integrated with two control buttons that control the indoor tags together with tag's ID and a serial communication port RS232 to be connected with PC at monitoring station. Figure 8 shows the block diagram of the modified RFID reader that is capable to work in mesh network environment. The RFID reader is programmed in API mode, whereby all the data transmission and reception are based on the packet frame. The developed algorithm for RFID reader must be suitable for API mode communication and all the received data from RFID tags are translated by the reader into meaningful information before sending it to user at monitoring station. The power management module implemented in the modified RFID reader has same configuration with tag, however it can be powered up by a fixed power supply in between 5-12 VDC.

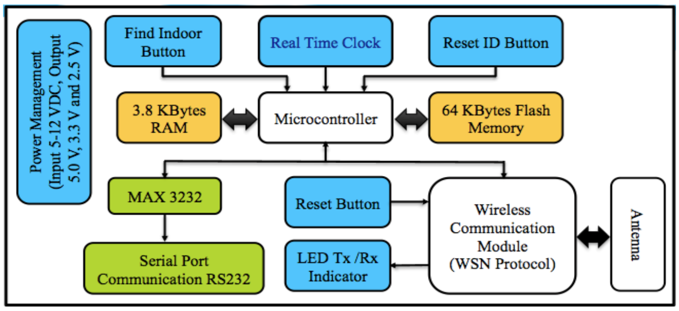

Figure 8: Modified active RFID reader

3. RF Power Transmission and RSS Calibration Test

Equivalent Isotropically Radiated Power (EIRP) is defined as the power radiated by an isotropic antenna with input power P_tG_t [17]. These two factors RF transmit power, P_t and transmit antenna gain, Gt characterize the transmitter as stated in equation (1)

$$EIRP = P_t G_t \qquad (1)$$

For a given frequency, range, and receiver antenna gain, the received power is proportional to the EIRP of the transmitter, and can only be increased by increasing the EIRP. This can be done by increasing the transmit power, or the transmit antenna gain or both.

The transmit power having close relationship with reading range and the strength of signal received by the reader. Reading range is defined as the distance from a reader to which a tag can be read. It also affected by many factors, including the frequency of the radio waves, the size of the antenna, orientation and type of RFID system either passive or active [18]. Therefore, to investigate the performance of proposed embedded RFID tag in terms of RF transmit power and RSS, a calibration test is performed by measuring the tag's RF transmit power and the RSS reading at the RFID reader for both standalone RFID tag and proposed embedded RFID tag.

3.1. Measurement Setup

Before the RF power transmission and RSS calibration test are conducted for two systems, the actual power produced by standalone RFID system is measured at power level 4 (PL 4) for two conditions; 1) 3.0 V batteries and 2) 7.4 V rechargeable batteries with power management circuit. The purpose of this evaluation is to prove that regardless of either direct connection from 3.0 V battery or power management circuit that regulates 7.4 V to 3.3 V supply was used, the power transmission produced by the standalone RFID system tag is the same for both conditions. The results of Figure 9 prove that as long as the RF module is supplied with required voltage between 2.7 V to 3.3 V, the power transmission produced by RF module is same under all conditions. The results also indicate that the standalone RFID system tag using 3.0 V battery has 2.21 % better performance than the standalone RFID with a 7.4 V battery embedded with power management circuit.

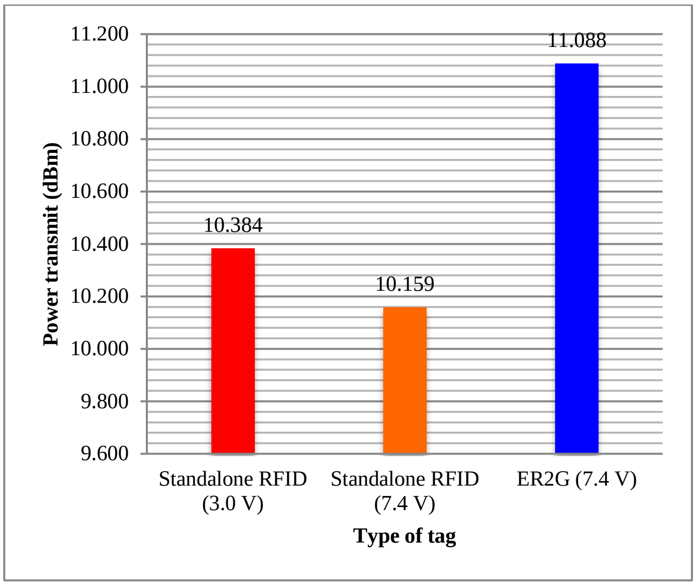

Figure 9: Actual transmit power

Therefore, the RF power transmission and RSS calibration test were done by connecting the RFID tag antenna connector to the power divider at the center port, while the other two ports are connected to the spectrum analyzer and antenna as shown in Figure 10. The 2.4 GHz quarter wavelength dipole antenna with 2 dBi gain is utilized by the RFID tag. The spectrum analyzer is used to display and measure the tag's transmission power in dBm. The amount of transmission power measured by spectrum analyzer has taken into account the losses comes from cables and power divider. Special measurement is done to measure the losses indicated by cables and power divider that contributes about 1.39 dBm losses for each cable and 2.782 dBm losses for power divider.

