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A NOVEL ADAPTIVE WI-FI SYSTEM WITH RFID TECHNOLOGY

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Abstract—A novel adaptive Wireless-Fidelity (Wi-Fi) system is the combination of radio frequency identification (RFID) technology, programmable intelligent microcontroller development board (PIDB) and reconfigurable antenna with beam shape characteristics. The system is capable to sustain a Wi-Fi signal adaptively above its threshold level (−81 dBm) within a range up to 100 m across three different buildings with variety indoor environments and floors. It is found that the modified ground reflection model has successfully predicted the total path loss of the test-bay buildings which consist of corridors, several floors and windows. The modified propagation model is extremely crucial in determining the projection and height of

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reconfigurable antenna to efficiently cover the scattered measurement points across the three buildings. The need of comparable signal strength is compulsory since the signal strength between 2.4 GHz of reconfigurable beam shape antenna and 0.433 GHz of RFID tag is different within the same distance. When reconfigurable beam shape antenna radiates with a minimum gain of 4.85 dBi, the measured signal strength shows that most of the measurement points are below Wi-Fi's threshold level which is from −69.001 dBm to −115.4530 dBm. However, the proposed system is able to boost all the signal strength above the threshold level with three different gain of reconfigurable beam shape antenna, 7.2 dBi, 9.9 dBi and 14.64 dBi through the activation of mobile RFID tag at different measurement points at one time. The boosted signal strengths are within the range of −69 dBm to −73.056 dBm. The capability of the mobile RFID tag in producing certain level of signal strength has been successfully exploited as a wireless stimulator for the system to adaptively activate certain PIN diode switches of reconfigurable beam shape antenna in this finding. The proposed system also has a great potential in realizing a new smart antenna system replacing the conventional switching beam array (SBA) antenna.

1. INTRODUCTION

The novel adaptive system is realized by four major components: RFID tag, low power data radio modules (LPDRM), PIC development board (PIDB) and reconfigurable beam shape antenna [1] which functions as the stimulator, RFID reader, control unit and directive radiating antenna respectively. The measurements are carried out in different environments such as corridors, floors and windows across the three different buildings with different structures and stories. In order to verify the best route of excellent signals at every measurement point, an accurate model is crucial to estimating the path loss and signal strength across the test-bay buildings [2, 3].

The Ground Reflection (Two-Ray) propagation model and Rappaport's model are considered to be deployed in this research. However, Rappaport's model neglected the effects of corners, walls and windows on the buildings [2, 6]. Meanwhile, the Ground Reflection model had been focusing on diffraction and reflection signals which have been disregarded by the Rappaport's model [4, 5, 7, 8]. Still, the same issues were neglected in Rappaport's model. For this reason, the conventional Ground Reflection (Two-Ray) propagation model has been modified by adding the effects of corners, walls and windows to eventually obtain more accurate path loss prediction compared to the previous models. Hence, the new Ground Reflection model has the capability to assess the diffraction and reflected signals within the buildings, around the buildings corners and penetration through the windows.

Conventionally, Wi-Fi uses an adaptive bandwidth modulation and unfixed levels of forward error correction (FEC) to optimize transmission rate for better performance [9–11]. However, other than expensive system to be deployed, the interference effects such as shadowing and multipath could deteriorate the speed of Wi-Fi signals [12]. The front-end transmitter which is an antenna might be a beneficial replacement for the conventional system to optimize and extend the transmission rate and coverage areas. Wi-Fi system usually uses an omni-directional antenna to radiate its beam equally in all directions with the same signal strength [12, 13]. Unfortunately, this antenna enables the end-user to receive the Wi-Fi signals up to only 20 m in range. A single-directional antenna indeed can be used to increase the signal strength by projecting the main lobe to the desired direction. However, Wi-Fi signal decreases quadratically as distance increases at constant radiation levels [14]. Hence, the dynamic beam shape reconfigurable antenna might be favorable. With the assistance of radial line slot array (RLSA) antenna that has a property of high gain, Wi-Fi signals are expected to achieve a greater range up to 100 m.

