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Signal Detection Scheme in Ambient Backscatter System With Multiple Antennas

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ABSTRACT The ambient backscatter technique is a communication technology that uses ambient radio frequency signals to enable battery-free devices to communicate with other device. This paper proposes the ambient backscatter technique using multiple antennas. Since the tag only plays a role of reflecting signals, a signal is transmitted with a power allocation in the case of multiple antennas. At the receiving end, the higher power signal is detected first via the received signal. Next, signal from other antenna is detected by using the first detected signal. Since the backscatter technique generally uses energy detection, it has a low data rate using a single antenna. The proposed method can obtain a higher data rate than conventional methods by using multiple antennas. Also, it can be usefully used for the Internet of Things system, which requires high data rate through the proposed backscatter method.

INDEX TERMS Ambient backscatter, multiple antenna, IoT.

I. INTRODUCTION

Recently, the Internet of Things (IoT) connects all devices including existing equipment to the network. Also, the IoT needs connection of many devices to the network [1]. To widely realize the IoT vision, the IoT has several requirements [2], [3].

First, the IoT communication must have sufficient throughput and range. The IoT wireless communication must be at least a few Mbps or more with an uplink at a distance of 1 to 5 meters. Second, the IoT devices must have a low power design. The IoT devices should not replace or use the battery for a long time. In a recent study, it is ongoing to harvesting power from ambient radio frequency (RF) sources such as TV and cellular signals. Third, the IoT devices need to reuse ambient signals. The IoT devices need transmission of data on the ambient signal. For example, when the Wi-Fi access point (AP) generates a signal, the IoT device can send its own data using the ambient Wi-Fi signal.

Ambient backscatter system is a suitable system for the IoT [4]. In the backscatter system, the tag collects ambient RF signal for energy harvesting [5], [6]. Also, the tag transmits data to the reader by using ambient signal from the RF source. When the tag transmits a signal, it distinguishes '0' or '1' by reflecting the ambient RF signal. The tag dose not reflect the signal when sending '0', but the tag reflects the signal when sending '1' for distinguishing the signal. Therefore, at the receiver, the received power is used to determine the bit [7], [8].

This paper provides a new ambient backscatter system based on Wi-Fi. In the conventional Wi-Fi backscatter system, the tag sends signals by distinguishing between '0' and '1' with one antenna. Therefore, the conventional backscatter system has the disadvantage of having a low data rate. This paper proposes a Wi-Fi backscatter system that the tag can use multiple antennas. The proposed scheme reflects signals from two antennas with different powers and transmits data. At the receiver, a signal having higher power than the received signal is detected first. Then, the signal from the other antenna is detected by using the first detected signal. Therefore, the proposed scheme can obtain a higher data rate than the conventional scheme.

II. AMBIENT BACKSCATTER SYSTEM MODEL

Fig. 1 shows the ambient backscatter system model. The ambient backscatter system is composed of the three devices such as RF source, reader and backscatter tag. In the Fig. 1, the RF source means the Wi-Fi AP. The reader is a device that supports Wi-Fi and receives signals from backscatter

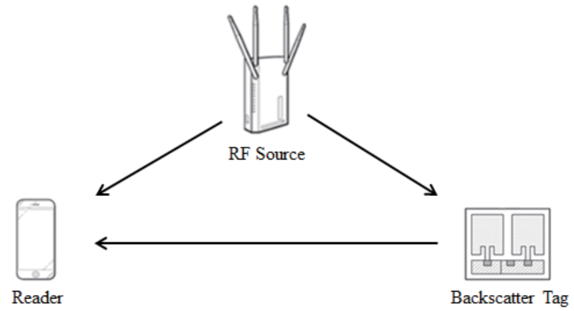

FIGURE 1. Ambient backscatter system model.

tag. This paper considers IEEE 802.11n among the Wi-Fi protocols. On the other hand, tag without batteries dose not support protocols such as Wi-Fi. The tag only reflects the received signal from the Wi-Fi AP for communication.

