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Link Quality of Wireless Household Energy Meter with an Embedded RFID in LOS Indoor Environment

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Abstract The data monitoring system using radio frequency identification (RFID) and automatic identification and data capture (AIDC) technologies[3] have become pervasive applications. They have the potential in providing indoor monitoring and location services. The aim of this study is to analyze the radio wave propagation based on the received signal strength indication (RSSI) value versus the various distances compared between the proposed embedded RFID tag with and without the household energy meter for LOS indoor environment. In the proposed RFID communication system, Zigbee[4] (IEEE 802.15.4) protocol is applied to monitor and read the data from the remote energy meters in the residences. Embedding a monitoring RFID tag module into the energy meter with a power management (without battery cell) is able to communicate with a reader at a RF signal of 2.45 GHz. The location of RSSI testing is carried out at a narrow area inside a building and compared with a wide area at a library's hall for testing distances up to 90 m with 10 m increment in each test. The transmitted power is working at the maximum range of 18 dBm to link a wireless communication between the reader and embedded part of end tag. The results indicated that the proposed wireless monitoring RFID tag module with an embedded energy meter proved that a RSS values (received power) are higher in average by 2.503% in wide area, and 3.050% in narrow area than the one without the embedment (standalone active RFID) with no difference of reliability at statistical significant of 95%. This means that the embedment of the proposed RFID system into an energy meter can

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extend the communication range compared to the standalone RFID since the power management circuitry is able to improve the stability of power supply for RFID transmission directly from the energy meter.

Keywords RFID · AIDC · RSSI · WSNs · LOS · Zigbee · Energy meter

1 Introduction

Recent evolutions in the electronics and wireless communication technologies have significantly lowered down the cost of miniature embedded devices provided with a few capabilities. Such advancements in technology have made pervasive monitoring and tracking applications which are cost-effective in small-scale deployments and wide-scale scenarios where data must be collected in hundreds of different locations [1, 2].

RFID is a wireless identification technology, applied in a variety of applications. It is used mainly to monitor and track objects, whereas Wireless Sensor Network (WSN) is used to sense parameters in the environment. Both technologies serve in the local physical space layer. Other than that, the connection from the physical space to the virtual space is necessary and it is usually done via the internet [3]. Since both the identity and location information can be provided, therefore it has the potential for providing indoor tracking/location services. The integration of the promising technologies of RFID and WSNs will maximize their effectiveness, give new perspectives to a broad range of useful applications, and bridge the gap between the real and the research worlds. This is because the integrated technology obtained from the results of research will have extended capabilities, scalability, and portability as well as it can reduce unnecessary costs [4, 5]. The RSSI-based measurement has been researched for analyzing the performance of link quality in indoor environment, such as a RFID-based indoor guidance and monitoring system [6]. A real-time big data gathering algorithm based on indoor wireless sensor networks for risk analysis of industrial operations [7]. It also enhanced the long-range wireless sensor networks for geo-location tracking: Design and evaluation [8].

In this paper, the RFID tag embedded with energy meter for LOS indoor environment is tested for the link quality based on RSSI values. Zigbee-based sensor network employed in this study, is operated at a frequency of 2.4 GHz, low power, low data rate (for up to 250 kbps) and used the wireless technology for RSSI-signature-based indoor localization. The link quality performances are analyzed between the proposed and standalone RFID systems (without interfaced to a power meter).

The remaining of this paper is organized as follows. Section 2 describes the principle, which is divided into two parts consist of RSS ranging and RSS indoor environment. Section 3 presents research methodology and Sect. 4 shows the measurement results. Finally, the conclusions are summarized in Sect. 5.

2 Principles

In this part, the principle of RSS ranging in an indoor environment is presented as in the following sections.

2.1 RSS Ranging

The strength of the received signal power can actually be used to estimate the distance between them. All electromagnetic waves have an inverse-square relationship between received power and distance [8] as shown by the following expression:

$$\Pr \propto \left\{ \frac{1}{d^2} \right\} \tag{1}$$

where P_r is the received power at a distance d from a transmitter. This expression has clearly stated that the distance of signal travelled can be found by comparing the difference between transmission power and received power, or it is called as the "*path loss*".

