Energy-Efficiency Random Network Coding Scheduling Based on Power Control in IoT Networks

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Abstract. Random network coding (RNC) is an efficient coding scheme to improve the performance of wireless multicast networks, especially for the IoT network with multiple devices. Meanwhile, energy-efficient transmission is also an insistent demand in IoT network. Therefore, in this paper, we considered the heterogenous wireless channels of the devices caused by the transmitting distances and analyzed the energy consumption of overall network by using adaptive random network coding (ARNC). Then, we proposed a new power control metric that both considered the energy consumption and the network throughput. Based on the new metric, we optimized the transmitting power of the BS and proposed an energy-efficient ARNC scheduling based on power control to improve quality of service. The simulation results also showed the effectiveness of the optimization and proposed methods compared with the traditional methods.

Keywords: IoT networks · ARNC · Power control · Energy-efficiency

1 Introduction

With the rapid development of the mobile communications and demand of the connection among the different kinds of the devices, the Internet of Things (IoT) becomes an important part of the information technology of the future. Technically, IoT is expected to enable people-thing and thing-thing interconnections by combining communication technologies and networks. Nowadays, IoT was included in the fifth Generation (5G) standard through the 3GPP access network, where the more reliable connection, the higher throughput, the lower energy consumption are required in IoT.

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On the other hand, network coding (NC) has drawn significant attention to increase system throughput and reliable connection for the last few years since the pioneering work of Alswede et al. [1]. NC has shown the potential abilities to improve network efficiency for reducing the number of transmitted packets. As for multicast networks, random network coding (RNC) in [2] that is based on the concept of NC has attracted significant research interest. And the sender encodes original packets by combining them using random coefficients, So the receivers can decode the complete information only they get a full set of independent coded packets. It means the lower quality of service (QoS). Therefore, an adaptive random coding is proposed by our team in [3], where the users can decode out more data according to the dynamic coding structure in ARNC and the network throughput remarkably improved when the user number is large. This property is suitable in IoT networks to provide the high throughput and reliable connection.

In our previous work [4], we proposed a novel network coding (adaptive random network coding) with different feedback schemes. But we didn't take energy consumption into account. Consequently, in this paper, we considered a IoT networks in which the devices had different transmitting distances from the base station (BS). We first introduced the ARNC scheduling schemes and analyzed the corresponding energy consumption. Then we proposed the energy-efficient metric called energy-efficiency ratio (EER) that both considered the overall energy consumption and network throughput. Based on the EER, we optimized the transmitting power of the BS and proposed an energy-efficient ARNC scheduling based on power control to improve quality of service. Moreover, the impact of network parameters on the EER was discussed based on the simulation results.

For the related work, [5] investigated the feasibility of improving the energy efficient that was applied to battery-limited IoT networks. From [6], it considered the energy harvesting for mass deployment of IoT devices in heterogenous networks and developed an effective energy-harvesting-aware routing algorithm to improve energy efficiency. To further enhance energy efficiency performance of 5G IoT, in [7], the authors proposed one integrated system structure for better energy efficiency. In addition, there are lots of concepts and techniques dedicated to save energy, mainly focus on reducing transmission, since the energy used for encoding is incomparable smaller than energy for broadcasting. Therefore, the goal of [8] was to develop new coding scheme for data compression to save energy for IoT solution. However, Some papers about NC focus more on the higher throughput, coding latency and transmitting delay. The contribution in [9] was to develop diversity schemes to optimize the throughput of system with RNC. [10] mainly focused on the low latency application of RNC as well as data storage application that use large blocks of data. For [12], it analyzed the delay bounds for transmitting packets from a source node to the destination by introducing RNC, but it ignored the energy consumption.

This work is organized as follows: Sect. 2.1 presents the system model. Then the details of different ARNC transmission schemes are introduced in Sect. 2.3.

And the energy consumption is presented in Sect. 3. While in Sect. 4 shows simulation results and discussion. Finally, we present our conclusion in Sect. 5.