In [15, 17–22], received signal strength indicator (RSSI) is a parameter that has been used in predicting the location of wireless device in Wi-Fi positioning systems. To the authors' knowledge, none of these designs has demonstrated an adaptive Wi-Fi system using a combination of RFID technology with reconfigurable beam shape antenna controlled by PIC microcontroller.

Typically, RFID technology is specialized and created for the security purpose. However, this novel system uses the RSSI bytes of a

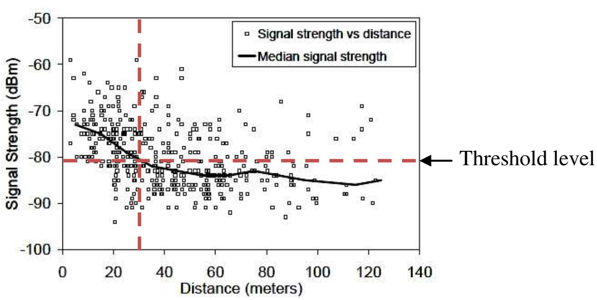
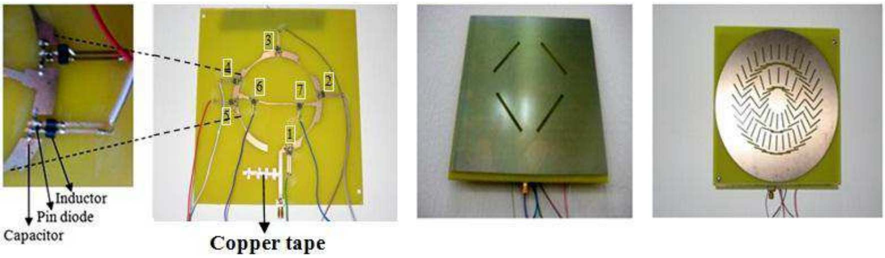


Figure 1. Wi-Fi signal strength over distance [14].

mobile RFID tag as significant stimulator to stimulate the PIN diode switches of reconfigurable beam shape antenna to sustain the Wi-Fi's threshold level. The signals which are below the threshold level will not be received or experience from slow or dropped internet connections. Another advantage of the proposed system lies in its cost effectiveness since it does not require expensive digital signal processor (DSP) as the platform to execute an adaptive bandwidth modulation functions. Moreover, this combination produces a mobile and less complexity with the deployment of RFID tag and PIDB.

2. RECONFIGURABLE BEAM SHAPE OF RLSA ANTENNA (R-RLSA)

The reconfigurable radial line slot array antenna (R-RLSA) is used as reconfigurable beam shape antenna in this research as shown in Figure 2. The reconfigurable antenna is made up two types of switches, which are the end-fire beam shaped reconfigurable switches (EBRS) and broadside reconfigurable switches (BRS). In Figure 2(a), the first up to the fifth switches being the EBRS, while the other switches that are not pointed out make up the BRS. However, the research focuses only on the EBRS, and the BRS of no significant effects could be ignored. This antenna originally operates at frequency of 2.3 GHz [1]. Hence, the copper tape is applied to the feed to allow the operating frequency shifted to 2.4 GHz as shown in Figure 2(a). The configuration of the EBRS switches is shown in Table 1. The EBRS switches are then connected to the output ports of PIC microcontroller through port B0 up to port B5 as shown in Figure 3.



(a) (b) (c)

Figure 2. The reconfigurable beam shaped antenna [1], (a) feed line with PIN diode switches, (b) aperture slots, (c) RLSA radiating surface.