The Wi-Fi AP transmits the Wi-Fi packets to reader and backscatter tag. The tag harvests the energy via the Wi-Fi packets because the tag can not decode the information of Wi-Fi packets. The tag reflects the Wi-Fi packet if the transmission data is ‘1’ and it dose not reflect if it is ‘0’. The reader uses the power of the signal received from the tag to determine the bit [9]. Therefore, the communication performance of the backscatter system depends on the influence of noise between the reader and the tag.

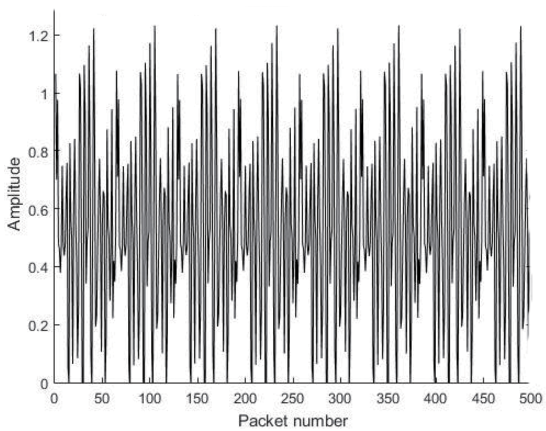

FIGURE 2. Amplitude of received signal in reader in the case of message 1010101010.

Fig. 2 shows the received signals from a backscatter tag in reader. The Wi-Fi packet has the symbol duration of $50\mu s$. At the receiver, not only the tag signal but also the AP signal is added to the received signal. The reader determines the threshold value with the received signal. And, the reader decides the bit ‘1’ or ‘0’ by using the threshold value. The state information of the channel between reader and backscatter tag is obtained by channel state information (CSI) or received signal strength indicator (RSSI). The received signal is written as follows,

$$y_R(t) = x(t)h_{ar}(t) + \alpha\{(x(t)h_{at}(t))h_{tr}(t)\} + n(t), \qquad (1)$$

where $y_R(t)$ denotes the received signal at the receiver and $x(t)$ is a signal transmitted from the AP. $h_{ar}(t)$ is complex channel between the AP and the reader and $h_{at}(t)$ is complex channel between the AP and the backscatter tag. Also, $h_{tr}(t)$ is complex channel between the backscatter tag and the reader. $n(t)$ is additive white Gaussian noise (AWGN) that has zero mean and variance σ^2. α means ‘1’ or ‘0’ where the tag reflects. In the Eq. (1), the first term is the received signal from AP and the second term is the received signal from the tag. Recent studies are also underway to transmit more information from the tag [10], [11]. This paper proposes a ambient backscatter scheme that uses multiple antennas and transmits multiple bits with each antenna.

III. PROPOSED AMBIENT BACKSCATTER SCHEME

This section explains the proposed ambient backscatter scheme. Fig. 3 shows the proposed ambient backscatter system model. If the backscatter tag uses two antennas, each antenna reflects the signal from the AP using different power. At this time, the two antennas sufficiently reflect signals with different power. In this paper, the proposed scheme allocates power P such as conventional backscatter scheme at the first antenna. Also, the second antenna allocates $\frac{1}{2}P$ or $\frac{1}{4}P$ power.

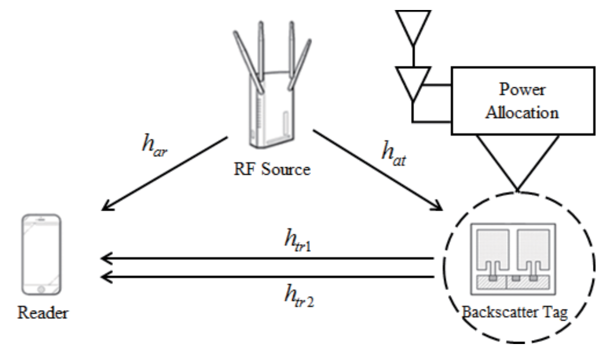

FIGURE 3. Proposed Ambient backscatter system model.

The reader detects received signals in two stages. First, the reader detects a signal with high power in the received signal [12]–[14]. Because the transmit power from each antenna of the tag is different, the first received signal detects a signal with higher power.

