An Energy-optimized Algorithm for the Data Packet Transmission with Circuit Power Consumption

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Abstract. The development of 5G communication and Internet of Things (IoT) technology has brought massive data transmission. This paper considers a first-in-first-out packet data transmission scenario with actual circuit power consumption and proposes a data transmission strategy with optimal energy efficiency. Specifically, the proposed algorithm in this paper uses a double-layer iteration algorithm, then compare and replace the optimal solution of the ideal circuit power consumption with the optimal solution of the actual circuit power consumption. The numerical results show that our proposed algorithm can significantly reduce energy consumption.

1. Introduction
With the development of economy and technology, the people require a more efficient way to communicate with each other [1]. The 5G communications technology and the mobile Internet promote the demand for video and other data, and a variety of different data demand is growing rapidly. Currently, the allocated bandwidth resource is difficult to meet the enormous data requirements [2]. Due to the non-uniformity and burst of the data, it brings a serious load problem to the base station [3]. The demand for high reliability and low delay of the data transmission brings great energy consumption, and how to improve the energy efficiency (EE) of the system has attracted people's extensive attention [4]-[7].

In previous studies, there has been some research on how to improve the EE of the data packet transmission and reduce energy consumption. For example, a WiMAX network-based data transmission strategy was applied to achieve the system EE by minimizing the energy consumption of the terminal devices in [8]. In [9], a new node structure was adopted to achieve the reduction of energy consumption for the wireless sensor network. An optimized time allocation method was presented in [10], by adjusting the transmission time for each data packet by double iterations, and an optimal allocation strategy was obtained. In this case, only the power consumption of the radio frequency (RF) was considered. and the circuit power consumption of the base station was ignored.

Due to the existence of circuit power consumption, the relationship between the total power consumption of the system and the transmission time of the data packet is no longer monotonically decreasing [10]. when the circuit power consumption is considered, the transmission strategy in [10]...
may not be the optimal solution. As mentioned in [11], the intermittent transmission is the optimal transmission strategy for this case.

In this paper, an EE optimal data transmission strategy with the circuit power consumption is considered, when the total data packets should be transmitted in a limited time, and the data packets arrive at different time. The proposed algorithm minimizes the energy consumption of the data transmission by a finite number of double iterations. In each iteration, the current transmission rate is compared with the optimal transmission rate.

The remaining part of this paper is organized as follows: Section II describes the system model and the problem formulation. Section III gives a specific algorithm to solve the problems mentioned in this paper. Section IV simulates and verifies the proposed algorithm. Finally, section V gives a conclusion.

2. System model

As shown in Fig.1, consider that there are N data packets to be transmitted during the period [0, T]. We assume that the size of the packet \( P_i \) is \( B_i \), \( \tau_i \) and \( E_i \) are the corresponding transmission duration and energy consumption, respectively. The arriving time of the data packet \( P_i \) is \( T_i \), and \( t_i \) is the time point to start transmitting the data packet \( P_i \).

![Fig.1 The data transmission model](image)

When we ignore the circuit power consumption \( p_c \), for the ideal case, according to [5], the longer the transmission time for a single data packet, the smaller the energy consumption to transmit this data packet. When considering \( p_c \), the optimal transmission strategy in the ideal case will be no longer applicable, and the optimal transmission strategy in this actual case is intermittent transmission. According to the Shannon channel capacity formula, the rate can be expressed as

\[
r_i = \ln (1 + h_i p_i),
\]

where \( h_i \) represents the channel power gain from the data transmission. Here, the additional white Gaussian noise (AWGN) channel model is considered, (1) can be further expressed as \( p_i = e^{r_i} - 1 \). Therefore, the energy consumption \( E_i \) of the data packet \( B_i \) can be expressed as

\[
E_i = \tau_i (e^{r_i} + p_c - 1),
\]

where \( p_c \) is the circuit power consumption. Each packet must be transmitted no earlier than the time it arrives at the system, or earlier than the total time limitation, i.e.:

\[
T_i < t_i < T.
\]

In addition, the transmission duration of each packet must satisfy the following condition
\[ 0 < \tau_i < T - T_i, \quad (4) \]

Therefore, the corresponding optimization problem can be written as follows

\[
\begin{align*}
\min_{\tau_i} & \sum_{i=1}^{N} E_i \\
\text{st.} & E_i = \tau_i \left( e^{\tau_i} + p_c - 1 \right) \\
& 0 < \tau_i < T - T_i \\
& i = 1, 2, \ldots, N \quad (5)
\end{align*}
\]

For this problem, we can use the instantaneous transmission algorithm, that is, the arrival time of each packet is its time to start transmission and the arrival time of the next packet is its time of end transmission. This transmission strategy results in a large amount of energy consumption. Therefore, in this paper, a low complex transmission algorithm to minimize the total power consumption is proposed.