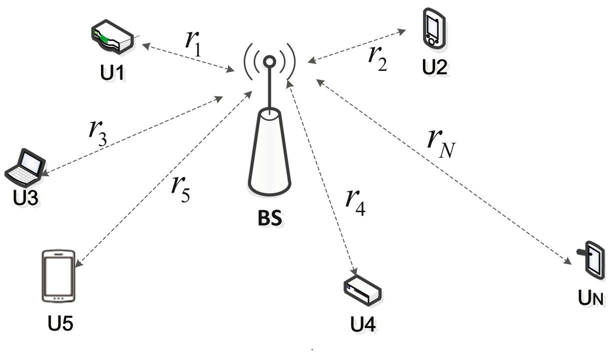


Fig. 1. System model. System with one BS and N users.

2 System Model and Setting

2.1 System Model

As shown in Fig. 1, we consider a single hop wireless network, such as Wi-Fi networks or micro cell network in 5G, which consists one transmitter (AP or micro base station (MBS)) and N devices. For simplicity, we assume the IoT network operates on a single frequency and each time slot only transmits one packet. The information at the transmitter are divided into data batches. Each data batch consists of M source packets (denoted as $\alpha_1, \alpha_2, ..., \alpha_M$) and sends to the N devices within a transmission deadline of T time slots (usually $T > M$). In our system, the devices always have the different transmitting distances, causing the heterogenous wireless channels between the transceivers, as shown in Fig. 1. According to [11], the received signal-to-noise ratio (SNR) γ_n at the device n can be written as:

$$\gamma_n = \frac{GE_{tx}|h_n|^2}{{r_n}^2 N_0} \tag{1}$$

where N_0 is the white Gauss noise power, E_{tx} denotes the transmitting energy consumption per bit for BS. $G = \left(G_r G_t \lambda^2\right) \Big/ \left(M_l N_f (4\pi)^2\right)$, where G_t and G_r indicate the transmitter and receiver antenna gains respectively. λ represents the carrier wavelength, N_f is the noise figure and M_l is the link margin. When the packets are modulated by QPSK, the average bit error rate (BER) for the n can be expressed as

$$p_n^b = \int_0^\infty Q\left(\sqrt{2\gamma_n}\right) f\left(|h_n|^2\right) d|h_n|^2 \tag{2}$$

where $Q(x)$ is the Q-function, $|h_n|^2$ follows the exponential distribution, i.e.,$|h_n|^2 \sim E\left(1/\sigma_n{}^2\right)$. We set the packet length as f bits. Similar to [11], the PER of user n (ϵ_n) is defined as:

$$\epsilon_n = 1 - \left(1 - p_n^b\right)^f. \tag{3}$$

2.2 ARNC Encoding and Decoding

Adaptive random networking coding (ARNC) is the coding scheme that suitable for high throughput transmission with lower latency scenarios and proposed by our team in [4]. For easily understanding of paper, we introduce the ARNC briefly in this section below.

As for M prioritized packets, the BS creates M generations. At time slot t, generation G_m $(1 \leq m \leq M)$ generates the coding packet $c_{mt} = \sum_{j=1}^{m} \alpha_{tj} p_j$, where α_{tj} is coding coefficient which is randomly chosen from the finite field $\mathbb{F}_q$. For example, when $M = 3$, the coding packets from the three generations are

* G_1: only contains p_1, i.e., $G_1 : c_{1t} = p_1$.
* G_2: combines p_1 and p_2, i.e., $G_2 : c_{2t} = \alpha_{t1}p_1 + \alpha_{t2}p_2$.
* G_3: combines p_1, p_2 and p_3, i.e., $G_3 : c_{3t} = \alpha_{t1}p_1 + \alpha_{t2}p_2 + \alpha_{t3}p_3$

Please note that at each time slot, the scheduler decides which generation to work and controls the type of RNC packets for multicasting. While for the decoding, at the receiver side, each device has a $M \times T$ decoding matrix $\mathbf{s}$, which includes the received ARNC coefficient vectors. For example, when $M = 3$ and $T = 5$, the decoding matrix of n may be shown as

$$\boldsymbol{s}_n^t = \begin{pmatrix} 1 & \alpha_{12} & 0 & 0 \\ 0 & \alpha_{22} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \tag{4}$$

which indicates the device n successfully receives four ARNC packets (c_{11} and c_{22}) until the tth time slot. Apparently, although n doesn't collect a full set of the coded packets, it can still recover the partial transmitted packets (p_1 and $p2$). After that, if n receives one more coding packet from G_3, it can decode all the information in one block.