Second, the reader uses the first detected signal and the estimated channel information to detect the second signal. The reader uses the difference of power between the received signal and the estimated signal. In addition, the reader uses the power of the received signal from the AP to detect the second signal. These processes are represented in Fig. 4.

The reader uses CSI or RSSI to estimate the channel information between the tag and the reader [14]. And, the reader creates y_1 via the estimated channel and the first detected signal. Next, the reader adds the signal y_1 and y_a received from AP. After that, the reader detects the second signal after subtracting the added value with y_{reader}. The received signal

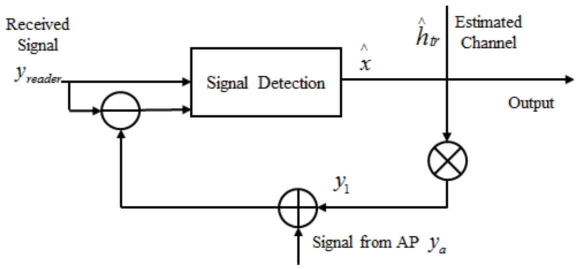

FIGURE 4. Signal detection process of the proposed ambient backscatter system.

is written as follows,

$$y_R(t) = \underbrace{x(t)h_{ar}(t)}_{\text{AP Signal}} + \underbrace{\alpha\{(x(t)h_{at}(t))h_{tr1}(t)\} + \beta\{(x(t)h_{at}(t))h_{tr2}(t)\}}_{\text{Tag Signal}} + n(t)$$

$$\alpha, \beta = \begin{cases} 1, & \text{when the signal is reflected} \\ 0, & \text{when the signal is not reflected} \end{cases} \quad (2)$$

where $y_R(t)$ denotes the received signal at the reader and $x(t)$ is signal transmitted from the AP. $h_{ar}(t)$ is complex channel between the AP and the reader. $h_{tri}(t)$ means the complex channel between the i-th antenna of the tag and the reader. Also, α is a value to be transmitted from the first antenna and β is a value to be transmitted by the second antenna. α and β have values of '1' and '0', respectively.

A threshold value for detecting a signal is set to determine whether it is '1' or '0'. The threshold value is obtained by '10101010' which is the preamble promised beforehand. When the reader receives the promised preamble, the reader determines the average power for '1' and '0' and sets the threshold. The formula for determining the threshold value η is as follows,

$$\eta = \begin{cases} (P_1 + P_3 + P_5 + P_7)/4, & \text{preamble bit is '1'} \\ (P_2 + P_4 + P_6 + P_8)/4, & \text{preamble bit is '0'}. \end{cases} \quad (3)$$

In the case of a tag that transmits 2 bits, the reader sets a threshold as follows,

$$\eta = \begin{cases} (P_1 + P_3 + P_5 + P_7)/4, & \eta_{11} = \text{bit is '11'} \\ (P_2 + P_4 + P_6 + P_8)/4, & \eta_{00} = \text{bit is '00'} \\ (\eta_{11} - \eta_{00})1/3 + \eta_{00}, & \eta_{01} = \text{bit is '01'} \\ (\eta_{11} - \eta_{00})2/3 + \eta_{00}, & \eta_{10} = \text{bit is '10'}. \end{cases} \quad (4)$$

In the Eq. (3), P_i means the i-th bit of the preamble. The threshold of the Eq. (4) is also set via the preamble. The reader uses the threshold value to detect the first signal. Thereafter, the process of obtaining the second signal is as follows,

$$y_2(t) = y_{\text{reader}}(t) - [\underbrace{\hat{x}(t)\hat{h}_{ar}(t)}_{\text{AP Signal}} + \underbrace{\alpha(\hat{x}(t)\hat{h}_{at}(t)\hat{h}_{tr1}(t))}_{\text{Tag Signal From First Antenna}}] , \quad (5)$$

where $y_2(t)$ is denotes a received signal from the second antenna and $\hat{x}(t)$ is the estimated value of the AP signal. Also, $\hat{h}_{ar}(t)$ and $\hat{h}_{tr1}(t)$ are complex channel estimated from CSI or RSSI. After setting the threshold value, the received signal is discriminated based on the following equation.

$$d(x_t, \hat{S}_{res}) = \sqrt{\sum_{i=1}^{t} (x_i - \hat{S}_{res})^2}. \quad (6)$$

Eq. (6) indicates that the bit is estimated by using the Euclidean distance. $\hat{S}_{res}$ means a threshold value and x_t means the signal received every t times. In Eq. (6), the distance between the received signal and the threshold is determined, and the received signal is determined through this distance.

