Performance Analysis of a New Mechanism of 2.4 GHz Embedded Active RFID Based WMSN Location Tracking and Monitoring System

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***Abstract*—This paper describes the experiments and analysis conducted on a new mechanism of 2.4 GHz embedded active Radio Frequency Identification (RFID) – Wireless Mesh Sensor Network (WMSN) 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 such as the Radio Frequency (RF) transmitting power, Received Signal Strength Indicator (RSSI), tags collection time (latency) and throughput to prove that the embedded active RFID tag is capable to provide better performance compared to standalone RFID tag. Experiments are carried out on three RFID tags which are active RFID tag embedded with Global Positioning System (GPS) and Global System for Mobile (GSM) (ERFIDG^2); active RFID tag embedded with Global Positioning System (GPS) (ERFIDG) and standalone RFID tag communicating with the same active RFID reader. The developed ERFIDG^2 contributes 9.14 % transmit power and 13.79 % RSSI reading higher than standalone RFID tag. In addition, the tags collection time (latency) is 7.14 % slower than the standalone RFID, while the throughput is 6.62 % lower than the standalone RFID over multihop communication. The results conclude that the ERFIDG^2 gives better performance compared to standalone RFID tag and can be used as guidelines for future design improvements.**

***Index Terms*—Active RFID; RSSI; GPS; GSM; Transmit Power; WMSN.**

I. INTRODUCTION

The US 20080030306 A1 [1] describes an active RFID device is a transceiver that comprises a transmitter, receiver and a microprocessor. The invention is used to predict the position of objects that are attached with RFID tag. However, the work is lack of information on how to track and monitor the objects indoor and outdoor. Another invention US 20090085745 A1 [2] explains the development of RFID tracking device that is capable of detecting the identification (ID) from the tag attach to an object and obtaining the coordinate of location provided by GPS receiver. Although the GPS working perfectly in outdoor environment, however, the performance is completely weak in indoor or at environment with obstacles. In addition, there are a lot of works focusing on designing an RFID system using active RFID for tracking purposes either in indoor or outdoor location [3-6], however, none of them has been done to track and monitor in both indoor and outdoor environments. Therefore, a proper solution is needed to extend the capabilities of a standard RFID system by introducing an embedded active RFID system with Machine to Machine (M2M) capabilities, which able to switch between two environments by incorporating active RFID, GPS and GSM technologies on a single platform working in WMSN environment as presented in [7]. The proposed system may contribute to an important technological opportunity that could provide companies or authorities with the full potential of both positioning technologies on the same platform. Table 1 shows the comparison with other patented system.

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
Radio frequency identification sensor tag apparatus (US 20080030306 A1) [1]	433 MHz active RFID	No	No	No	No	No	Yes	No	Yes
RFID tracker and locator (US 20090085745 A1 [2]	Near Field Communication (NFC)	No	No	No	Yes	No	Yes	No	Yes
Combination RFID and GPS functionality on intelligent label (WO2003050960 A2 [3]	Active RFID	No	No	No	Yes	No	Yes	No	Yes
Portable RFID reader having location determination (EP 1752908 A2/2006) [4]	Active RFID based on IEEE 802.11b Wireless Local Area Network (WLAN)	No	No	No	Yes	No (Tag-Reader) Yes (Reader-Work Station)	Yes	No	Yes
Hybrid tag includes active RFID, GPS, satellite and sensors [5]	433 MHz active RFID and Satellite Communication	No	No	No	Yes	No	Yes	No	No
Wireless sensor network for pilgrims tracking [8]	IEEE 802.16.4 protocol that support 315/433/868/915 MHz ISM/SRD bands	Yes	No	No	Yes	No	Yes	No	Yes
Proposed System [7]	2.4 GHz Active RFID-ZigBee Technology based on IEEE 802.15.4 standard and Mobile Communication	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Instead of embedding the GPS and RFID technologies, Wireless Sensor Network (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 increase 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 is 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 the previous system and the proposed system that are related to indoor and outdoor tracking and monitoring applications.

