Performance Analysis of Multi–Tag Multi–Reader Ambient Backscatter Communication Systems

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***Abstract*—In this paper, we propose a multi-tag and multi-reader ambient backscatter communication (ABC) system which improves decoding performance of the readers by exploiting receiver diversity. The proposed system uses multiple versions of the received signals at the different readers. We also design a simple location based tag–reader paring scheme which provides better decoding performance in realistic network environments. The peformance of the proposed multi–tag multi–reader ABC system and tag–reader paring scheme is evaluated numerically through simulations. The numerical results show that our proposed scheme outperforms a conventional scheme.**

***Index Terms*—Ambient backscatter communication, multi–tag, multi–reader, decoding performance.**

I. Introduction

Internet of things (IoT) technology is a key component for future smart city and smart home applications. According to the report of international data corportation, the IoT device market will grow to 1,700 billion dollars by 2020, which takes 31.8% of entire IoT market [1]. For future applications, the IoT sensor devices should be able to communicate with very low power because the sensor devices only rely on small batteries.

Ambient backscatter communication (ABC) is an important candidate technology for the low power IoT devices. The ABC transmits binary data within a short range by scattering ambient radio frequency (RF) signals radiated from television (TV) broadcasting towers, Wi-Fi access points, and so on. The binary data '0' and '1' are presented by 'absorbing' and 'reflecting' the ambient RF signals in the ABC transmitter, which is called as the *tag* [7]. For detection in the receiver, which is called as the *reader*, there have been several previous studies based on maximum likelihood (ML) in [2]–[4] and energy detection (ED) methods in [5], [6]. Moreover, the authors in [8] and [9] implemented tag and reader modules to show practical feasibility.

Although the ABC has good features as an IoT technology, its coverage and data rate are quite limited [8]. To enhance usability of ABC, it is required to further improve the decoding performance. Most of exisiting studies consider multi–tag and single–reader topologies as in [5]. In this paper, we propose a multi–tag and multi–reader ABC system which improves decoding performance of the reader by exploiting receiver diversity. The proposed system uses multiple versions of the received signals at the different readers. We also design a simple location based tag–reader paring scheme which provides better decoding performance in realistic network environment. The peformance of the proposed multi tag and multi reader ABC system and the tag–reader paring algorithm is evaluated numerically through simulations. The numerical results show that our proposed scheme outperforms the conventional scheme in [5].

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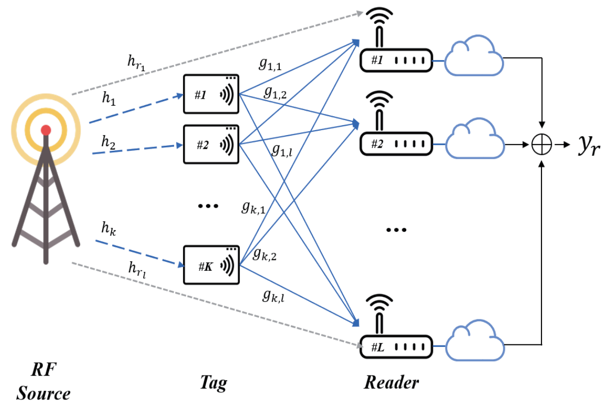

Fig. 1. Proposed multi–tag multi–reader ABC system.

The rest of the paper is organized as follows. In Section II, we present the multi–tag multi–reader system model. In Section III, we propose a decoding scheme using multiple readers according to the distance between tag and reader. The numerical results are presented in Section IV and finally, conclusive remarks are drawn in Section V.

II. Multi–Tag Multi–Reader ABC System

Fig. 1 shows the system model considered in this paper. The RF source represents a TV tower or a Wi-Fi access point, of which RF signals will be exploited by the ABC system as ambient signals. The ABC system consists of K tags and L readers. We assume that the readers are connected to the central controller. In our scenarios, the readers are data sinks which collect data from the IoT sensor nodes and forward them to a data server. Hence, the assumption that the readers are connected to the central controller can be justified. The tags send their data using backscattering technique, and the readers receive and forward the signal to the central controller.

