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LETTER

# Backscatter Assisted Wireless Powered Communication Networks with Non-Orthogonal Multiple Access

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**SUMMARY** This letter considers a backscatter assisted wireless powered communication network (BAWPCN) with non-orthogonal multiple access (NOMA). This model consists of a hybrid access point (HAP) and multiple users which can work in either backscatter or harvest-then-transmit (HTT) protocol. To fully exploit time for information transmission, the users working in the backscatter protocol are scheduled to reflect modulated signals during the first phase of the HTT protocol which is dedicated for energy transfer. During the second phase, all users working in the HTT protocol transmit information to the HAP simultaneously since NOMA is adopted. Considering both short-term and long-term optimization problems to maximize the system throughput, the optimal resource allocation policies are obtained. Simulation results show that the proposed model can significantly improve the system performance.

***key words:*** *wireless powered communication network, backscatter communication, non-orthogonal multiple access, throughput maximization*

## 1. Introduction

Radio frequency signals have recently been seen as potential energy sources by employing energy harvesting techniques [1]. Inspired by this fact, wireless powered communication networks (WPCNs) have been receiving a lot of attention [2], [3]. In [2], the well-known harvest-then-transmit (HTT) protocol was proposed. For this protocol, the time slot was divided into two phases. During the first phase, the hybrid access point (HAP) broadcast energy to all users in the downlink. Then, these users transmitted information to the HAP in the uplink during the second phase via time division multiple access (TDMA). However, in [2], the harvested energy was assumed to be used up during the same slot in which the energy was harvested (short-term optimization). To improve the system performance, [3] focused on the long-term optimization problem.

In 5G communication networks, non-orthogonal multiple access (NOMA) was proved to increase spectral efficiency [4], and was applied to support the Internet of Things (IoT) [5] with the employment of grant-free transmission [6], [7]. In [8], NOMA was introduced in the WPCNs by employing the HTT protocol. Different with [2], the users transmit information to the HAP simultaneously during the second phase since NOMA is adopted. The throughput maximization problem was studied, and the fairness of users was improved by two types of decoding order strategies, i.e., fixed decoding order and time sharing. In [9], the authors extended [8] to the long-term optimization problem, which was proved to increase the system performance. However, in both [8] and [9], the first phase of the HTT protocol was only used for energy transfer.

Backscatter communication (BackCom) [10] has been seen as a new communication method. In [11], the resource allocation problem was investigated in multi-user BackCom systems. The optimal control polices were obtained to maximize the successful transmission bits. The physical layer security of BackCom systems was studied in [12]. In [13], BackCom was introduced in the WPCNs, where each user could work in both HTT and backscatter protocols. An optimization problem was studied to find the optimal permutation of the users' working modes. Different with the HTT protocol, the users in BackCom systems backscatter information to the HAP (or the reader) based on the instantaneous excitation energy radiated by the HAP so that the dedicated time for energy transfer is not required. Inspired by this property, BackCom can be employed in the proposed WPCNs with NOMA [8], [9] for fully exploiting time, particularly the phase used for energy transfer, to improve the system performance.

In this letter, we propose a backscatter assisted WPCN (BAWPCN) with NOMA, which includes a HAP and multiple users which can work in either backscatter or HTT protocol. To the best of our knowledge, no work has been conducted on the proposed model. In the proposed model, during the first phase of the HTT protocol, the HAP broadcast energy to all users, while the users working in the backscatter protocol simultaneously reflect modulated signals to the HAP. On the contrary, the users working in the HTT protocol transmit information to the HAP by employing NOMA during the second phase. The key contributions of this letter are summarized as follows. First, we propose a new model for WPCNs with NOMA, which employs both backscatter and HTT protocols to fully exploit time for information transmission. Second, we consider two cases, i.e., short-term and long-term optimization problems to maximize the system throughput. Third, the optimal resource allocation policies are obtained.

## 2. System Model

We study a BAWPCN with NOMA, which composes of a HAP and $K$ nodes. Among these $K$ nodes, $K_b$ users, denoted as $U_i, i = 1, \cdots, K_b$, work in the backscatter protocol, and the

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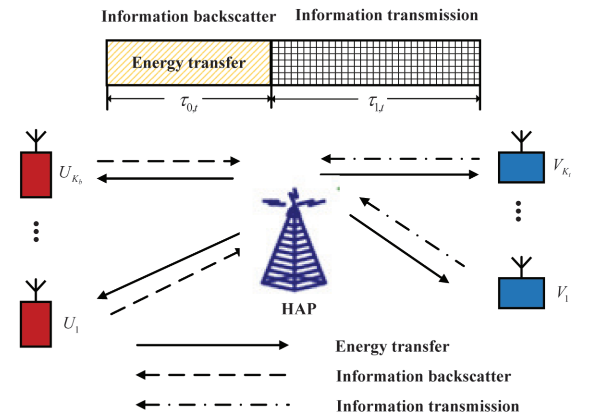


**Fig. 1** Backscatter assisted wireless powered communication network with NOMA.

remaining $K_t = K - K_b$ users, denoted as $V_j, j = 1, \cdots, K_t$, work in the HTT protocol. The HAP and all users are with a single antenna. The system model is illustrated in Fig. 1. It is assumed that the HAP is with a stable energy source and all users have no initial energy. The BAWPCN is studied based on time slots and the number of slots is given as $T$. Without loss of generality, the duration of each slot is normalized to one.