II. Development of Active RFID System

The proposed system presented in [7] is designed and developed by combining four technologies; 2.4 GHz active RFID, GPS, WSN ZigBee based IEEE 802.15.4 standard and GSM mobile communication with Tri-band frequencies 900/1800/1900 MHz on a single platform. A switching mechanism is proposed between active RFID and GPS tracking to locate the tag in indoor and outdoor environments. The proposed system provides M2M communication between tags-reader-tags that support mesh network topology and having mobile communication as an alternative communication during WSN network disruption. The system applies Tag Talk First (TTF) and Reader Talk First (RTF) protocols and AT/API modes of configuration during operation. There are three types of nodes implemented in the network, which are ZigBee End Device (ZED) as tags, ZigBee Router (ZR) as a router and ZigBee Coordinator (ZC) as a reader in the proposed system. The proposed system can be used for many applications such as to track and monitor vehicles, humans, logistics, assets and many more.

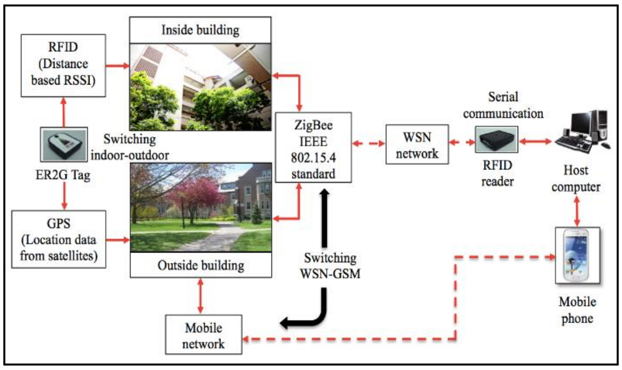


Figure 1: Active RFID system architecture

The overall architecture of the proposed system is shown in Figure 1, whereby the main hardware parts consist of the active RFID system components (reader, tags and routers) interacting with each other to track objects in indoor and outdoor environments.

III. Proposed Active RFID System Mechanism

Two important components that can be used to merge the physical and virtual world are RFID and WSN. The RFID based WSN system consists of 3 main parts, which are storing data, retrieving data and produce reliable data report. Basically, RFID tags receive the broadcast command from the reader having a waiting time before sending their own data identification response. However, in the proposed system, a new mechanism is introduced, whereby the broadcast command sent by the reader is based on transmit request command. Using this mechanism, tags will process the information after receiving the transmit request command from the reader and send the response via transmit request command back to the reader. A comparison of the standard and the proposed ERFIDG^2 system mechanism is presented in Figure 2, whereby the standard mechanism as shown in Figure 3 (a) having a longer packet (33 bytes) than the proposed mechanism (29 bytes) as shown in Figure 3 (b). The mechanism to identify tags is the same for the subsequent rounds. If the tag is identified by the reader, it will turn into duty cycle or sleep mode after receiving an acknowledgement packet from the reader. By using this mechanism, the recognition time between transmission and reception of the identification in the WMSN network for the proposed system is expected to be lower than the standard IEEE 802.15.4 system.

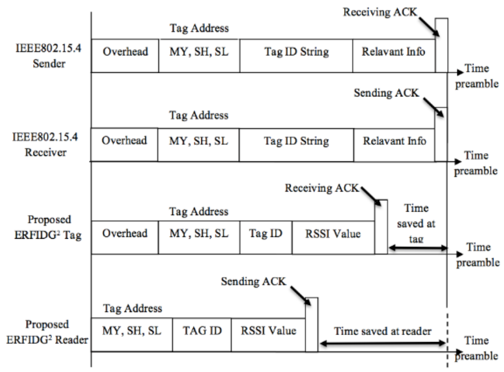
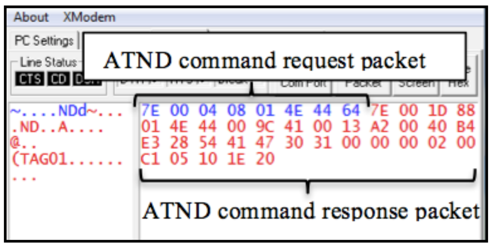
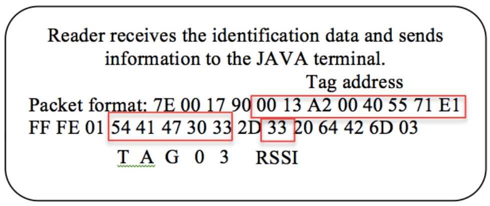


Figure 2: Comparison between IEEE 802.15.4 and proposed system (ERFIDG^2) system mechanism



(a)



(b)

Figure 3: (a) IEEE 802.15.4 mechanism (b) Proposed ERFIDG^2 mechanism.