In practical measurement, the increment of path loss due to the increment of distance may be different when it is in different environment conditions. This leads to an environmental characterization using the attenuation or path loss exponent n as shown by the following expression (2) [9] in Fig. 1:

$$\Pr = \frac{P_{(d_0)}}{\frac{d}{d_0}} \tag{2}$$

where $P_{(d0)}$ is the received power measured at distance d_0. Generally, d_0 is a fixed value of 1.0 m. In case the increment of path loss is more drastic when the distance increases, the value of path loss exponent n would be larger. Figure 1 shows the top solid blue line indicates the attenuation or path loss of $n = 2.0$ followed by the other non-solid lines which indicate the attenuations when n is more than 2.0.

The measurement of the received power is just an auxiliary function. The measured received power may not be exactly the in dBm. Therefore, the RSSI is chosen to represent the condition offset calibration to the correct level, which is generally implemented in most of the wireless communication standards. The obtained RSSIs are converted to digital values and processed by a controller for data acquisition.
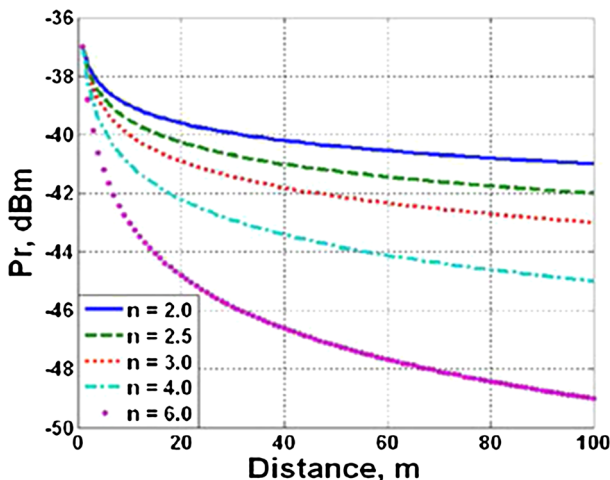
Fig. 1 The effects of attenuation or path loss exponent n [9]

Table 1 Various factor for indoor location tracking

Issues	Factors
Path loss	Affected by multi-path and shadowing
Accuracy	Difficult to achieve but important (small space)
Space	Small and mostly rectangular
Deployment	Can be planned
Transmission power	Adjusted to avoid interference
Height of reference nodes	Ceiling
Map	Local

2.2 RSSI Measurement in Indoor Environment

The RSS ranging is able to effectively analyze the differences between standalone active RFID and the household energy meter with embedded RFID. They were tested in narrow and wide areas at LOS indoor environment. The RSSI performances are totally different for the indoor and outdoor locations, whereby they are able to easily simplify the complexity of a system and improve the estimation method in the indoor environment compared to the outdoor one. The factors that affect the RSS testing for the indoor environment are shown in the Table 1 [10].

3 Research Methodology

In this part, the methodology when applying RSS ranging in the indoor environment is presented as details in the following sections.
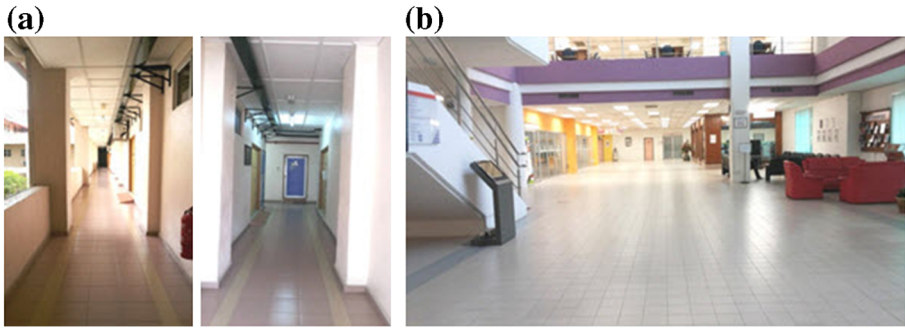
3.1 Location of RSS Testing

The RSSI values involved two locations were tested in the narrow and wide hall areas, which are inside a building. The aim of this study is to analyze the RF signal strength of the proposed active RFID with embedded energy meter in comparison to the standalone RFID.