3. The proposed algorithm

When the circuit power consumption is considered, the transmission rate that maximizes the system EE \( r_{ee} \) satisfies the condition \( r_{ee} = \arg \max \frac{r}{e^r - 1 + p_c} \), and \( r_{ee} \) is called the optimal rate in the general actual situation.

The proposed algorithm can be divided into two steps. For the first step, we consider the approximate value of the optimal solution of the problem within \( K \) times of external iterations when \( p_c = 0 \), which mainly using the double-layer iterations and weighted average method. It includes \( N - 1 \) internal iterations and some number of external iterations. For the second step, the optimal transmission rate \( r_{ee} \) is compared with which does not consider \( p_c \). The specific process of the proposed algorithm is as follows:

3.1. The first part.

The transmission start time of each packet is set as its arrival time, namely, the transmission duration satisfies \( \tau_i = \left\{ \begin{array}{ll} t_{i+1} - t_i & i = 1, 2, \ldots, N - 1 \\ T - t_i & i = N \end{array} \right. \), which means the transmission duration of each packet is the result of the instantaneous transmission algorithm. Subsequently, in each internal loop, the transmission time occupied by the two adjacent packets is weighted according to their packet size, in this case, the transmission start time of the latter packet in each internal iteration cannot be earlier than its arrival time. After \( N - 1 \) internal iterations, we perform the external iteration. The total energy consumption after \( N - 1 \) internal iteration is calculated and is compared with that of the last external iteration. The number of external iterations depends on the threshold value of the difference value \( \Delta \) between the two external iterations.

1-1: Initialization of the transmission duration. Calculate the transmission duration of each packet \( \tau_i = \left\{ \begin{array}{ll} t_{i+1} - t_i & i = 1, 2, \ldots, N - 1 \\ T - t_i & i = N \end{array} \right. \), and the total energy consumption in this case is \( W_0 = \sum_{i=1}^{N} \tau_i \left( e^{\tau_i} - 1 \right) \).

1-2: The internal and external iteration.

Let \( \tau_{best} = \left\{ \begin{array}{ll} \frac{B_i}{B_i + B_{i+1}} \times (t_i + 2 - t_i) & i = 1, 2, \ldots, N - 2 \\ \frac{B_i}{B_i + B_{i+1}} \times (T - t_i) & i = N - 1 \end{array} \right. \), if \( \tau_{best} < T_{i+1} - t_i \) then \( t_{i+1} = T_{i+1} \), else \( t_{i+1} = T_i + \tau_{best} \).
We can get \( \tau_i = \left\{ \begin{array}{ll} t_{i+1} - t_i & i = 1, 2, \ldots, N - 1 \\ T - t_i & i = N \end{array} \right. \), \( W = \sum_{i=1}^{N} \tau_i \left( \frac{b_i}{e^{\eta_i}} - 1 \right) \). If \( \frac{W_0 - W}{W_0} \leq \Delta \), then break, else \( W_0 = W \).

### 3.2. The second part.

2-1 The transmission start time of the packet should be the larger value of the transmission end time of the former packet and the arrival time of this packet, that is \( t_i = \left\{ \begin{array}{ll} 0 & i = 1 \\ \max(T, t_{i-1} + \tau_t) & i = 2, 3, \ldots, N. \end{array} \right. \) Then we choose the larger value of the actual optimal transmission rate \( r_{ee} \) and \( r_t \) obtained from the double iterations as the final result, that is \( r_{best} = \max(r_{ee}, r_t) \). The corresponding transmission duration is taken as the minimum value, i.e. \( \tau_{t_{best}} = \min(\tau_t \frac{b_t}{r_{ee}}) \).

2-2 According to the actual optimal transmission duration and the arrival time of the previous packet, the actual start time of the current packet is determined as \( t_t = \left\{ \begin{array}{ll} 0 & i = 1 \\ \max(T, t_{t-1} + \tau_{t_{best}}) & i = 2, 3, \ldots, N. \end{array} \right. \) Then we can calculate the new transmission time of the data packet \( \tau_t = \left\{ \begin{array}{ll} t_{i+1} - t_i & i = 1, 2, \ldots, N - 1 \\ T - t_i & i = N \end{array} \right. \).