IV. Measurement Setup

The capabilities of the proposed system tag with new mechanism is tested in terms of power transmission, Received Signal Strength Indicator (RSSI), tags collection time (latency) and throughput during transmission and reception processes. The measurements are performed in real-world indoor and outdoor environments within a specified read range for Point-to-Point (P2P) and multihop communication. The standard measurement setup for both P2P and multi-hop communications is shown in Figure 4.

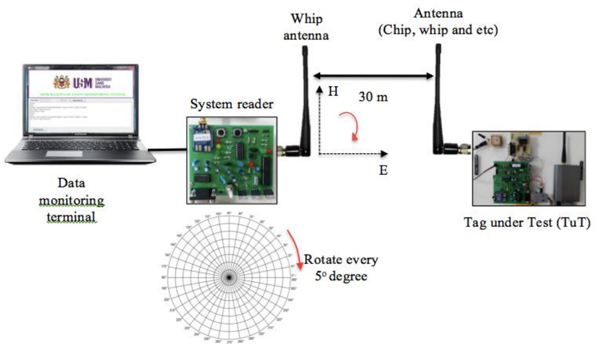


Figure 4: Standard measurement setup

V. Results and Discussions

The proposed system (ERFIDG^2) uses AT command request and response function to perform the mechanism using AT or API mode. Therefore, it is important to analyze the performance of the proposed system in terms of tags collection time (latency) during the transmission and reception of the AT command request and response function using both AT and API modes. A comparison with other types of system (ERFIDG tag and standalone RFID) was made to benchmark the performance.

A. Power transmission and Received Signal Strength Indicator (RSSI)

Figure 5 shows the measured power transmits of both types of standalone RFID in comparison with the ERFIDG and the proposed ERFIDG^2 system tags for verification. The average power transmit produced by the proposed ERFIDG^2 system tag is 0.67 % and 9.14 % higher than the ERFIDG and standalone RFID system.

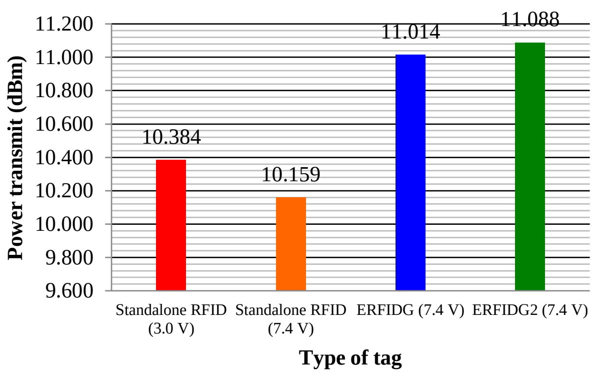


Figure 5: Power transmission of the tag under test (TUT)

The measurement is further extended to obtain the RSSI value of three systems from 5 m to 60 m during data reception at the system reader. Figure 6 shows the measured RSSI value of the ERFIDG^2 (proposed system tag) is better than the ERFIDG and standalone RFID by 7.41 % and 13.79 %. From the observation, it is concluded that the RSSI value decreases when the range increases. This finding is consistent with [9], which indicates that the power transmits has a direct impact on the RSSI value. The higher the power transmission, the higher the RSSI value.

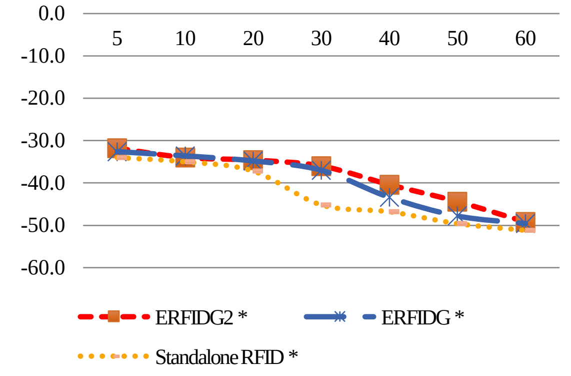


Figure 6: Measured RSSI value

B. Tags Collection Time (Latency)

The experiment was conducted based on Design of Experiment (DoE) factorial analysis method with two factors; (i) type of mode (AT and API) and (ii) type of RFID (ERFIDG^2 tag, ERFIDG tag and standalone RFID tag). The response is the time taken by the tags to process the AT command request and response starting from sending a packet from a reader, tags receive and process the requested data, send the response to reader and turn to sleep mode (round trip time). Two-Way ANOVA is used to analyze the data and the results are described in Table 2. From the table, it can be seen that the P-value is less than 0.05 with 95% reliability, which indicates that the type of mode is significantly affected by the tags collection time.