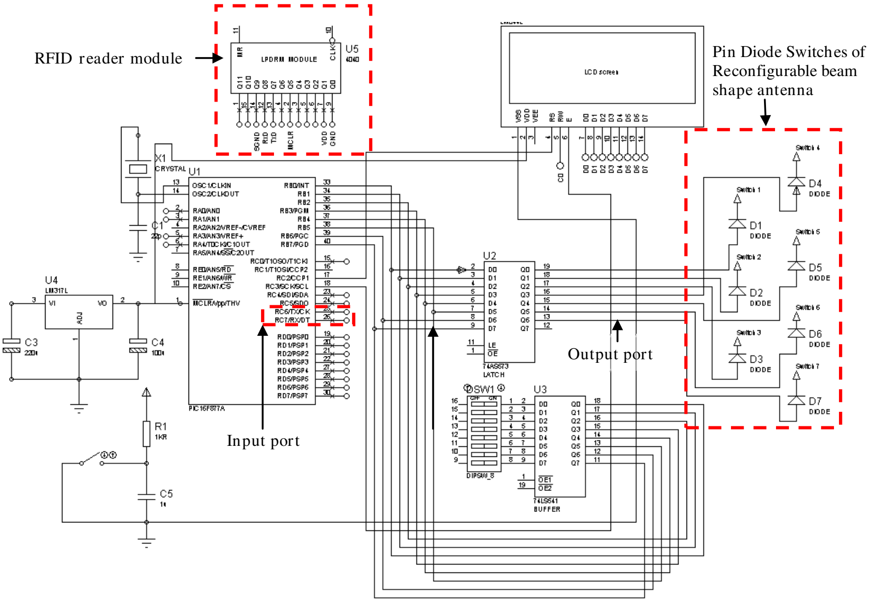


Figure 3. The schematic of Integration RFID technology and R-RLSA antenna into PIC Development Board (PIDB).

Table 1. Configuration of reconfigurable beam shape antenna [1].

Type of switch	Number of PIN diode switch	PIN diode status			
End-fire beam-shaped reconfigurable switches (EBRS)	i	ON	ON	ON	ON
	ii	OFF	ON	ON	ON
	iii	OFF	OFF	ON	ON
	iv	OFF	OFF	OFF	ON
	v	OFF	OFF	OFF	ON
Gain (dBi)		**4.85**	**7.2**	**9.9**	**14.64**
HPBW(°)		**−65° to 70°**	**−40° to 45°**	**−15° to 20°**	**−10° to 15°**

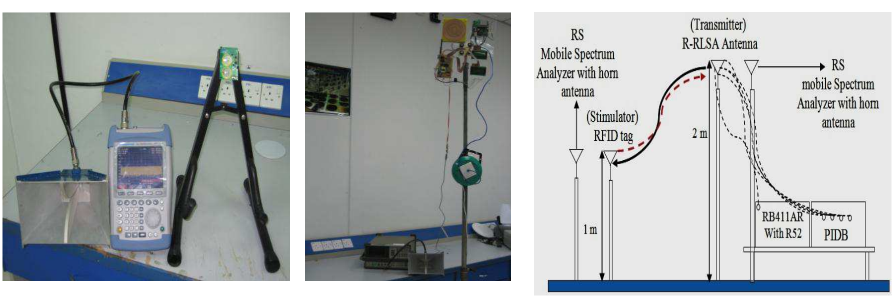
3. ADAPTIVE WI-FI SYSTEM

In Figure 3, the control unit which is PIDB is developed by several electronic components such as PIC microcontroller, crystal clock oscillator, voltage regulator, latch, buffer, capacitors, transistors, diodes, resistors and liquid crystal display (LCD). The RFID reader is interfaced with the PIC microcontroller using the universal synchronous and asynchronous receiver/transmitter (USART) protocol through an input port of C6 and C7 as shown in Figure 3. The protocol is required to act as a medium in ensuring the communication link existing between the two types of devices. Figure 3 also demonstrates that the R-RLSA's PIN diode switches are connected to port B0 up to port B7 of PIC microcontroller through the latch component.

4. MEASUREMENT SETUP

A Rohde & Schwarz (RS) wireless mobile spectrum analyzer with horn antenna is deployed as a device to verify the strength of incoming signals from the R-RLSA antenna and RFID tag as shown in Figure 4(a) and Figure 4(b). The measurements are performed at frequencies of 2.4 GHz and 0.433 GHz for R-RLSA antenna and RFID tag respectively. All devices are located at the base station except the RFID tag and another RS spectrum analyzer which are located at each of the measurement points.