According to the new transmission time, we can get the optimal energy consumption.

### 4. Simulation results

In this section, some numerical results are presented to assess the performance of the proposed algorithm. When \( p_c = 1 \) watt, the size of the packet is changed, the optimized rate \( r_{ee} \) does not change with the change of \( B \). As shown in Fig.2 when \( B \) takes 1, 2, 3, 4, 5 Mbits, respectively, the value of \( r_{ee} \) is always around 1 Mbps. We can get the conclusion that the actual optimal transmission rate is independent of the size of the data packet. When \( B = 1 \) Mbits, the energy consumption changes with the transmission rate for different \( p_c \) is shown in Fig.3. When \( p_c \) takes 0.6, 0.8, 1.0, 1.2, 1.4 watts, respectively, \( r_{ee} \) increases gradually.

![Fig. 2 The energy consumption vs. the transmission rate for different size of the data packet.](image1.png)

![Fig. 3 The energy consumption vs. the transmission rate for different \( p_c \).](image2.png)
The size of five packets is \{15, 12, 8, 13, 4\} Mbits. The first internal iteration is carried out by the proposed algorithm can be seen in Fig. 4. After the iterative steps, we can obtain the ideal transmission time for each packet, with the transmission duration \( \tau_i \) of \{17.78, 13.56, 12.61, 24.80, 6.25\} seconds, respectively.

The second step with these five packets is shown in Fig.5. Compare \( r_{ee} \) with the previously obtained \( r_1 \) (\( r_1 = B_i / \tau_i \)), taking the larger of them as the final single packet optimal transmission rate (recorded as \( r_{i_{best}} \)). As shown in Fig.5.(a) and Fig.5.(b), where \( B_1 \) represents the situation of \( r_1 \geq r_{ee} \), which finally sets \( r_1 \) as the final \( r_{1_{best}} \); and \( B_2 \) represents the case of \( r_2 < r_{ee} \), which finally sets \( r_{ee} \) as the final \( r_{2_{best}} \). After transmitting the packet \( B_2 \), in the rest time, there is no data to be transmitted, and the corresponding power consumption is 0, which is shown as a straight line in Fig.5(b).

The difficulty of the proposed algorithm is that after processing the transmission rate of the first packet, such as \( B_2 \), the system has a suspending time, which increases the maximum time available for the latter packet. As shown in Fig.5(c), if the start transmission time of \( B_{i+1} \) is not adjusted after operating the transmission rate of \( B_i \), then \( r_{i+1} \) will continue to be used as its final transmission rate. As shown in Fig.5(d), after adjusting the start transmission time of \( B_{i+1} \) (not earlier than the arrival time of this packet and the end transmission time of the previous packet), the optimal transmission rate can be achieved.

After comparing and replacing \( r_1 \) and getting \( r_{i_{best}} \), Fig. 6 shows the specific transmission process of five data packets. In the case of this example, the optimal solution can be obtained through this algorithm. The first three data packets are transmitted by using \( r_{ee} \) and there is no time interval; the fourth and fifth data packets use their arrival time as the transmission start time, and use \( r_{ee} \) for
transmission. Their start transmission time are \{0, 16, 32, 58.45, 65.12\} seconds and the transmission time are \{16.30, 13.04, 8.69, 14.13, 4.35\} seconds.

The impact of the number of data packets on the total energy consumption is investigated in Fig.7. In this set of simulations, the size of the data packets we adopted is all between 4 and 15 Mbits. As a comparison, the instantaneous transmission strategy is given. For the two algorithms, the energy consumption all increases with the number of data packets. It can be clearly seen that the instantaneous transmission algorithm consumes a larger amount of energy than the proposed algorithm, which indicates that the proposed algorithm can save more energy.

![Fig.6 The specific transmission process of five data packets.](image1)

![Fig.7 The energy consumption vs. the number of data packet.](image2)
5. Conclusion
In this paper, we consider a data packet transmission with the circuit power consumption, the problem of minimizing the energy consumption of packet transmission is formed. Then we introduce an energy-optimized algorithm for the data packet transmission, which includes the double iterations and the adjustment of the optimal transmission rate according to the actual case. The simulation results show that the proposed algorithm can achieve optimal energy consumption, which is more efficient than the instantaneous transmission strategy.

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