Table 2
Two-Way ANOVA: Time versus Mode, Circuit

Source	DF	SS	MS	F	P
Mode	1	11616.0	11616.0	291.95	0.000
Type of RFID	2	2626.8	1313.4	33.01	0.000
Error	20	795.8	39.8		
Total	23	15038.5			
S = 6.308 R-Sq = 94.71 % R-Sq(adj) = 93.91 %					

The results are further explained in Figure 7, whereby the tags collection time is plotted over the type of mode. The time taken by the API mode is about 0.391 s, which is 10.11 % faster than the AT mode per round trip time. This is due to the less processing time during transmission and reception since in AT mode the application must enter AT command mode, change the address and exit command mode to transmit data [8]. In addition, the new mechanism introduced also contributes to the less processing time during transmission and reception. A similar finding is obtained in [10], in which the implementation of AT command in the RFID system design contributes to increase the processing time. Due to this reason, the API mode was chosen as a primary communication mode for the proposed system.

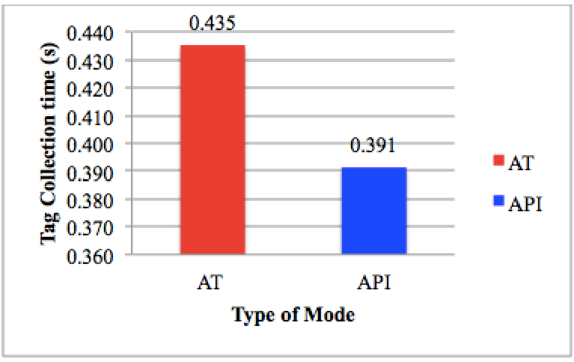


Figure 7: Tags collection time comparison (a) AT and API mode

The experiment is further extended for a single tag in single hop environment using the same DoE factorial analysis method. The command was broadcasted from the reader once in a minute and was repeated for thirty times. Meanwhile, the measurement was replicated eight times to maintain the validity and reliability of the round trip time. In this experiment, One-Way ANOVA was used to analyze the output and the findings were summarized in Table 3. According to the results, the P-value is lower than 0.05 with 95% reliability, which indicates that the tags collection time is statistically significant with type of system, whereby the mean tags collection time measured for ERFIDG^2 tag is 1.63 % faster than ERFIDG tag and 0.28 % slower than the standalone RFID tag as shown in Figure 8. Each RFID system is provided with 48 bytes of data packet including the payload. Even though, the proposed ERFIDG^2 system was developed by combining 4 technologies on a single platform that is controlled by a single controller. The system is still able to provide faster tag recognition time as fast as standalone RFID system.

Table 3
One-Way ANOVA: Tags Collection Time

Source	DF	SS	MS	F	P
Type of RFID	2	203.1	101.5	5.37	0.013
Error	21	396.8	18.9		
Total	23	599.9			
S = 4.347	R-Sq = 33.85 %	R-Sq(adj) = 27.55 %			

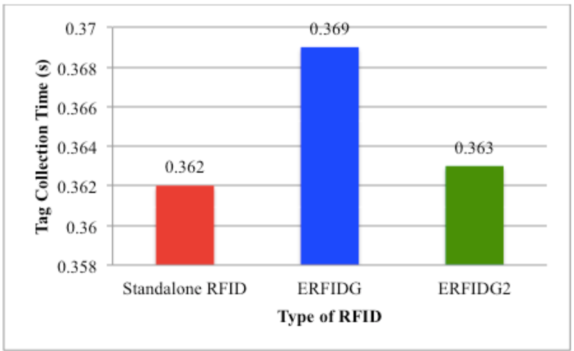


Figure 8: Single tags collection time (P2P)

The experiment was repeated for multiple tags in the multihop environment. According to Figure 9, the mean tags collection time for the proposed ERFIDG^2 system utilize 0.404 seconds to complete the round trip of multiple tags transmission, which is 2.97 % faster than ERFIDG tags. The tags collection time increases when the number of hops increases. The average latency of the proposed system is 0.105 s, while 0.106 s and 0.098 s per-hop transmission for ERFIDG and standalone RFID system. Generally, the tag implies an interrupt function to receive the broadcasted command from the reader. All the current operation performed by the tags must be held after receiving the interrupt signal to respond to the reader command. In order to hold the current operation, the tags must complete the cycle of the previous operation as stated in [11]. This process will cause an increment of tags collection time especially when multiple technologies are integrated together with the tags. Therefore, it can be concluded that the standalone RFID system having faster tags collection time than the proposed ERFIDG^2 system due to the less processing time needed during interruption process.