The comparison of the proposed RFID embedded an energy meter and the standalone RFID one in the narrow and wide areas because the study requirements of various factors, such as the path loss, accuracy, area, deployment transmission power and height of reference nodes.

Figure 2a and b presents the testing location, which including of narrow area of 2.0 m width and wider area in a library building of 12.0 m width. Both locations were tested by using the proposed modules in the same range of distance from 0.0 to 90.0 m with an increment of 10.0 m for each data collection.

3.2 RSSI Measurement Step

The RSSI values were tested and collected from the reference sensor nodes. Practically, the RSSI value is not exactly the received power at the RF pins of the radio transceiver. Therefore, it has to be converted to the actual power values in dBm using the following expression (3) [9]:

Fig. 2 The location of RSSI testing **a** *Narrow area* with the width of 2.0 m in the LOS indoor environment **b** *wide space* area with the width of 12.0 m in the LOS indoor environment

$$P_i = \left(RSSI_i + RSSI_{offset} \right) \tag{3}$$

P_i: The actual received power from beacon node i.$RSSI_i$: The measured RSSI value for reference node i stored in the RSSI register of the radio transceiver.$RSSI_{offset}$: The RSSI offset found empirically from the front end gain.

The $RSSI_{offset}$ was set to be approximately equal to -45 dBm. This was performed to make sure that the actual received power value has a dynamic range from -100 to 0 dBm.

3.3 Experimental Setup

The RSSI testing between the RFID end tag and the reader was setup in two arrangements, which were the RFID tag module embedded into an energy meter and the standalone RFID as shown in Fig. 3a and b.

The proposed RFID system is designed to read the power consumption of an energy meter which can be interfaced for the other universal energy meters. On top of this, it can identify a particular energy meter in case there are several meters present in the testing area. The RFID tag modules functioned as a wireless sensor network that monitored the value of energy meter and transmitted data by the RF signal of 2.45 GHz to the reader at
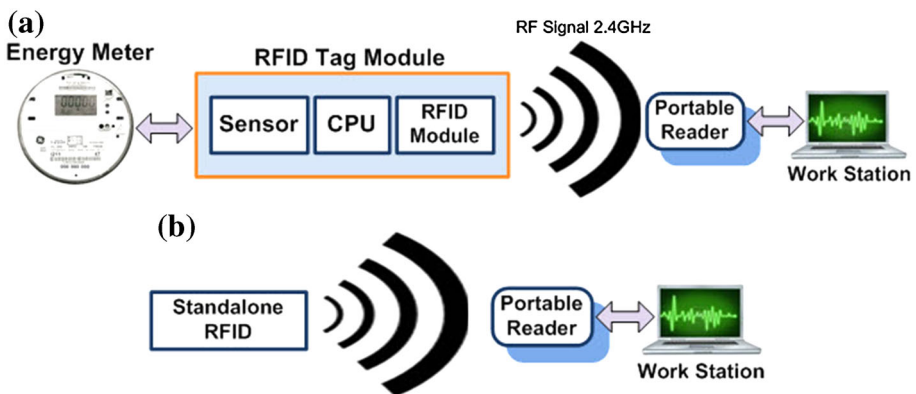
Fig. 3 **a** Proposed RFID system embedded with a household energy meter. **b** Standalone RFID system

the maximum transmission power of 18 dBm. Since ZigBee Pro Series 2 (IEEE 802.15.4 standard) is employed, the RSSI can be measured in the intermediate frequency stage, which is before the intermediate frequency of an amplifier or in the baseband stage of a circuit. The obtained results are recorded to show the condition of the received power level at a distance d from the end part of the tag module to the reader. After that, the processor or microcontroller with a built in analog-to-digital converter (ADC) converted it to the digital value. This value is then stored in a register of the controller for a quick data acquisition [10].

4 Measurement Results

The measurement results of this study are divided into three activities, such as A) active RFID tag embedded with an energy meter for LOS indoor environment test B) standalone active RFID without an energy meter and the last C) performance analysis. The contented results are detailed as the following.