The R-RLSA antenna is fed by micro-miniature coaxial, MMCX connector of MikroTik Router-Board, RB411AR while its PIN diode switches are connected with PIDB as shown in Figure 5. The Router-Board has an integrated 802.11 b/g wireless card with mini PCI slot occupied by R52H modulation radio. The modulation radio is designed to operate in 802.11 b/g standard protocol at frequency range of 2.192 GHz up to 2.507 GHz and able to support bandwidth up to 54 Mbps. RFID unit consists of the RFID tag and RFID reader. The



(a) (b) (c)

Figure 4. Measurement setup at (a) Measurements point. (b) Base station. (c) Graphical setup.

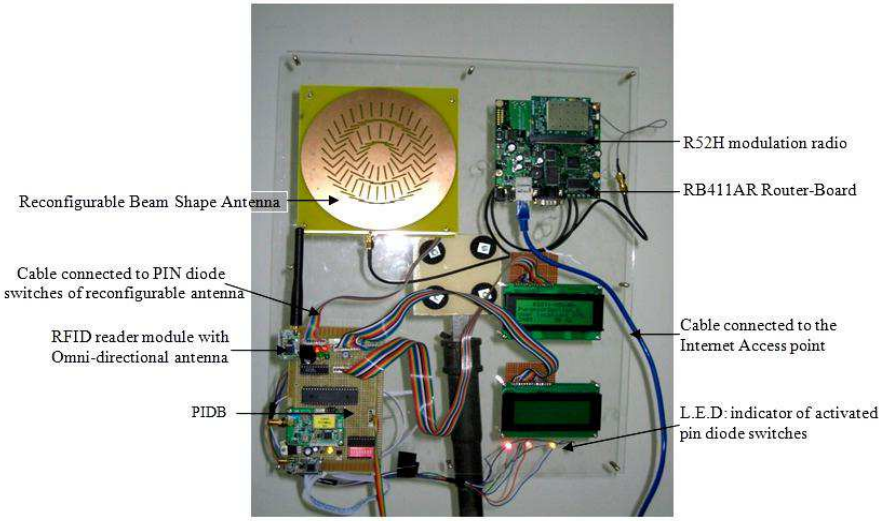


Figure 5. Complete prototype of adaptive Wi-Fi system.

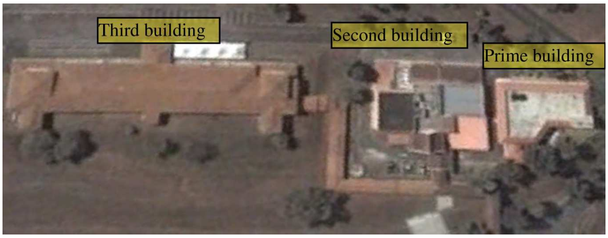


Figure 6. Test bay buildings.

tag is a wireless mobile active transmitter which is capable to emit the received signal strength indicator (RSSI) signals while the LPDRM module with omni-directional antenna acts as a reader of that RSSI signals. The RFID tag conserves a maximum power up to 10 mW or 10 dBm.

In Figure 4(c), the R-RLSA antenna height is fixed at 2 m above ground on the second floor of the prime building. The inside and outside walls of the three buildings, primer, second and third buildings, are constructed of concrete as shown in Figure 6. The RFID tag and mobile RS spectrum analyzer are moved to the measurement points as shown by yellow circular dots in Figure 7. The system is tested by taking 20 measurements of RSS within 100 m of ranges. There are glass windows and doors along the corridors and inside every lecture