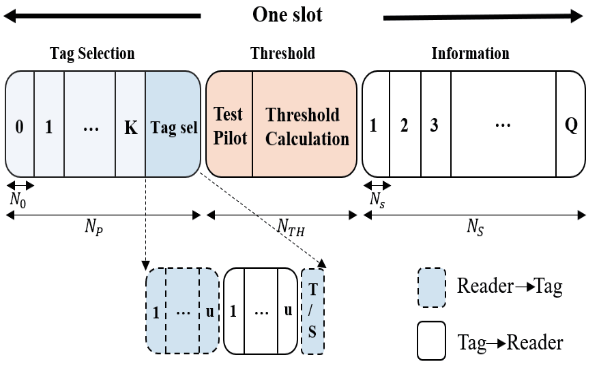

Fig. 2. Transmission protocol.

The central controller decides '0' or '1' based on the signals received from the multiple readers. The central controller also handles the scheduling operation, which selects a single tag out of multiple tags to send data at certain time. The scheduling procedure is the same as in [5].

In the system model, h_k and h_{rl} denote the channels from the RF source to the tags and to the readers. $g_{k,l}$ represents the channels between the tag k and the reader l. All channels in Fig. 1 are assumed to be the complex zero-mean Gaussian, i.e., $h_k \sim \mathcal{CN}(0,1)$, $h_{rl} \sim \mathcal{CN}(0,1)$, $g_{k,l} \sim \mathcal{CN}(0,\sigma^2_{g_{k,l}})$, where $\sigma^2_{g_{k,l}}$ is the variance of the channels between the tags and the readers. It is noted that $\sigma^2_{g_{k,l}}$ represents the channel quality, which can be varied by the distance between the tags and the readers. We also assume that all channels are independently distributed.

Fig. 2 shows the transmission protocol which consists of 3 steps: tag selection, threshold selection, and information. The tag selection is a scheduling procedure where the controller measures the average power of each tag and selects a single tag with the best power [5]. In the threshold selection step, the controller adjusts its decision threshold with which the controller decides '0' or '1' from the received signals. For the threshold selection, the selected tag sends the pre-defined binary patterns and the controller adjusts its threshold which minimizes bit error rate (BER). In the final information step, the data transmission from the selected tag is performed.

The signal transmitted from the tag k can be written as

$$y_r(n) = \sum_{l=1}^{L} h_{r_l} s(n) + \sum_{l=1}^{L} h_k g_{k,l} \eta_k s(n) B(n) + w_r(n),$$

where $s(n)$ is the signal from the RF source, η_k denotes the attenuation factor of the circuit in the tag, $B(n)$ is the binary signal transmitted from the tag, and $w_r(n)$ is the additive white Gaussian noise (AWGN) with zero mean and unit variance. $B(n) = 0$ when the tag wants to send '0', hence the reader receives the signal from the RF source only. On the other hand, if the tag sends '1', the reader receives the additional reflected version of the signal of the RF source. It is worthy to note that the reflected RF signal is naturally attenuated in the tag.

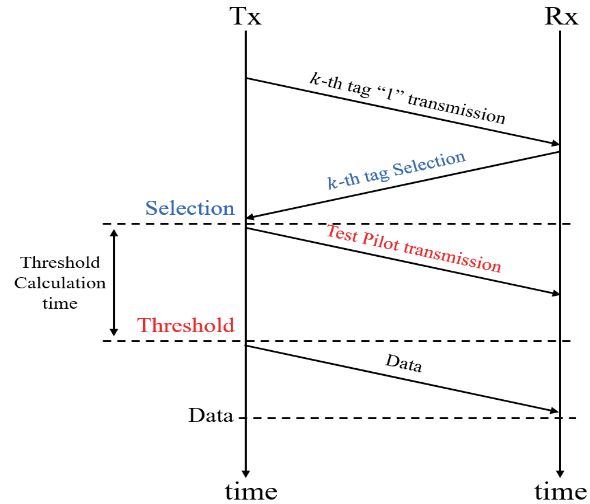

Fig. 3. Transmission process diagram.

III. Proposed Decoding Scheme And BER Performance

In this section, we propose the decoding scheme where the readers cooperatively utilize multiple versions of the received signals at the different readers and simple location based tag–reader paring scheme. Transmission protocol in detail can be referenced in [5].

