Joint Delay Reduction and Power of Device for Differentiated Data Transmission in D2D Network

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Abstract In wireless communication, Device-to-Device (D2D) networks will become more and more common with the popularity of mobile terminals. However, in a D2D network, the processing capabilities of different terminals may be different, and the energy of different terminals is different due to battery life. In order to improve the quality of experience (QoE) of terminals with different processing capabilities and energy, and realize the transmission of differentiated data streams, this paper combines the existing base station retransmission and terminal retransmission algorithms in D2D network. In the transmission process, the data packet is divided into a basic layer and several enhancement layers according to the definition of the data. Based on the link quality, the basic layer data packet is transmitted firstly, then the enhancement layer data packet is transmitted. Moreover, not only the base station retransmits the data packet, but also the terminal that has received the corresponding data packet also participates in the retransmission. In order to extend the average life of the network, we propose the maximum weight packet selection algorithm based on channel quality and terminal energy (MWP-QE). The simulation results show that compared with the existing retransmission algorithm, this algorithm can realize the transmission of differentiated data, reduce the retransmission delay and extend the life of the network.

1. Introduction
In recent years, with the spread of various mobile terminals such as smart phones and tablets, it has become more and more common for people to use these smart devices as terminals to receive and transmit various data. On the one hand, the exponential growth of mobile terminals has led to an explosion of cellular traffic [1]. Study [2] have shown that by 2021, global mobile data traffic will increase seven fold. On the other hand, the difference in terminal processing capabilities is growing. At the same time, due to the innate physical characteristic of the wireless channel, the difference of transmission links is more prominent. In addition, since the energy of the mobile terminal is limited, the terminal energy is also a problem to be considered. Therefore, extending the average network lifetime as long as possible while implementing differentiated data stream transmission becomes a problem that needs to be solved in this paper.

In order to realize the transmission of differentiated data in wireless networks, researchers at home and abroad have done a lot of work and achieved rich results. At present, there are some methods to solve the problem: In [3], the paper assign a weight value to each lost data packet, and propose a differential data transmission algorithm based on Maximum-Weight-Clique (MWC), which can
effectively solve the problem of differentiated data transmission caused by different terminal capabilities. The literature [4], aiming at maximizing the total network throughput, proposed a heuristic algorithm for determining the optimal coding type of each link, but the algorithm sacrifices the throughput of the receiver with high processing capability. In [5], instant video coding (SVC) is proposed. SVC stratifies data, and the terminals can obtain different layers of data according to requirements, which can achieve differentiated data transmission. In recent years, with the advent of the 5G era, device-to-device (D2D) technology can be used for wireless network transmission because it can communicate directly with nearby mobile terminals without going through the base station [6]-[9], in the literature [9], the D2D technology is applied to wireless network transmission, during each retransmission, the base station and the terminal randomly select data packets that can be combined and retransmitted. Due to the solution does not consider the terminal energy problem, it cannot guarantee the stability of the network. In this paper, the base station sends layered data packets to the terminals. Since some terminals cannot receive all the required data packets, it is necessary to retransmit the partial data packets. In the retransmission phase, the base station and the terminal respectively retransmit the layered data packets to implement differentiated data stream transmission, and at the same time, in order to extend the average network lifetime, the terminal energy is considered.

The rest of this article is organized as follows: In the second part, we will introduce the system model. In the third part, based on the D2D network, we combine the base station retransmission with the terminal retransmission, and assign weight to each data packet that needs to be retransmitted according to the channel quality, and use this weight as the basis for selecting the data packet. Then on this basis, in order to extend the network the average lifetime, we proposes MWP-QE. In the fourth part, we will analyze the simulation results. The fifth part is the conclusion of this paper.

2. System Model

2.1 System Model

The system model consists of one base station and N terminals with different processing capabilities. The base station needs to send M data packets to these terminals, and the system model also satisfies the following assumptions:

1) All datas are transmitted through data packets, and each data packet is transmitted by the sender within a fixed time interval slot;
2) All terminals are close to each other and can receive data packets from the base station and one other terminal simultaneously;
3) There is no loss when the receiver sends feedback information to the sender through the uplink;
4) The sending end knows the processing capabilities of all the terminals;
5) Terminal nodes are heterogeneous, and all wireless channels are independent of each other, that is, the packet loss behavior between the sender and all terminal nodes is a set of independent Bernoulli processes, and the transmission packet loss rates are independent of each other.
6) The remaining energy of the terminal is independent of each other, and each time the mobile terminal transmits a data packet, it consumes part of the energy, regardless of the energy consumed by the terminal to receive the data packet.