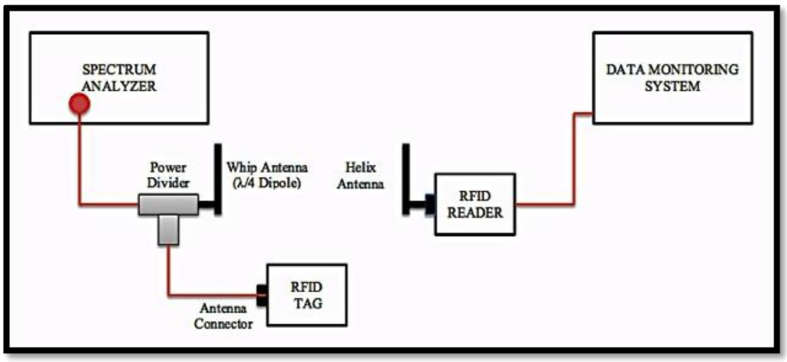

Figure 10: Calibration test setup

In addition to RFID tag, the active RFID reader is attached with 2.4 GHz Helical antenna that function as directional antenna radiating a beam off the ends of the helix, along the antenna's axis. The RFID reader is then connected to data terminal to receive data and extracts the RSS reading based on the received signal from the RFID tag under test. The tag's RF transmission power and RSS reading are measured at 5 meters distance between reader and tags and tag's power level are varied from level 4 (max) to level 0 (min), while the reader's power level is fixed at maximum level of power. The theoretical value for each power level is +10 dBm for level 4 and +2 dBm for level 0, respectively. The test further continued by increasing the distance between reader and tag from 10 meters to 60 meters distances with 10 meters increment to see the variation of RF transmission power and RSS reading at each distance.

3.2. Results and Discussion

During transmission and reception process, the amount of power transmission is equal to +7.799 dBm as shown in Figure 11 for ER2G system tag. The amount of transmission power captured is approximately half of the amount of actual transmit power transmitted by the tags. Therefore, the actual transmit power is equal to the amount of transmit power given by spectrum analyzer multiplied by two and added with 2 dBi gain for whip antenna used in this calibration test. The total amount of transmit power produced by the tag is +17.598 dBm which is more than theoretical value +10 dBm declared by [19]. The difference between actual and theoretical value is due to embedment method, which caused increment in the amount of current flow in the circuit and at the same time increase the amount of transmission power produced by the tag.

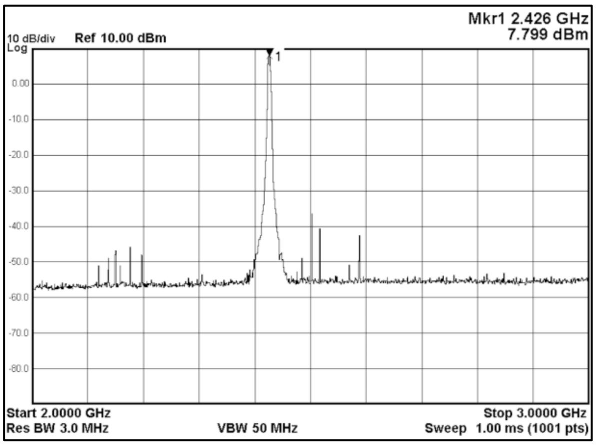

Figure 11: Transmit power at PL 4 for ER2G

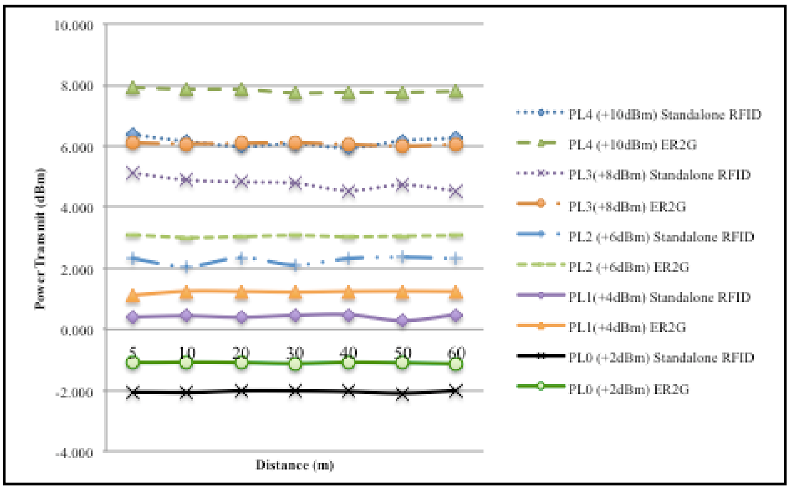

Figure 12: The transmit power of the tag at PL 4, PL 3, PL2, PL 1 and PL 0 settings