After the process of Eq. (6), $y_2(t)$ again finds the threshold through the process of Eq. (3) or Eq. (4) and detects the signal of the second antenna.

IV. SIMULATION RESULTS

Fig. 5, Fig. 6 and Fig. 7 show the improved performance of the proposed ambient backscatter transmission scheme. The parameters for the simulation are defined as follows: The standard of the IEEE 802.11n is used and the bandwidth of the channel 20MHz. The Wi-Fi packets are composed of orthogonal frequency division multiplexing (OFDM) using 64 fast Fourier transform (FFT) size and 32 cyclic prefix (CP) size. The number of antennas of tag is set to two and the number of antennas of reader is set to one. The modulation scheme of the tag uses the 2-ary modulation that transmits 1 bits and the 4-ary modulation that transmits 2 bits. Also, the distance between the tag and the reader is set to 1m, 3m, 5m. Each channel uses the ultra wide band (UWB) channel model. The power allocation of first antenna is allocated at P and the power allocation of the second antenna is allocated at $\frac{1}{2}P$ and $\frac{1}{4}P$, and P is normalized to 1 ($P = 1$).

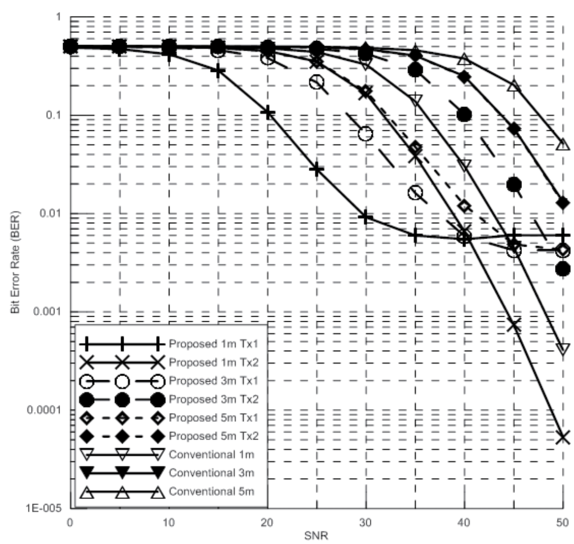

FIGURE 5. BER performance of proposed ambient backscatter system (2-ary, second antenna power=$\frac{1}{2}P$).

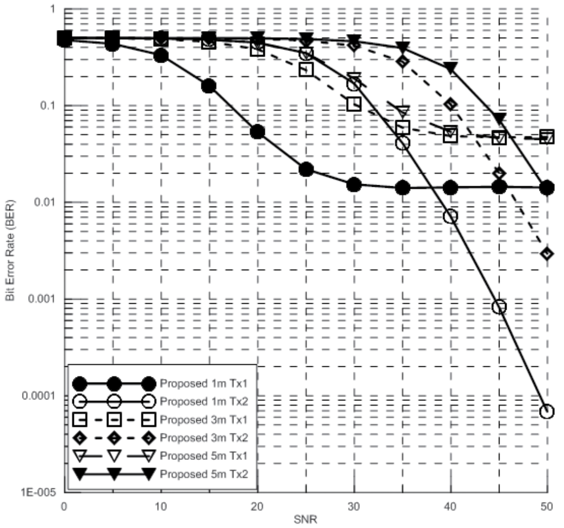

FIGURE 6. BER performance of proposed ambient backscatter system (4-ary, second antenna power=$\frac{1}{2}P$).