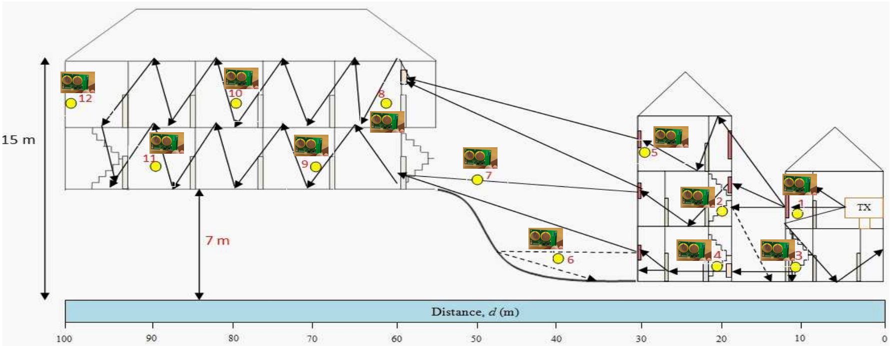


Figure 7. Measurement points of test-bay buildings model with RFID tag.

halls as shown in Figure 7. All windows and doors are closed during the measurements.

The original Ground Reflection (Two-Ray) propagation model in [4] has been modified with adding effects of the walls, glasses, and floors as depicted by Equation (1) to predict the path loss attenuations. The coefficients of walls, glasses and floors for the specified buildings are defined as $T_{wall} = 2.2\,\text{dB}$, $T_{glass} = 0.25\,\text{dB}$ and $T_{floor} = 13.0\,\text{dB}$ [2].

$$P_L = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r + T_{wall} + T_{glass} + T_{floor}) \quad (1)$$

Equation (2) will be used to calculate the signal strength for both devices; RFID tag and R-RLSA antenna, once the path losses, have been determined by using Equation (1).

$$\mathbf{P}_R = \mathbf{P}_T + \mathbf{G}_T + \mathbf{G}_R - \mathbf{P}_L \quad (2)$$

where $\mathbf{P}_R$ = Received power, $\mathbf{P}_T$ = transmitting power, $\mathbf{G}_T$ = Gain of transmitting antenna, $\mathbf{G}_R$ = Gain of receiving antenna (Horn antenna), $\mathbf{P}_L$ = Path loss.

5. RESULT AND DISCUSSION

The objective of this novel system is to sustain 2.4 GHz Wi-Fi signal strength adaptively above its threshold level which is −81 dBm across the three different buildings with different structures and stories as shown in Figure 7. As previously mentioned, the original beam shape antenna in [1] is operating at 2.3 GHz. However, by deploying the copper tape with dimension of 18 mm × 35 mm in width and length, the copper tape has behaved as a capacitor for the operating frequencies of this antenna shifted to ≈ 2.4 GHz as shown in Figure 8.

The effects of the walls, glasses and floors on Wi-Fi path loss across the three different buildings are verified using Equation (1) and then compared to the measured value as shown in Figure 9(a) and Figure 9(b). It can be seen that the predicted path losses have provided a good agreement with the measured lines. However, the path losses of these two components are obviously different where the base station states the path loss between 40.415 dB to 111.524 dB. Meanwhile, the RFID tag path loss is laid between 22.219 dB to 62.481 dB at the same measurement points. This is due to the higher operating frequency of 2.4 GHz at base station resulting in higher losses compared to 0.433 GHz of RFID tag. The modified path loss model has proven that the walls, glasses and windows are the dominant effects on propagation for the test-bay buildings. Once the path loss has been determined,

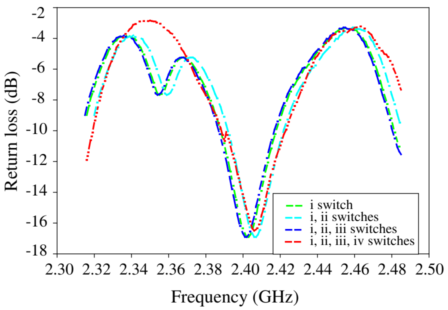


Figure 8. Return loss of R-RLSA antenna with copper tape.