4.1 Active RFID Tag Embedded with Energy Meter for LOS Indoor Environment

Figure 4 shows the experimental results for the link quality performance of the proposed RFID system embedded with energy meter. They are collected in terms of RSSI testing for a wide area in indoor environment.

The RSSI measurements are all taken at an increment of 10.0 m from 0.0 m to 90.0 m. The measured RSSI means (dBm) are −48.30, −53.20, −59.00, −60.80, −64.20, −69.20, −73.90, −75.80 and −78.50 dBm, respectively. The finding indicated that the signal strength is slightly decreased, whenever the distance between a tag and a reader is far
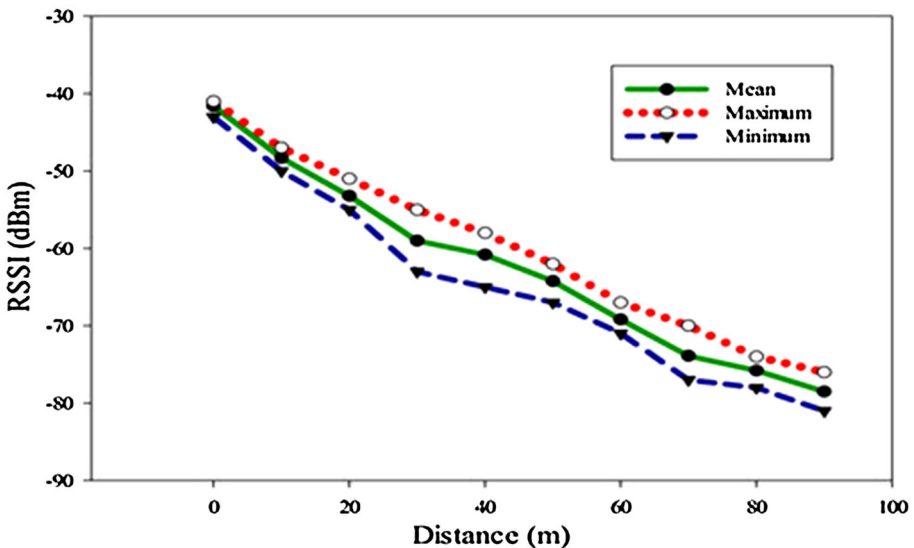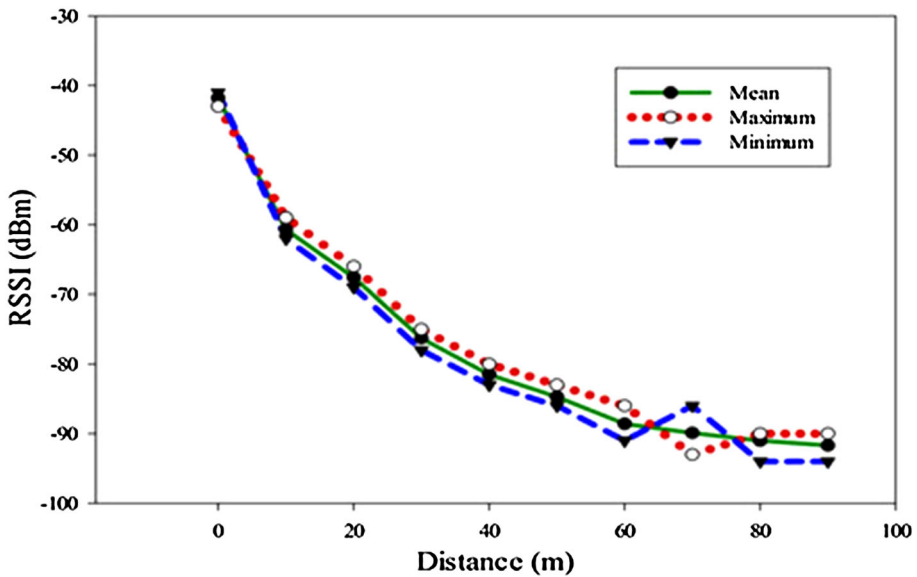

Fig. 4 RSSI of data transferring in a wide area (proposed RFID system)

Fig. 5 The RSSI of data transferring in *narrow area* (proposed RFID system)

away. Moving to the next results tested in the narrow area, which is shown in terms of graphical as in Fig. 5 below.