A. Cooperative Reader Scheme

Fig. 2 and Fig. 3 show the transmission protocol and transmission process, respectively. The transmission process proceeds following 3 steps.

a) Tag selection: In the first step, each tag will transmit N_0 bits of '1' to reader during $N_p = (K+1)N_0$ symbols. While the k-th tag transmits '1', other (k - 1) tags remain non-backscatter state. The signal transmitted from the tag k can be written as

$$y_r(n) = \begin{cases} h_{r_l} s(n) + w_r(n), & \text{n} \in [1, N_0], \\ \mu_k s(n) + w_r(n), & \text{n} \in [kN_0+1, (k+1)N_0], \end{cases}$$

where $\mu_k = h_{r_l} + h_k g_{k,l} \eta_k$, $k \in [1,K]$ and $l \in [1,L]$. The controller will measure the average power $\phi_{k,l}$ of each tag as

$$\phi_{k,l} = \frac{1}{N_0} \sum_{n=kN_0+1}^{(k+1)N_0} |y_{r_l}(n)|^2.$$

The controller selects a single tag with the best power as [5]

$$k^* = \underset{k \in \mathcal{K}, l \in \mathcal{L}}{\text{argmax}} \, |\phi_{k,l} - \phi_0|,$$

where ϕ_0 is the ambient RF signal power.

b) Threshold selection: In the second step, for the threshold selection, the selected tag transmits a pre-defined test pilot

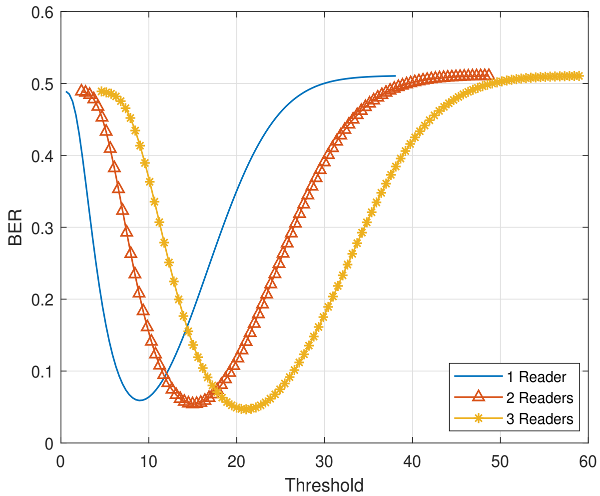

Fig. 4. Threshold selection.

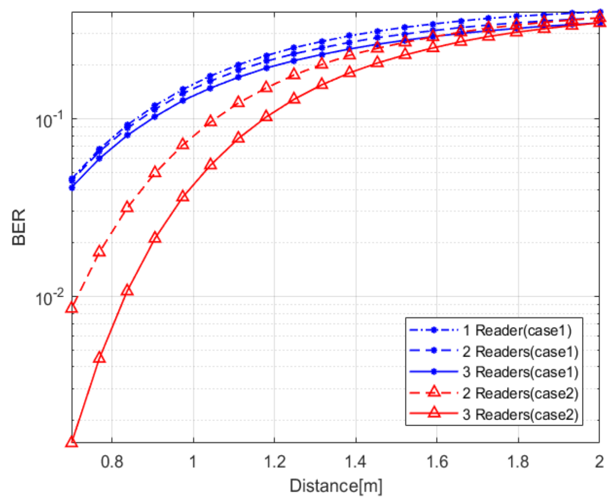

Fig. 5. Cooperative scheme : BER vs Distance.

signal. Then, the controller receive signal from the multiple readers. The received signal $y_{r,k^*}(n)$ is given by

$$y_{r,k^*}(n) = \sum_{l=1}^{L} h_{r_l} s(n) + \sum_{l=1}^{L} h_{k^*} g_{k^*,l} \eta_{k^*} s(n) B(n) + w_r(n). \quad (1)$$

The controller adjusts its threshold which minimizes BER. Fig. 4 shows the threshold value according to multiple readers and the threshold is decided through simulation.

c) Data transmission: In the final step, transmits the data from the selected tag. Then, the controller decides ‘0’ or ‘1’ based on the received signal (1) from the k^*-th tag by using an energy detection method with the threshold value determined in the second step.

$$Y_{r,k^*}(n) = \frac{1}{N_s} \sum_{n=(q-1)N_s+1}^{qN_s} |y_{r,k^*}(n + N_p + N_t + N_{th})|^2,$$

$$\hat{B}(n) = \begin{cases} 1, & Y_{r,k^*} > Thr^*, \\ 0, & Y_{r,k^*} < Thr^*, \end{cases}$$

where N_s denotes the number of samples and $\hat{B}(n)$ is estimated as a result of decoding.