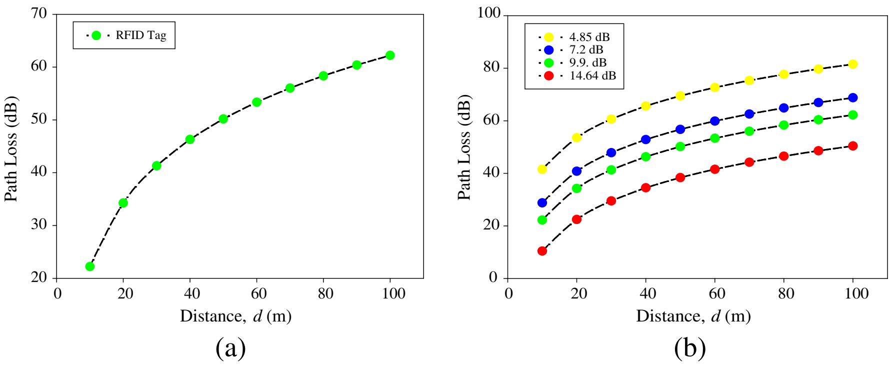


Figure 9. Calculated path loss (a) RFID tag, (b) R-RLSA antenna at base station.

Equation (2) will be deployed to calculate the RSS signals and compare it with the measured signals of R-RLSA antenna and RFID tag. The calculated signals strength almost has the same figure as the measured lines as shown in Figure 10, Figure 11(a) and Figure 11(b). Moreover, it is found that 2 m and 1 m heights for the R-RLSA antenna and RFID tag respectively are the optimum heights to obtain excellent signals strength and path losses prediction.

The difference in operating frequency and transmitting power between RFID tag and base station contributes to the different path losses and signal strengthes at the same measurement points. Investigation on signal strength is crucial for both components to find comparable values at each measurement point to sustain the RSS signals adaptively above the threshold level. The measured signal

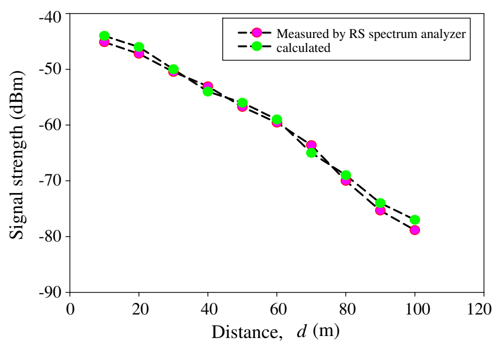


Figure 10. Measurements of signal strength of RFID tag.

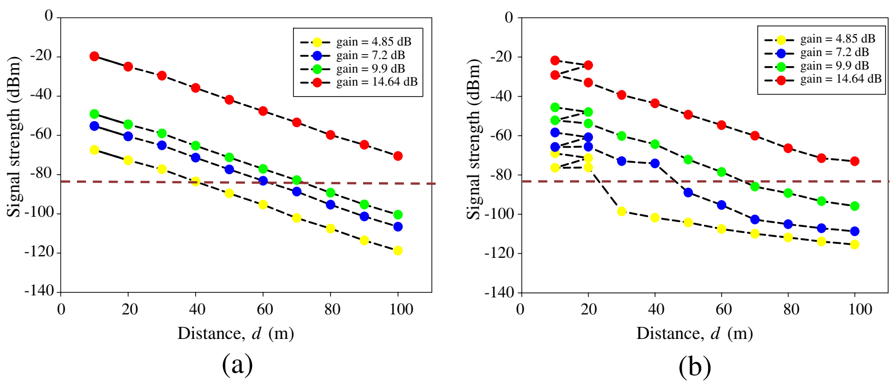


Figure 11. Signal strength of R-RLSA antenna (a) calculated, (b) measured.