### 2.1 HTT Protocol with NOMA

For $V_j$, the HTT protocol is employed so that each slot, denoted as $t, t = 1, \cdots, T$, is divided into two phases. During the first phase with duration of $\tau_{0,t}$, the HAP broadcasts energy to all users with a constant energy $P_H$. During the second phase with duration of $\tau_{1,t}$ that satisfies $\tau_{1,t} \leq 1 - \tau_{0,t}$, all users working in the HTT protocol transmit information to the HAP independently and simultaneously with the employment of NOMA. Denote the forward channel gain between the HAP and $V_j$ and the backward channel gain between $V_j$ and the HAP during slot $t$ as $h_{j,t}$ and $g_{j,t}$, respectively. With loss of generality, we assume that the forward and backward channels are reciprocal, i.e., $h_{j,t} = g_{j,t}$, and the indices of $V_j, \forall j$ are assigned in a way that the values $h_{j,t}, \forall j$ are sorted in descending order during each slot, i.e., $h_{1,t} \geq h_{2,t} \geq \cdots, \geq h_{K_t,t}$. Moreover, it is assumed that the HAP and $V_j$ have the perfect information of the channel power gains. The energy harvested by $V_j$ during slot $t$ is given as

$$\hat{E}_{j,t} = \eta_j P_H h_{j,t} \tau_{0,t},$$

where $\eta_j$ is the energy harvesting efficiency of $V_j$.

For fairness, the fixed decoding order scheme according to the indices of $V_j, \forall j$ is employed [8]. Denote the energy used for transmitting information of $V_j$ during slot $t$ as $E_{j,t}$. From [14], during slot $t$, the achievable throughput of $V_j$ $(1 \leq j \leq K_t - 1)$, denoted as $R_{j,t}$, is given by

$$R_{j,t} = \tau_{1,t} W \log_2 \left( 1 + \frac{\frac{E_{j,t} g_{j,t}}{\tau_{1,t}}}{\sum_{n=j+1}^{K_t} \frac{E_{n,t}}{\tau_{1,t}} g_{n,t} + \sigma^2} \right),$$

and the achievable throughput of $V_{K_t}$ is given by

$$R_{K_t,t} = \tau_{1,t} W \log_2 \left( 1 + \frac{\frac{E_{K_t,t} g_{K_t,t}}{\tau_{1,t}}}{\sigma^2} \right),$$

where $W$ is the bandwidth and $\sigma^2$ is the noise power at the HAP.

### 2.2 Backscatter Protocol

In [8], [9], $\tau_{0,t}$ is only used for transferring energy. To further improve the system performance, BackCom is employed during $\tau_{0,t}$, i.e., $U_i$ is scheduled to work in the backscatter protocol, of which $U_i$ reflects the modulated signals to the HAP based on the instantaneous excitation energy radiated by the HAP. Different with $V_j$, $U_i$ is scheduled via TDMA. Denote the backscatter rate of $U_i$ as $B_i$, which is controlled by the setting of the RC circuit elements [15]. The achievable throughput of $U_i$ during slot $t$, denoted as $\hat{R}_{i,t}$, is given by

$$\hat{R}_{i,t} = \tau_{0,t} B_i, \ i = 1, \cdots, K_b.$$

Hence, the sum-throughput of all users during slot $t$ is given by

$$R_t^{\text{sum}} = \sum_{i=1}^{K_b} \hat{R}_{i,t} + \sum_{j=1}^{K_t} R_{j,t}$$

$$= \sum_{i=1}^{K_b} \tau_{0,t} B_i + \tau_{1,t} W \log \left( 1 + \frac{\frac{\sum_{j=1}^{K_t} E_{j,t} g_{j,t}}{\tau_{1,t}}}{\sigma^2} \right).$$

From [16], to maximize the sum-throughput, only the user with the maximal backscatter rate can be scheduled. Without loss of generality, let $K_b = 1$. Hence, $R_t^{\text{sum}}$ is rewritten as

$$R_t^{\text{sum}} = \tau_{0,t} B_1 + \tau_{1,t} W \log_2 \left( 1 + \frac{\frac{\sum_{j=1}^{K_t} E_{j,t} g_{j,t}}{\tau_{1,t}}}{\sigma^2} \right).$$

Finally, the system throughput of all users during $T$ slots is given by

$$R^{\text{sum}} = \sum_{t=1}^{T} R_t^{\text{sum}}.$$

## 3. System Performance on Short-Term Optimization

In this section, we focus on the system performance on short-term optimization. Assume that the harvested energy $\hat{E}_{j,t}$ will be exhausted by $V_j$ during $\tau_{1,t}$, i.e., $E_{j,t} = \hat{E}_{j,t}$ so that each slot is independent. In other words, to maximize $R^{\text{sum}}$ is equivalent to maximizing $R_t^{\text{sum}}$ individually. For simplification, $R_t^{\text{sum}}$ is rewritten as