2.2 State Feedback Matrix and IDNC Undirected Graph

The entire packet transmission process is divided into two processes: the broadcast phase and the retransmission phase. During the broadcast phase, the base station sends data packets to all terminals. Some packets were not successfully received by the terminal due to link path loss. In the retransmission phase, the base station and the corresponding terminal respectively retransmit the data packets that have not been successfully transmitted. After each transmission, the base station will receive status feedback from the terminals and update the Status Feedback Matrix (SFM):
When all values that are not "-1" in the state feedback matrix are "0", it indicates that all the terminals have successfully received all the data packets, and the data transmission ends.

For each "1" in SFM, we use a vertex $v_{ij}$ to represent, where $i$ represents the ordinal number of the terminal corresponding to the vertex, and $j$ represents the ordinal number of the data packet corresponding to the vertex. When the two vertices $(v_{ij}, v_{km})$ in the SFM meet one of the following two conditions: (1) $p_i = p_k$, the terminals corresponding to the two vertices lose the same data packet; (2) $p_i \in H_i$ and $p_k \in H_m$, $H_i$ is a set of packets that has been received by terminal $i$ and $H_m$ is a set of packets that has been received by terminal $m$, then we will connect the two vertices.

3. Improved Retransmission Algorithm

3.1 The Priority of Base Station and Terminal

We first divide the data packets that need to be retransmitted into two categories: The first type is the data packets that all terminals have not successfully received. These data packets can only be transmitted by the base station during the retransmission process, which denoted by Packet by Base station (PB). The second type is the data packet successfully received by some terminals, such data packets can be retransmitted by the base station or terminal, which denoted by Packet by Base station or Terminal (PBT). Each time, the base station and a certain terminal simultaneously transmit one packet combination respectively. The principle of selecting a packet is as follows:

1) When the PB is not empty, the base station selects a data packet from the PB, and the terminal selects a data packet combination from the PBT; since the two types of data packets do not have an intersection, it is not necessary to consider the order of two type data packets.

2) When the PB is empty, both the base station and the terminal select a packet combination from the PBT. As we all know, the base station contains all the data packets, it can combine and transmit any data packets combination, but due to the terminal may only successfully receive some data packets, there are certain restrictions on the combined transmission of the data packets. Therefore, in this case, Packets Combination retransmit by Base station (PCB) is preferentially searched for each retransmission, and then search for Packets Combination retransmit by Terminal (PCT).

3.2 IDNC-based packet selection algorithm under D2D network

According to the introduction in 3.1, each retransmission phase, we need to find the PCB and PCT successively, and transmit it by the base station and the corresponding terminal. When looking for PCB, we first judge whether PB is empty. If PB is not empty, randomly select a packet to retransmit; if PB is empty, we find PCB in PB.

When the PCB is found, we search for the PCT from the remaining packets. For each "1" in the SFM that consists of the remaining packets, if the two vertices satisfy one of previous conditions, and existing terminal has both the data packets corresponding to the vertices, the we will connect the two vertices.

At the $t$-th retransmission, we can get two undirected graphs, one is an undirected graph transmitted by the base station, denoted by $G_b$, and the other is an undirected graph transmitted by the terminal, denoted by $G_t$. Then, the problem of finding a packet combination turns into the problem of finding the largest group in an undirected graph. For each node $v_i$ in $G_b$, $p_i$ is the packet loss rate of the data packets transmitted by the base station. In order to find the largest group, we assign a weight to each vertex in the undirected graph. In the undirected graph transmitted by the base station, we only need to consider the packet loss rate of the data packet transmitted by the base station, so for each node we set the weight of the following formula (1):

$$\begin{align*}
    f_s &= \begin{cases} 
    0, & \text{if packet } P_i \text{ is received by } R_i \\
    1, & \text{if packet } P_i \text{ is missing at } R_i \\
    -1, & \text{if } R_i \text{ does not need packet } P_i
    \end{cases}
\end{align*}$$
In $G_i$, we need to consider the packet loss rate of the packet sent by the terminal and the energy of the terminal. Since each data packet can be sent by a different terminal, there are many choices for the weight of each vertex, and we choose the largest and smallest probability value as the weight of the vertex. So set the weight of the following formula (2) for each node:

$$w_i = 1 - p_i$$  

$$W_{ij} = \arg \max \left\{ \frac{E_i}{E_{\text{max}}} \right\}$$

Where $i$ and $j$ represent terminal numbers, $E_i$ represent the energy of the terminal $i$, $E_{\text{max}}$ represent the maximum energy of the terminal, and $p_{ij}$ represent the packet loss rate between terminal $i$ and terminal $j$.