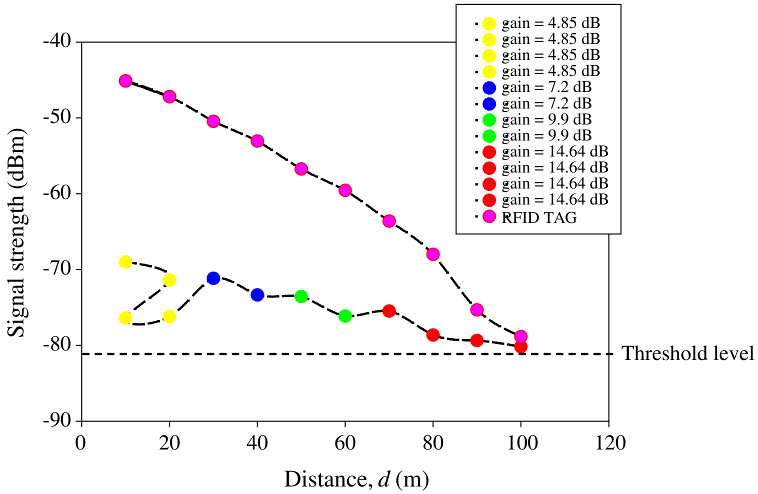


Figure 12. Signal strength measurements of the base station after activation of RFID tag.

strengths of RFID tag are laid between −45.13 dBm and −78.86 dBm as shown in Figure 10. Meanwhile, the measured signal strength of R-RLSA antenna startes at default gain of 4.85 dBi. The same procedure will be followed by a gain of 7.2 dBi, 9.9 dBi and 14.64 dBi.

In Figure 11(b), the default gain of R-RLSA antenna (4.85 dBi) has been achieved in sustaining the threshold level from point 1 up to point 4 with RSS signals of −69 dBm, −71.4 dBm, −76.39 dBm and −76.221 dBm. The RSS signals are going down below the threshold beginning from point 5 up to point 12 with RSS between −98.56 dBm and −115.453 dBm. Meanwhile, the 7.2 dBi gain has covered up to point 6 from the base station with signal strength from −58.437 dBm to −74.1980 dBm. However, it is recurring to decrease below the threshold when it comes to point 7. Signal strength of −45.6380 dBm to −78.5310 dBm has been obtained for point 1 up to point 8 when the R-RLSA antenna is producing a gain of 9.9 dBi. However, the signals have returned to decreasing lower than the threshold starting with point 9 to point 12. The signal strength of −21.7950 dBm up to −73.0560 dBm is stated from point 1 up to point 12 when it is measured with a gain of 14.64 dBi. It is found that a gain of 14.64 dB has not produced the RSS signals below the threshold level at all measurement points. All the RSS signals are summarized in Figure 11(b). Table 2 shows comparable values between the RFID tag and R-RLSA antenna based on the measurements obtained from Figure 10 and Figure 11.

Table 2. Comparable table of RFID tag and R-RLSA antenna.

Distance (meter)	RSS of RFID tag, dBm (measurement)	Gain of R-RLSA antenna, (dBi)	R-RLSA antenna PIN diode switches	RSS of R-RLSA antenna, dBm (measurement)
10	−45.13	4.85	1st	−69.001
20	−47.21			−71.4021
10	−45.13			−76.3906
20	−47.21			−76.221
30	−50.46	7.2	1st and 2nd	−71.1624
40	−53.06			−73.3612
50	−56.74	9.9	1st , 2nd and 3rd	−73.5594
60	−59.57			−76.143
70	−63.62	14.64	1st, 2nd, 3rd and 4th	−75.482
80	−68.01			−78.6418
90	−75.33			−79.3649
100	−78.86			−80.18

In order to realize an adaptive system, the PIC microcontroller is programmed to be sensitive in detecting any changes of RSS signals received by omni-directional antenna of RFID reader. Consequently, when certain RSS signals 'flow' from antenna into their module (RFID reader), the range of the RFID tag is automatically detected by the input ports of PIC microcontroller. Once the range of the tag is known, the PIC microcontroller will adaptively responde by activating the PIN diodes of R-RLSA antenna based on Table 1 through its output port B0 up to port B4.

The descended lines of RSS values show that all the measurement points are below the threshold level (−81 dBm) over 100 m of range except point 1, point 2, point 3 and point 4 as shown in Figures 11(a) and 11(b). It means that the signals have been deteriorated by the effects of the walls, windows and floors from −98.5620 dBm of point 5 down to −115.453 dBm of point 12 at transmitting gain of 4.85 dBi with HPBW of 135°. Once this condition is detected by the Wi-Fi's signal detector, the RFID tag is activated to emit the RSSI signals to the base station. Certain RSS signals of RFID tag adaptively activate certain PIN diode switches of R-RLSA antenna through the coding burned in the PIC microcontroller based on Table 2.