The calibration test results are further discussed by comparing the measured power transmission of both tag for PL 3, PL 2, PL 1 and PL 0 settings to see the variation. The result of Figure 12 indicates that the tag's transmission power decreases when the power level decreases. The average power transmission produced by the proposed ER2G system tag is 20.22 % higher than the standalone RFID systems. In addition to transmission power, the measured RSSI of both systems are visualised in the form of contour to see the variation of RSS in an actual environment. It is found that the RSS value changes when the power level changes and the proposed ER2G system provides better radiation performance than the standalone RFID system tags as shown in Figure 13. From this observation, it is concluded that the RSSI value decreases as the range increases and the power transmission is constant for all distances (5m-60m) and types of system. This finding is consistent with Horvat *et al.* [20], which indicates that the power transmission has a direct impact to the RSS value. The difference between transmit power produced by ER2G and standalone RFID tag is due to the embedded power management module implemented in the ER2G that produce stability of energy compared to standalone RFID tag as stated by Sorrells [21].

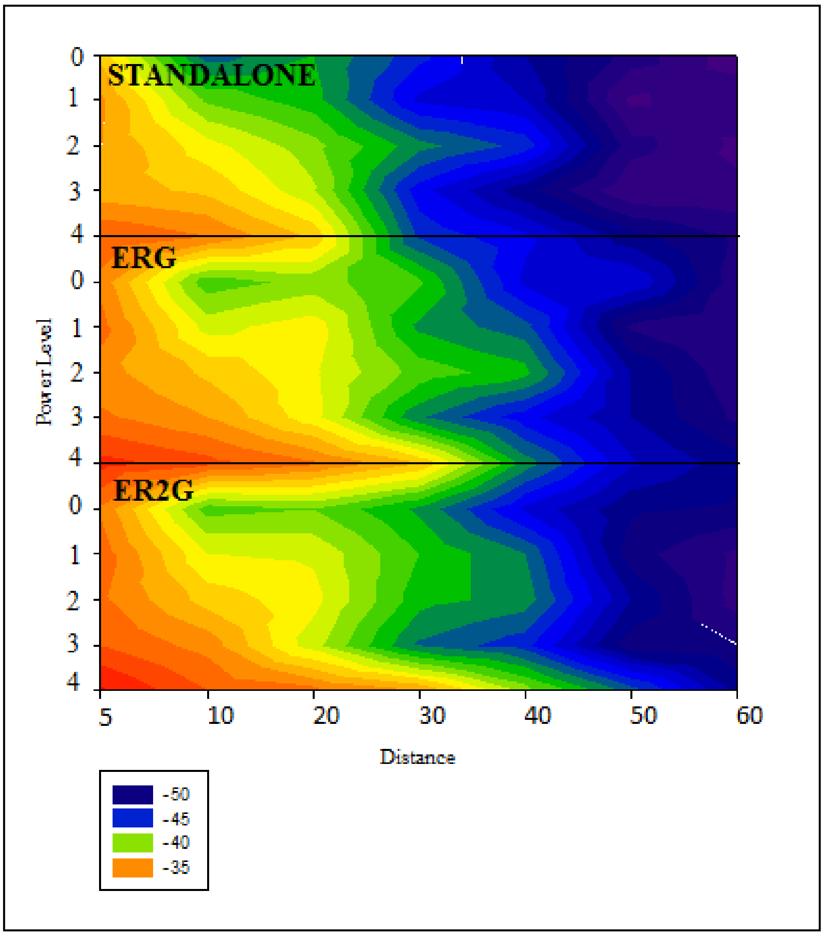

Figure 13: RSSI contour of three systems

4. Conclusion

The active RFID system for M2M indoor and outdoor location tracking and monitoring applications is successfully developed and implemented using embedded method. The effectiveness and performance of the developed active RFID system in terms of transmission power and RSS were evaluated by performing a calibration test. Each test had been repeated ten times for data analyzing purpose and the average of transmission power and RSS reading were calculated. The calibration test was conducted in the range of 5 m to 60 m distances due to limited space of indoor location. From the results, it was concluded that the transmission power of the developed ER2G at PL 4 was 12.26 % higher than standalone RFID tag at 5 m distances and it was constant at all distances (5m-60m). The transmission power were evaluated at different power levels (3, 2, 1 and 0) and the results were identical with PL 4, whereby the transmit power for ER2G was higher than standalone RFID tag and the result shows that the transmission power decreases when the power level decreases from level 4 to 0. The RSS reading were fluctuated at all distances and decreases when the range increases. Therefore, from the results obtained it was confirmed that the ER2G provides better performance than standalone RFID system tag in terms of transmission power and RSS, which can affect the maximum reading range between tags and reader in the network. Based on the results presented, it had been proven that the embedment method was capabled to improve RF transmission power and RSS reading, thus allow RFID system to work in long-range communication. The finding can be used by other researchers as a guideline for future development.

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