Figure 5 indicates the RSSI versus the various distances for the proposed energy meter embedded with RFID tag in narrow area. The RSSI testing were taken at an increment of 10.0 m from 0.0 m to 90.0 m. Then, the obtained RSSI means (dBm) are -60.7, -67.60, -76.30, -81.50, -84.70, -88.60, -89.90, -91.00, and -91.70, respectively. By the obtained RSSI results are indicated that the signal strength decreased, whenever the distance between tag and reader increased, which is consistent as the results obtained from Fig. 4, but only the proposed RFID system in the wide area had RSSI higher than testing results in narrow area. The finding proved that the obtained results are consistent with the theory. Namely, the quality of wireless RF communication affected from an attenuation or path loss of real environment such as a wall, neighboring object or interfering signal, reflection, scattering and other physical properties on RSSI measurement [8, 12] and also can use RSSI value measured for distance estimation in WSNs [13]. However, the proposed RFID tag system embedded into an energy meter still can be used inside a building both narrow and wider areas with no difference in RSSI obtained at statistical significant of 05 (reliability of 95%).

4.2 Standalone Active RFID Without an Energy Meter

In this section, the proposed standalone RFID system is tested based on RSSI of a wireless data transferring without embedded into an energy meter. This link quality is analyzed by the signal strength of standalone RFID without energy meter at LOS indoor environment. The RSSI measurement results are shown in Fig. 6.

Figure 6 displays the RSSI versus the various distances for standalone RFID system without an embedded energy meter, which is tested at wide area. The RSSI measurements
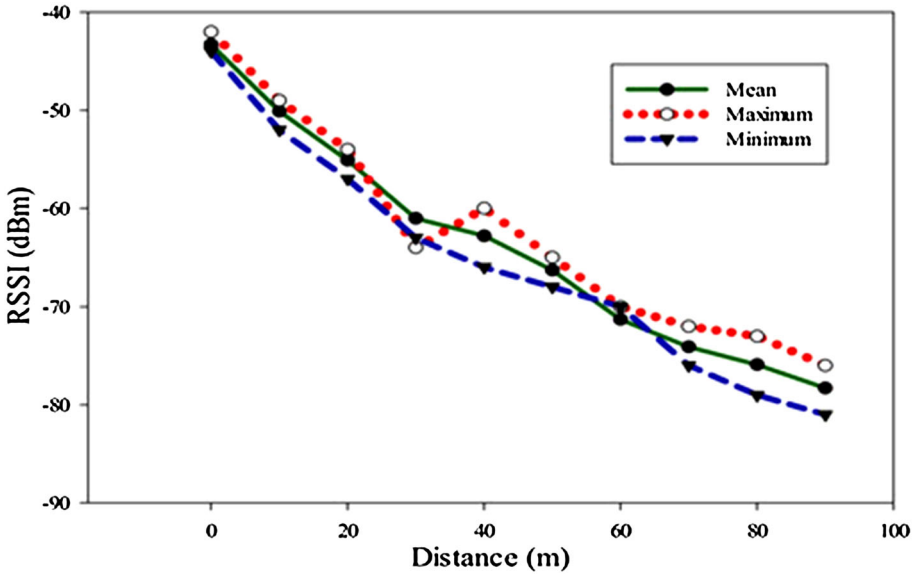
Fig. 6 The RSSI of data transferring in *wide area* (standalone RFID)

were all taken at an increment of 10.0 m from 0.0 to 90.0 m and the obtained RSSI means (dBm) were 43.30, −50.10, −55.10, −61.00, −62.80, −66.30, −71.30, −74.10, −75.90 and −78.30, respectively. The results indicated that the RSSI values are slightly decreased, whenever the distance of the end device and the reader tags are placed away.

Figure 7 indicates the obtained RSSI results versus the various distances for standalone RFID without embedded energy meter at narrow area. The RSSI measurements are −43.40, −62.80, −69.90, −78.70, −84.10, −87.40, −91.20, −91.70, −93.20 and −94.30, respectively.