In Figure 12, the proposed system has covered up to 40 m ranging from the base station with a gain of 7.2 dBi, a beamwidth of 85° and

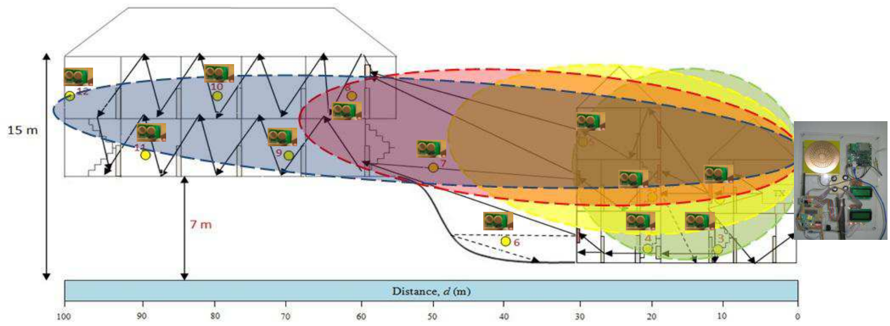


Figure 13. Illustration of adaptive Wi-Fi system using RFID tag.

signal strength from −58.4370 dBm to −74.1980 dBm, when the RFID tag is activated at point 1 up to point 6. An increment of gain up to 9.9 dBi, signal strength of −45.6380 dBm to −78.5310 dBm and a narrower beamwidth of 35° are obtained within a range of 60 m by activating the RFID tag at point 7 up to point 8.

Meanwhile, the 14.64 dBi gain has covered up to 100 m of range and a beamwidth of 25° when the tag has been activated at points 9, 10, 11 and 12 with signal strengths of −60.0790 dBm, −66.4370 dBm, −71.4942 dBm and −73.0560 dBm respectively. It is proven that the system is capable to increase the signal strength above the threshold level to receive the 2.4 GHz Wi-Fi signals at all points: point 1 up to point 12 as shown in Figure 12. Figure 13 illustrates the capability of an adaptive Wi-Fi system to intelligently cover a 100 m of range.

6. CONCLUSION

In this work, a novel adaptive Wi-Fi system with RFID technology and R-RLSA antenna is proposed. The PIDB is designed to connect those devices through the input and output ports of the PIC microcontroller's USART protocol to interface with the RFID tag and RFID reader. The modified ground reflection path loss model is used to predict the path loss over three different buildings with different indoor and outdoor environments. It is found that the windows, walls and floors have significant effects on signal propagation based on the modified ground-reflection model. The path loss in base station and RFID tag are laid between 40.415 dB to 111.524 dB and between 22.219 dB to 62.481 dB respectively at the same measurement points. It is realized that higher operating frequency of 2.4 GHz at base station resulting in higher signal losses compared to 0.433 GHz of the RFID tag. The measured signal strength shows that most of the measurement points are below the Wi-Fi's threshold level when R-RLSA antenna radiates with a minimum gain of 4.85 dBi. Via activation of RFID tag at different measurement points at one time, the proposed system is able to bring all the signal strengths above the threshold which is -81 dBm with three different gains of R-RLSA antenna: 7.2 dBi, 9.9 dBi and 14.64 dBi. Obliquely, the capability of the mobile RFID tag in producing certain level of RSSI signals to the base station is exploited as a wireless stimulator to adaptively activate certain PIN diode switches of R-RLSA antenna. It is proven that this novel system is capable to sustain a Wi-Fi's signals above -81 dBm across three different buildings with different structures and floors within a range up to 100 m. Moreover, the height and projection of the R-RLSA antenna are decided through the modified model to allow the best coverage signals of the test-bay buildings. It is also credited to the RFID technology with mobile RFID tag in realizing the adaptive mobile Wi-Fi system. With all the capabilities that have been demonstrated, the proposed system has a great potential as another alternative to conventional switching beam array (SBA) antenna.

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