The specific process is: constructing an undirected graph transmitted by the base station according to the obtained SFM, finding the first largest cluster PCB, and then constructing the undirected graph transmitted by the receiving end from the remaining data packets, looking for the second largest group PCT. When searching for the PCB, each time you select the vertex that is connected to the vertices in the largest group and has the highest weight, join the largest group. When the length of the largest group is equal to the number of receiving ends or traversing all the vertices, the searching process ends; when finding the PCT, when finding the vertice with the largest weight, it is first determined whether the terminal contains the largest group and the data packet corresponding to the vertex. If it exists, the vertex is added to the largest group; if it does not exist, discard the vertex and find other vertices to join the largest group. Then, the data packets in the two largest groups are separately XOR-encoded, and the PCB is sent by the base station, and the PCT is sent by the terminal that has the data packets at the same time. If more than one terminal has these data packets, the terminal with the highest energy will sent PCT. the energy of the mobile terminal is reduced after each data packet is sent.

3.3 Differentiated data hierarchical transmission under D2D network

In the broadcast phase, the base station broadcasts 15 data packets to all terminals. In the retransmission phase, for the low-processing capability receiver, since it only needs the base layer data packet, if we retransmit all the data packets at the same time in the retransmission phase, then some low-processing capability receivers can receive all the required data when the retransmission ends. Packet, which undoubtedly increases the latency of the receiver with low processing power. And all the receiving end needs the basic layer data packet, so we preferentially retransmit the basic layer data packet, and then all the basic layer data packets are successfully transmitted, and then retransmit the enhancement layer data packet.

4. Simulation Results

In this section, we compare and analyze the performance of the algorithm proposed in Section 3 through simulation, and use the retransmission time and terminal energy as indicators to compare the performance of different algorithms. Retransmission time is the time required for all terminals to successfully receive all required packets. In this paper, we use the comparative analysis method of control variables to change the number of terminals and data packets respectively, and compare the retransmission time of different algorithms in different situations. The less retransmission time, the better the performance of the algorithm. The four algorithms for comparison in the simulation are the MWP-QE algorithm, the MWP-Q algorithm, the MWC algorithm proposed in the paper [14], and the NCMI-Bacth algorithm proposed in the paper [12]. Since the first three algorithms are hierarchically retransmitted packets, in the simulation, the first few columns of the feedback matrix correspond to the reception of the base layer data packets, and the last few columns are the reception of the enhancement layer data packets. Although the NCMI-Bacth algorithm does not layer when retransmitting data packets, in order to ensure the fairness of performance comparison, the algorithm uses the same
feedback matrix as the first three algorithms for data retransmission. Since the algorithm selects packets in sequence, it selects from the base layer packet when selecting the packet, and considers the enhancement layer packet if the base layer packet cannot be retransmitted. This leads to some degree of layered retransmission of the algorithm.

Firstly, we fix the number of data packets to 18: \( P_1, \ldots, P_{18} \), in which \( P_1, \ldots, P_4 \) are the base layer packets; and \( P_5, \ldots, P_{12} \) are the first enhancement layer packets; the rest are the second enhancement layer packets. And increases the number of terminals from 10 to 30, and the processing capacity of any terminal is randomly selected between three levels. The packet loss rate between the sender and the terminal is randomly selected between [0.05-0.35]. The energy of the terminal is randomly selected between [5000J-10000J], and the energy consumption of the data packet transmitted by the terminal is 50J. The simulation results of averaging 20,000 times are shown in the figure. The simulation results of averaging 20,000 times are shown in the figure 1 and figure 2.