The results indicated that the RSSI value decreased, whenever the distance between tag and reader increased. Both results obtained from Figs. 6 and 7 supported the hypothesis made by the results provided by Figs. 4 and 5 as mentioned above. The wireless RF Signal communication through the medium in the air affected from the various parameters, which are mentioned as above [8, 12]. In addition, it found that the standalone RFID system had quality of RSS in wide area higher than narrow area with no difference in mean RSSI obtained at statistical significant of 05 (reliability of 95%).

4.3 Performance Analysis

The performance analysis in this section is done by compiling all results from Figs. 4 to Fig. 7. The overview of the obtained results shown that the household energy meter embedded with RFID tag had higher RF signal link quality than the provided standalone RFID system both at wide and narrow areas based on LOS at indoor environment testing. Table 2 shows that the mean of RSSI values versus various distances from 0.0 to 90.0 m for both conditions.
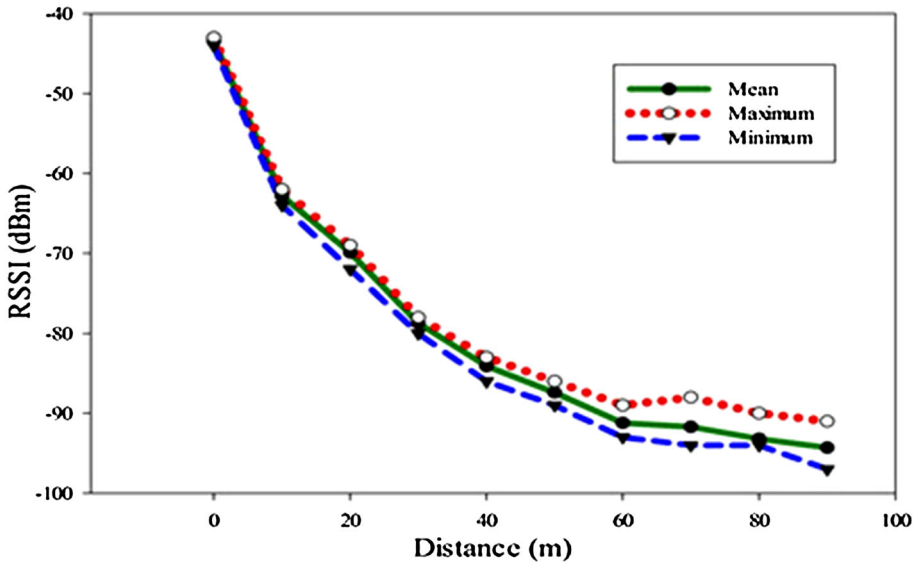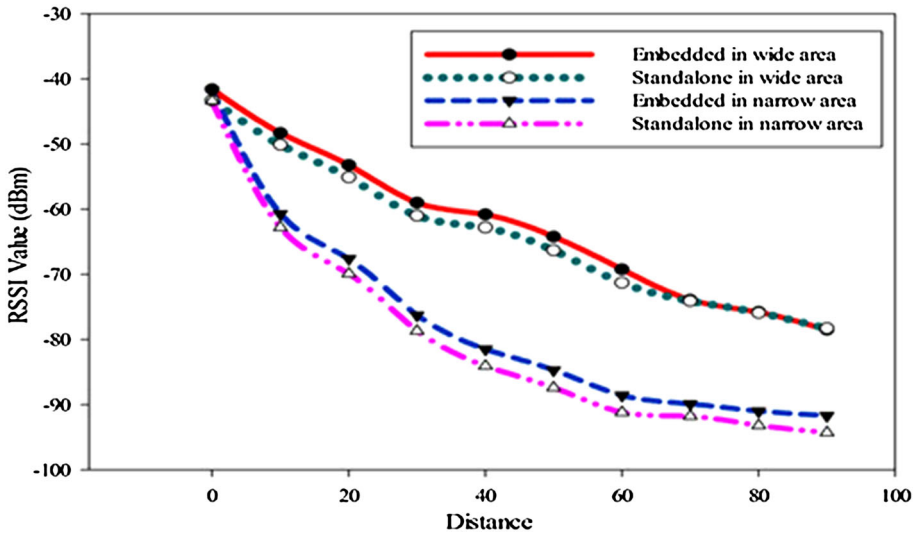
Fig. 7 The RSSI of data transferring in *narrow area* (standalone RFID)