2.3 Transmitting Scheduling Strategy

To find an optimal scheduling strategy that can maximize the network average throughput, the BS needs to make the action that decides the transmitting power and the coding packet in each time slot. To be specific, the optimal action a_t at time slot t depends on the current network status $\mathbf{S}_t$ that is gotten from the device feedback information. When all the users receive coded packets successfully or the hard deadline, the BS will turn to the next information block. To fully understand the strategy, we firstly specify the network dynamics by ($\mathbf{S}_t$, $\mathbf{A}$, E_{tx}, r, T), in which boldface letters refer to vectors or matrices.

1. T is the time slots associated with deadline, and the time slot index is t $(0 \leq t \leq T-1)$.
2. Network state $\mathbf{S}_t$: As for BS, $\mathbf{S}_t$ denotes all the devices status from the feedback information, which is defined by $\mathbf{S}_t = \boldsymbol{s}_1^t \cup \boldsymbol{s}_2^t \cup ... \cup \boldsymbol{s}_n^t \cup ... \cup \boldsymbol{s}_N^t$ where $\boldsymbol{s}_n^t$ shows the network status of n, according which the throughput of the n can be calculated. Therefore, the network throughput can be calculated depending on $\mathbf{S}_t$.
3. Action set $\mathbf{A}$: During the delivery process, the BS takes action a_t $(a_t \in \mathbf{A})$ to decide which coded packet will be sent at the next time slot according to $\mathbf{S}_t$. For instance, by taking the action $a_t =$\{transmit c_{2t} from G_2 at t\}, the BS transmits $c_{2t} = \alpha_{t1}p_1 + \alpha_{t2}p_2$ at t.
4. Transmitting energy consumption per packets E_{tx}: The BS broadcasts the coded packets with power E_{tx}, which is selected from $[E_{min}, E_{max}]$.
5. The immediate network throughput $r\left(\mathbf{S}_t, a_t, E_{tx}\right)$. This denotes the network throughput associated with a_t according to $\mathbf{S}_t$. It can be written as:

$$r\left(\mathbf{S}_t, a_t, E_{tx}\right) = \mathbb{E}\left[r\left(\mathbf{S}_{t+1}|\mathbf{S}_t, a_t, E_{tx}\right)\right] = \sum_{n=1}^{N} \mathbb{E}\left[r\left(\boldsymbol{s}_n^{t+1}|\boldsymbol{s}_n^t, a_t, E_{tx}\right)\right] \tag{5}$$

where $\mathbb{E}[\cdot]$ means the expectation function of $\mathbf{S}_{t+1}$. $r\left(\boldsymbol{s}_n^{t+1}|\boldsymbol{s}_n^t, a_t, E_{tx}\right)$ is the future network throughput of n when $\boldsymbol{s}_n^{t+1}$ is updated from $\boldsymbol{s}_n^t$ under P_{tx} and a_t. It is noticed that when the coded packet is correctly received by n, $\boldsymbol{s}_n^t$ will changed to $\boldsymbol{s}_n^{t+1}$. Otherwise, do nothing. Thus, we have

$$\mathbb{E}\left[r\left(\boldsymbol{s}_n^{t+1}|\boldsymbol{s}_n^t, a_t, E_{tx}\right)\right] = \left(1 - \epsilon_n(E_{tx})\right) r\left(\boldsymbol{s}_n^{t+1}\right) \tag{6}$$

where $r\left(\boldsymbol{s}_n^{t+1}\right)$ shows the throughput of n under $\boldsymbol{s}_n^{t+1}$ and can be calculated according to Sect. 2.2.