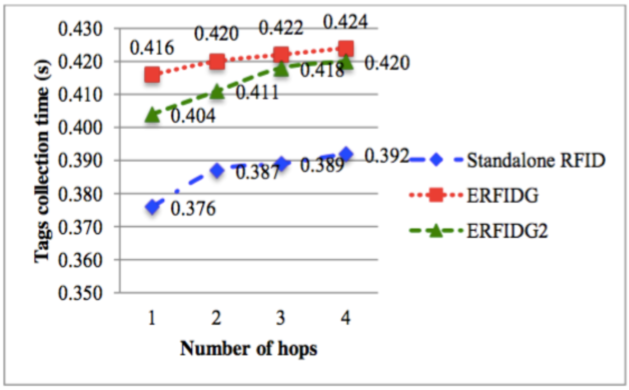


Figure 9: Multiple tags collection time in WMSN environment

C. *Throughput Evaluation*

Throughput is defined as the rate of successfully read message, which is measured in bytes per second [12]. Throughput is calculated as the total packet size divided by the total receiving time, while the interval between the transmissions is the period between the end of successful transmission of the previous message and the start of the next message [13].

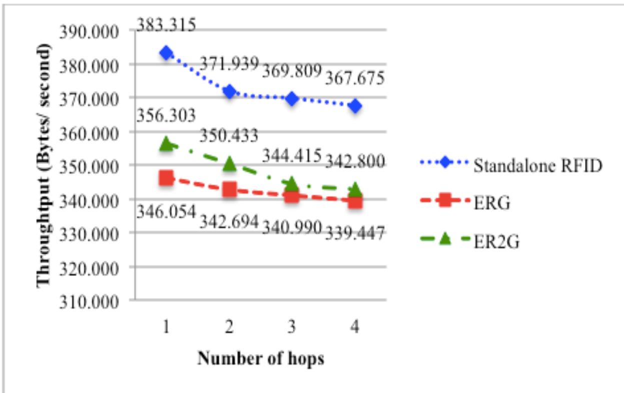


Figure 10: Throughput evaluations in WMSN environment

Generally, the proposed system communicates using the IEEE 802.15.4 ZigBee standard for PHY layer, which supports 84 bytes as the maximum number of RF payload [8]. The data transfer rate of the radio is 250 Kbps and the time for sending one byte over the radio is approximately 8bit/250 Kbps = 32 μs. The data packet size is equal to 48 bytes including payload per round trip transmission. Based on the characteristics given, the throughputs of the proposed system over 4 hops decrease by 3.79 % over 4 hops with 1.81 % higher than the ERFIDG system and 6.62 % lower than the standalone RFID system as shown in Figure 10. The results are consistent with [14] which indicates that the throughput drops as the number of hops increases and the throughput is lower due to the higher in tags collection time (latency). Even though the throughput of standalone RFID is better than the proposed system, however, the deficiency can be balanced with the functionality available in the proposed system.

VI. Conclusion

The performance of the developed active RFID system is predicted by measuring the tags collection time using AT and API mode in a single hop and multi-hops environment. The measurement of tags collection time was conducted in the real-world exemplary environment for all conditions. The result was compared with standalone RFID and ERFIDG system to show the variation of the tags collection time before and after the embedment. In the first measurement involving AT and API mode of communication, the API mode was proven to be faster than AT mode in terms of processing time, thus making it suitable for the application that needs real-time data transmission and reception. In the second measurement, the tags collection time of the proposed system almost has the same performance as standalone RFID system, even though, the proposed system has longer data packet (48 bytes) than the standalone RFID system (29 bytes). From the results obtained, the proposed system was proven to be effective in creating new wireless active RFID system for real-time M2M indoor and outdoor location tracking and monitoring applications and the findings can be used by other researchers as a guideline to enhance the active RFID system for future development.

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