Table 2 Comparison of the mean RSSI value between standalone RFID and household energy meter embedded with RFID tag in LOS indoor environment

Distance (m)	Mean RSSI value (dBm)				RSSI difference (dBm) between embedded and standalone			
	Wide area		Narrow area		Wide area		Narrow area	
	Embedded	Stand alone	Embedded	Stand alone	|D|	%D	|D|	%D
0	−41.60	−43.30	−41.80	−43.40	1.70	4.087	1.60	3.828
10	−48.30	−50.10	−60.70	−62.80	1.80	3.727	2.10	3.460
20	−53.20	−55.10	−67.60	−69.90	1.90	3.571	2.30	3.402
30	−59.00	−61.00	−76.30	−78.70	2.00	3.390	2.40	3.145
40	−60.80	−62.80	−81.50	−84.10	2.00	3.289	2.60	3.190
50	−64.20	−66.30	−84.70	−87.40	2.10	3.271	2.70	3.188
60	−69.20	−71.30	−88.60	−91.20	2.10	3.035	2.60	2.935
70	−73.90	−74.10	−89.90	−91.79	0.20	0.271	1.89	2.102
80	−75.80	−75.90	−91.00	−93.20	0.10	0.132	2.20	2.418
90	−78.50	−78.30	−91.70	−94.30	0.20	0.255	2.60	2.835
Average					1.41	2.503	2.30	3.050
Reliability of 95% at statistical significant level of 0.05					0.859		0.970	

It can be concluded that the testing done in wide and narrow areas, the energy meter embedded with RFID tag had higher RSSI than the standalone RFID. The comparison is summarized by the RSSI mean difference in dBm, which is shown in Table 2 and

Fig. 8 The RSSI of data transferring for the proposed RFID system embedded with an energy meter compared to the standalone RFID at wide and narrow areas

supported by results obtained from the statistics. The finding indicated that the energy meter embedded with RFID tag modules has higher mean of RSSI value than the standalone RFID within the range of 0.10–2.10 and the mean of RSSI value of 1.41 dBm (2.503%) at P value of 0.859 for the wide area testing and it is within the range of 1.60–2.70 with the RSSI mean value of 1.41 dBm (3.050%) at P-value of 0.970 for the narrow area testing. Hence, there is no difference at significant statistical of 0.05 (reliability of 95%) for both environments.

In addition to this, a comparison of RSSI performance between the testing conducted at wide and narrow area found that the RSSI efficiency at wide area showed higher quality of signal strength of 19.92% than at narrow area. The data is portrayed as in Fig. 8.

Figure 9a and b shows the differences in magnitude of RSSI of a mean value and b percentage. It indicated that the embedded RFID tag with an energy meter has higher mean RSSI value than the standalone RFID in both tested condition.

However, the demonstration of the results is analyzed by using the SPSS statistic. It was found that the difference has no difference at significant statistical of 95% reliability.