3 Energy Consumption Analysis with Perfect Feedback

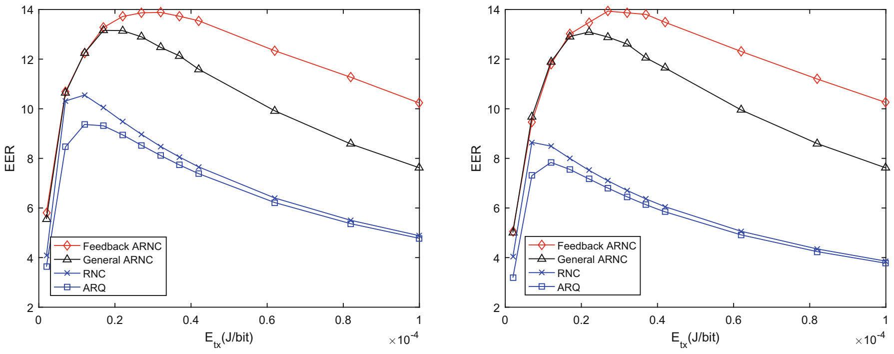
In this scheduling, BS exploits the feedback information from the devices to indicate whether the previous transmitted packet has been received successfully. Based on that, the BS updates $\mathbf{S}_t$ and decides the optimal action a_t depending on S_t. Thus, the overall network throughput is shown as

$$\varGamma(E_{tx}, T) = \sum_{t=0}^{T-1} r\left(\mathbf{S}_t, a_t, E_{tx}\right) + r(\mathbf{S}_T) \tag{7}$$

Correspondingly, the total energy consumption for each data block is

$$E_{total}(E_{tx}, T) = E_c + TLE_{tx} + TNLE_{cr} + TNE_{feed}. \tag{8}$$

Here E_c shows the circuit energy consumption for ARNC, and the detail is given by [13]. E_{cr} is the receiving and decoding energy consumption per bit for the devices. E_{feed} represents feedback energy consumption per packet. To



(a) M=5,N=6,T=8 (b) M=5,N=6,T=10

Fig. 2. Transmitting power versus EER.

fully evaluate the performance of the ARNC scheduling, we propose a new energy-efficient metric called energy-efficiency ratio (EER) that both consider the network throughput and total energy consumption. EER reflects the average throughput per time per device for unit energy consumption and is shown as:

$$\varepsilon(E_{tx}, T) = \frac{\Gamma(E_{tx}, T)}{NTE_{total}(E_{tx}, T)} \tag{9}$$

Our goal is to find an optimal transmitting power that maximizes the EER:

$$E_{tx}^{*} = \underset{E_{tx}\in\mathbf{E}}{\arg\max}\{\varepsilon\} \tag{10}$$

To solve the problem (10), we must first get the overall network throughput $\Gamma(E_{tx}, T)$. Here we adopt greedy scheduling technique (GST) during the scheduling decision with given $E_{tx}(E_{tx} \in \mathbf{E})$. In the GST, the BS finds the appropriate $a_t^{\dagger} \in \Omega$ (here Ω means the set of optimal action) in t to maximize $r(\mathbf{S}_t, a_t, E_{tx})$ until completion time slot or deadline, It is denoted as

$$\left\{a_t^{\dagger}|E_{tx}\right\} = \underset{a_t\in\mathbf{A}}{\arg\max}\left\{r\left(\mathbf{S}_t, a_t, E_{tx}\right)|E_{tx}\right\} \tag{11}$$

Accordingly, for given E_{tx}, we can get the overall network throughput $\Gamma_{\Omega}(E_{tx}, T)$ under the optimal transmission action in each time slot. That is

$$\Omega|E_{tx} = \left(a_0^{\dagger}, a_1^{\dagger}, \cdots, a_{T-1}^{\dagger}\right) \mid E_{tx} \tag{12}$$