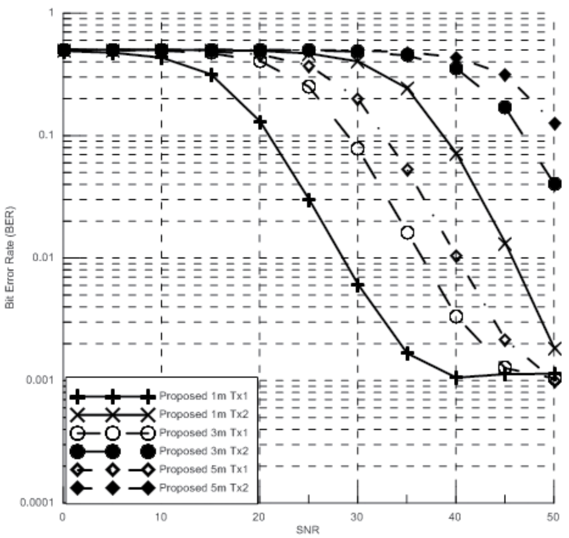

FIGURE 7. BER performance of proposed ambient backscatter system (2-ary, second antenna power=$\frac{1}{4}P$).

Fig. 5 and Fig. 6 show the bit error rate (BER) performance of proposed Wi-Fi backscatter system according to distance between the tag and the reader. Also, the Tx1 and the Tx2 mean the tag antennas. In the proposed scheme, the BER performance is determined based on the first detected signal. Therefore, as the distance between the tag and the reader is closer, the detection performance of the first signal increases, and the second signal also improves the performance. The error floor shown in Fig. 6 is generated by setting a threshold value to determine more bits. Therefore, in order to overcome error floor, it is necessary to transmit more difference power from the tag antennas.

Fig. 7 shows the BER performance when the power allocation of the second antenna is $\frac{1}{4}P$. Compared to $\frac{1}{2}P$ power allocation, the difference in power consumption is relatively large, so the detection performance of the signal from the first antenna is improved. However, since the strength of the signal from the second antenna becomes weaker, the detection performance of the signal from the second antenna is degraded.

Fig. 8 shows the throughput performance of the conventional and the proposed scheme. The distance between the tag and the reader is 1m, 3m, 5m, and the modulation method uses the 2-ary modulation.

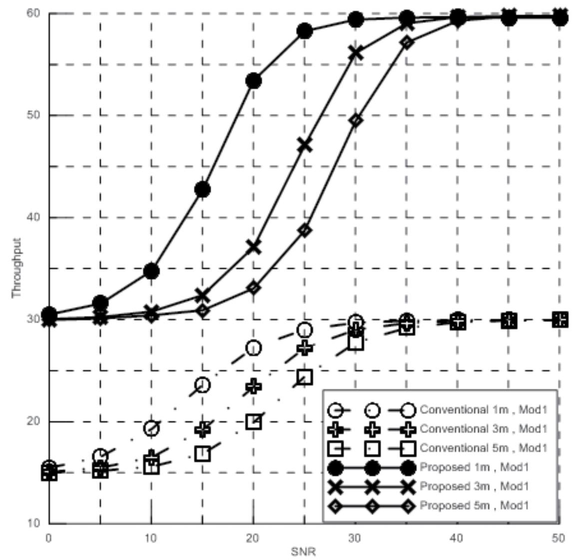

FIGURE 8. Throughput performance of conventional scheme and proposed scheme.

Since the proposed scheme uses two antennas in the tag, it shows twice the throughput performance compared with the conventional scheme.

V. CONCLUSION

This paper proposes an ambient backscatter system which is important usable technology in the IoT system. In this paper, the improved scheme for the Wi-Fi backscatter system using multiple antennas is proposed. Unlike the conventional backscatter system, the proposed scheme improves the data rate by using multiple antennas of the tag. Also, in the proposed scheme, the power allocation is different for each antenna in the tag, and the information can be detected with the reader. Therefore, as the power difference of the signals transmitted from each antenna increases, the performance of the system increases. But, when a higher-order modulation scheme is selected from the antenna in the tag, more power is required. If the energy harvesting is sufficient, high performance is also expected for the backscatter systems using high-order modulation scheme.

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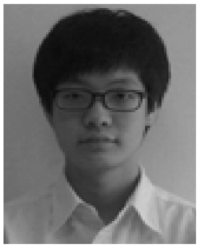

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