Another matter is also discussed about comparison of the proposed RFID system and the developed standalone RFID. The energy meter embedded with RFID tag has RSS values higher than standalone RFID tag by 2.503 and 3.05 0% at wide and narrow areas with the same condition tested at indoor environment. The proposed RFID system with built-in power supply management is taking the source of power from the energy meter side, which directly drove the DC portion of the RF module compared to conventional design using the external battery that actually powered up the provided standalone active RFID. Hence, the obtained results indicated that the performance obtained could be impacted by the power supply source management, which is very important in driving performance of circuit stability.
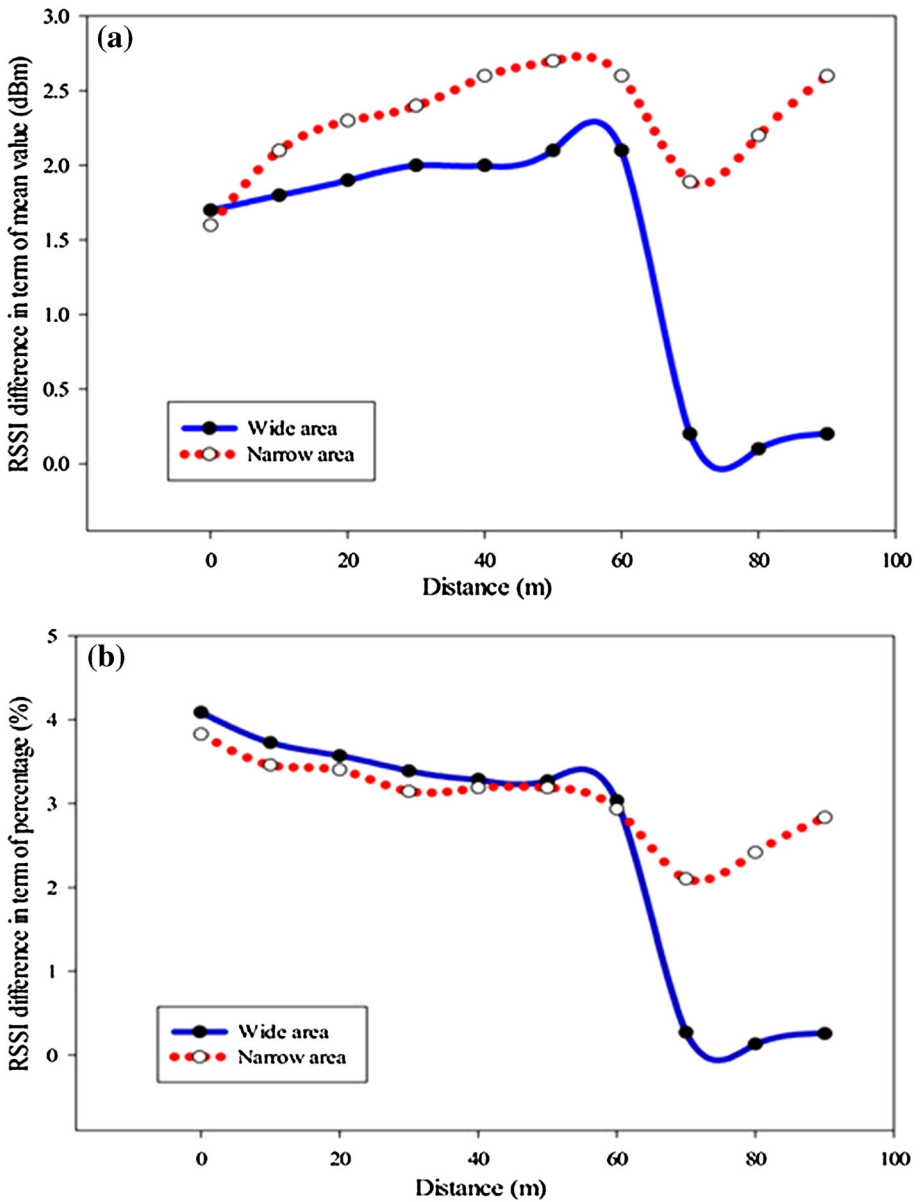
Fig. 9　a Comparison in magnitude for averaged RSSI values in both conditions. b Percentage comparison of RSSI magnitude in both conditions

5 Conclusion

In this paper, the household energy meter with an embedded RFID tag for indoor environment and characterization based on RSS performance are presented. The measurements testing were comprised of wide and narrow areas for LOS indoor environment, which later

compared the received power performance to the developed standalone RFID tag. The findings indicated that the household energy meter with embedded RFID tag had higher received powers than the standalone RFID by 2.503 and 3.050% at wide and narrow areas, respectively with no difference of statistical significant by 0.05.

Apart from this, the power source management of WSN node is very important to be discussed. The information of the power source management can be used by a wide range of wireless communication network, which can effectively route the data within the network to fully maximize the whole network lifetime. The proposed RFID tag managed the power management circuit by taking the DC voltage source from the energy meter. By doing this, it supported the possibility to apply the power supply source of active RFID tag based on Zig Bee Protocol from a single source. Therefore, the novel methods for adopting the embedded design according to the available source of power were proven through research.

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