![Figure 1. the retransmission time of basic layer](image1.png)

![Figure 2. the retransmission time of all layers](image2.png)

Figure 1 is the retransmission time of basic layer. We can see that when the number of terminals is the same, the number of retransmissions of the MWP-QE algorithm proposed in this paper is significantly less than that of the NCMI-Batch algorithm and the MWC algorithm. This is because the MWP-QE algorithm not only performs hierarchical retransmission, but does not consider the data packets of the subsequent enhancement layer when retransmitting the base layer data packet, only retransmits the data packets of the base layer, and retransmits the data packets between the terminals. The NCMI-Batch algorithm does not transmit in layers. The retransmission phase retransmits all layers of data packets. Although the MWC algorithm performs hierarchical retransmission of data packets, it only considers the retransmission of base stations during the retransmission phase. The terminal performs retransmission, so the number of retransmissions is more than the MWP-QE algorithm. From figure 1, the base layer and all layers of the MWP-QE algorithm have slightly more retransmission times than the MWP-Q algorithm, because each time the MWP-Q retransmits, only the packets with better channel quality are considered, and the MWP-QE algorithm considers comprehensively. Although the number of retransmissions is slightly increased, the MWP-QE algorithm is superior in maintaining the stability of the D2D network.

Due to the inconvenient comparison of terminal energy, we have done the following simulation to illustrate the advantages of the MWP-QE algorithm in ensuring network lifetime and ensuring D2D network stability. Assume the following scenario: there are 30 terminals, 20,000 data packets, and the terminal energy is randomly distributed between [5000J-10000J]. Each time a terminal is selected to send a packet combination, and the energy consumed is 50J, and for convenience, we do not consider the other energy consumption of the terminal, until all the terminal energy is 0, we stop the retransmission. In the retransmission phase, the MWP-QE algorithm and the MWP-Q algorithm are respectively selected, and the number of terminals with the terminal energy of 0 is recorded. The change graph of the number of transmissions is shown in figure 3.
Figure. 3. number of terminals with terminal energy 0

It can be seen from the simulation diagram that with the increase of the number of retransmissions, the MWP-Q algorithm has a terminal with energy of 0 at the 1000th retransmission time, while the MWP-QE algorithm has a terminal with energy of 0 at the 1500th retransmission time. The simulation results show that the MWP-QE algorithm can reduce the probability that the low energy terminal is selected as the pseudo base station, thus reducing the energy consumption of the low energy terminal, ensuring the stability of the D2D network and prolonging the service life of the D2D network.

5. Conclusion
In this paper, we propose MWP-QE algorithm in order to solve the differentiated data transmission caused by different processing capabilities and different energy terminals. Through simulation, we can conclude that this algorithm can realize differential data transmission of terminals with different processing capabilities, and reduce the transmission delay of low-processing terminals while reducing the retransmission time of all terminals as much as possible. Because the factor of terminal energy is taken into consideration, the stability of the D2D network is ensured and the service life of the network is improved.

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References
[1] Li. C, Yan. Y, Zhang. B, “Network coding aided collaborative real-time scalable video transmission in D2D communications,” IEEE Trans. Veh. Techno., vol. 67, no. 7, pp. 6203-6217, July. 2018.
[2] Forecast C V N I, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update,”2016–2021 White Paper, Cisco Public Information, March, 2017.
[3] Zou. W, Zhao. Y, Jiang. T, “Differentiated data transmission based on instantly decodable network coding,” Inter. Conf. Commu. Signal Process, and Syst., Springer, Singapore, 2017.
[4] Jingjing. S, Bojin. Z, Anni. C, “Hierarchical multicast with inter-layer random network coding,” High-tech Communication, vol. 7, no. 1, Jun. 2011.
[5] Orsino. A, Ometov. A, Fodor. G, et al, “Effects of heterogeneous mobility on D2D and drone-assisted mission-critical MTC in 5G,” IEEE Commun. Mag., vol. 55, no. 2, pp. 79-87, Feb. 2017.
[6] Douik. A, Sorour. S, Al-Naffouri. T. Y, et al, “Delay reduction in multi-hop device-to-device communication using network coding,” IEEE Trans. Wireless Commun., vol. 17, no. 10, Oct. 2018.
[7] Li. Y, Sun. K, Cai. L, “Cooperative device-to-device communication with network coding for machine type communication devices,” *IEEE Trans. Wireless Commun.*, vol. 17, no. 1, pp. 296-309, Jan. 2018.

[8] Wang. Q, Zhang. X, Wang. Q, et al, “The network coding algorithm based on rate selection for device-to-device communications,” *IEEE Access*, vol. 7, pp. 23396-23406, Feb. 2019.

[9] Keshtkarjahromi. Y, Seferoglu. H, Ansari. R, et al, “device-to-device networking meets cellular via network coding,” *IEEE/ACM Trans. Netw.*, vol. 26, no. 1, pp. 370-383, Feb. 2018.