Then, the Eq. (10) can be rewritten as

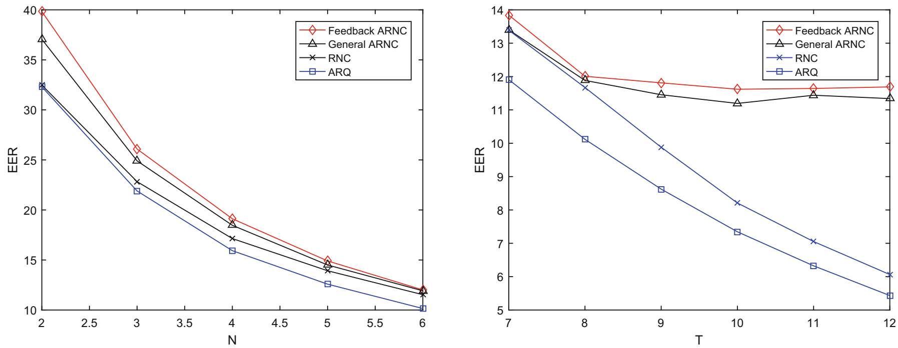
$$E_{tx}^{*} = \underset{E_{tx}\in\mathbf{E}}{\arg\max}\{\frac{\Gamma_{\Omega}(E_{tx}, T)}{NTE_{total}(E_{tx}, T)}\} \tag{13}$$

By traversing E_{tx} in the domain of definition, we finally get the optimal E_{tx}^{*}.

4 Simulation Results and Discussions

In this simulation, we assume each data block is divided into M packets and the BS needs to deliver these packets to N users within a deadline of $T > M$ time slots. Meanwhile, we assume all the fading channels between transceiver are independent and let $\sigma_n^2 = 1$. According to [11], the other system parameters are shown as follows: $1/\lambda = 2.4\,GHz$, $G_r G_t = 5\,\text{dB}$, $N_f = 10\,\text{dB}$, $M_l = 38\,\text{dB}$, $N_0/2 = -174dBm$, $f = 1000\,\text{bit}$, $E_{feed} = 6 \times 10^{-5}\,(J/bit)$, $E_{cr} = 1 \times 10^{-5}\,(J/bit)$. $E_c = 4 \times 10^{-5}\,(J/bit)$.

Figure 2 shows how E_{tx} affects the network performance using our proposed mechanisms under our metric. We incorporate the traditional automatic repeat request(ARQ), RNC, and general ARNC proposed in [4] for comparison. Here we set $M = 5$, $N = 6$, and the distance of the devices in $r_1 = 280\,\text{m}$, $r_2 = 250\,\text{m}$, $r_3 = 220\,\text{m}$, $r_4 = 190\,\text{m}$, $r_5 = 160\,\text{m}$, $r_6 = 130\,\text{m}$. As we discussed earlier, there exists an optimal E_{tx} for the transmit scheduling. It is clear that our ARNC scheduling scheme offers the best performance gain among all schemes, and the optimal transmission energy of the ARNC achieves the greatest energy efficiency.



(a) The device number versus EER (b) The Deadline versus EER

Fig. 3. Transmitting power versus EER.

Figure 3(a) depicts the number of devices versus the EER. Here we set $M = 6$, $T = 7$. The distance between BS and devices are 130 m, 160 m, 190 m, 220 m, 250 m, 280 m, respectively. From the Fig. 3(a), it is worth noticed that the performance curve declines as the number of users increasing in all cases. In order to satisfy the needs of more users, the average network throughput of system will inevitably decrease and consume more energy, simultaneously. However, our methods also achieve the better performance compared with other schemes.

In Fig. 3(b), the system parameters are set as follows: $M = 6$, $N = 6$, other parameters are the same to Fig. 3(a). It can be seen that when T increases, the EER of ARQ and RNC declines, correspondingly. This is because, when T increases, ARQ and RNC has more time to collect the coded packet to achieve more original packets. However, they also cost more energy consumption for transmission, leading to the lower EER. While for the general ARNC and our method, when the $T < 9$, the EERs decrease because we cost more time and energy consumption for decoding. However, when $T \geq 9$, the EER tend to stable because the general ARNC and our method already has enough time slots for decoding. Thus, the left time slots are the reluctant and the BS does not need to allocate the transmitting power in these time slots. Meanwhile, we can also find that our method has the best performance gain among the compared schemes, and this advantage is more obvious when T is large.

5 Conclusion

In this paper, we investigate the scenario that the BS multicasts prioritized data to the different transmitting distance users in the heterogenous wireless networks. Unlike [4], we consider the effects of total energy consumption and average network throughput by using ARNC. Then we propose a new power control to find an optimal transmitting power to improve the overall system performance by relying on the indicator of EER maximization. Finally, simulation results shows that the energy efficiency of proposed scheme is better than other traditional methods while meeting the target requirement of transmission.

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