B. Location Based Pairing Scheme

The above mentioned cooperative reader scheme can interfere with the received signal with low channel quality. Therefore, we propose a simple location based tag–reader paring scheme.

Transmission process is the same as in cooperative reader scheme in Fig. 3. In the location based pairing scheme, the controller compares the BER value of each reader and multiple readers in the threshold selection step by received test pilot from the k^*-th tag. If there is an extremely good channel gain between the tag and the reader, it is decided as a distributed mode which receives the signal with the best reader. In other cases, it is determined as a centralized mode which receives the signal with multiple versions.

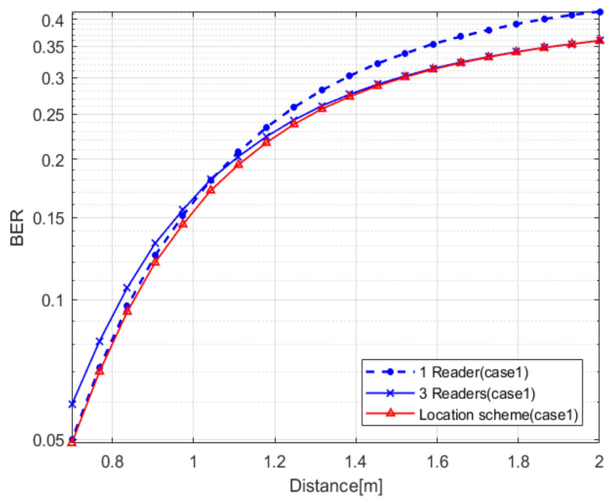

Fig. 6. Location scheme : BER vs Distance.

$$Receiver\ Scheme = \begin{cases} P_{BER}^{k,l} < P_{BER}^{com}, & Distributed, \\ P_{BER}^{k,l} \geq P_{BER}^{com}, & Centralized. \end{cases}$$

C. BER Performance

The result of the decoding is to determine the reliability of the signal with $\hat{B}(n)$. Assuming that $B(n) = 0$ and $B(n) = 1$ occur at the same probability, the BER can be obtained by

$$\begin{aligned} P_{BER} &= Pr(\hat{B}(n) \neq B(n)) \\ &= Pr(B(n) = 1) Pr(\hat{B}(n) = 0 | B(n) = 1) \\ &\quad + Pr(B(n) = 0) Pr(\hat{B}(n) = 1 | B(n) = 0). \end{aligned}$$

IV. Numerical Result

In this section, we analyze reliability of received ABC signal according to the number of readers. Fig. 5 shows the BER according to the distance between the tag and the readers using the cooperative reader scheme and Fig. 6 shows the BER according to the distance between the tag and the reader based on the location based pairing scheme. The number of readers is set to 3 and the number of tags is set to 2. The received power of the RF source is fixed as 5dB. The simulation compares 'Case1' which is in a state where the tag approaches only reader 1 but reader 2 and reader 3 remain far and 'Case2' which is in a state where all tags approach reader 1, 2 and 3.

Case1: The tag approaches reader 1 but reader 2 and reader 3 remain far away.

Case2: The tag approaches all readers.

Fig. 5 shows that more readers provide better performance of reliability in Case2. However, in Case1, it tends to get better to receive the signal from a single reader. The reason is that if differences in the reliability of the received signal occur, the received signal with high channel gain is destructed by the received signal with low channel gain. Fig. 6 shows the BER performance comparison for Case1 which the tag approaches only reader 1. It is shown that the proposed location based pairing scheme provides better decoding performance depending on distances if differences in the reliability of the received signal exist.

V. CONCLUSIONS

In this paper, we proposed a cooperative scheme and a simple location based tag–reader paring scheme to improve decoding performance in ambient backscatter communication networks. Numerical results show that the more the number of readers is the better performance of reception reliability in general situation, but when there is an extremely close to the tag, there is a difference in the reliability of the received signal. Therefore, if a tag with extremly dominant channel gain exists, a method of receiving from a single reader is optimal.

For further work, there will be the tag signal detection that removes the influence of interference in a unknown channel environment

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