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Packet Segmentation for Contention-based Transmission in 5G

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Abstract

Contention-based transmission is a promising solution for small packet traffic in the fifth generation mobile networks (5G). Packet segmentation is applied to efficiently support diverse services with relative fixed transport block (TB) setting. The packet segmentation defined by LTE RLC Unacknowledged Mode (UM) is used in the study. First, we determine the header overhead of the segmentation. Then the impact of packet segmentation on the network throughput is analyzed and evaluated considering the different traffic patterns, network traffic loads and numbers of retransmission. The results show that packet segmentation is essential for the traffic with a large range of packet sizes. The results obtained in this paper can be used for the design of packet segmentation in different conditions.

1 Introduction

Internet of thing (IoT) communications play a critical role in providing the increasing demand in services for future cellular networks. The fifth generation mobile networks (5G) need to efficiently support a range of new IoT services, which is featured with small packets, massive connections, low latency, and high reliability [1]. The uplink contention-based transmission is a promising solution in 5G network for small data packets transmission [2]. The contention-based transmission is usually configured with limited transport block (TB) size, and packet segmentation is applied to efficiently support diverse services with relative fixed TB setting. For a certain resource pool assigned to contention-based transmission, smaller TB size means that the resource pool contains more resource units (RUs), then provides more transmission opportunities. Meanwhile, it may lead to the increasing header overhead. Thus, packet segmentation should be carefully designed for contention-based transmission. In the paper, the impact of packet segmentation on the network throughput is analyzed and evaluated considering different traffic patterns, network traffic loads and numbers of retransmission. The packet segmentation defined by LTE Radio Link Control (RLC) UM mode is applied.

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The reminder of the paper is organized as follows. Section 2 introduces the packet segmentation defined by LTE RLC UM and related Layer 2 header. Section 3 gives the system model and an analytical method for the collision-free rate. Section 4 shows the simulation results. Finally, Section 5 concludes this paper.

2 Packet Segmentation

In LTE, RLC Layer performs the packet segmentation. The RLC entity performs a framing function to make RLC SDUs fit into RLC PDUs. The framing function comprises segmentation and concatenation in the RLC transmitter, and reassembly in the RLC receiver [3]. In the study, LTE RLC layer procedure and RLC data structure are reused for contention-based transmission.

2.1 The Function of LTE RLC Layer

A RLC entity receives/delivers RLC SDUs from(resp. to) upper layer and sends(resp. receives) RLC PDUs to(resp. from) its peer RLC entity via lower layers. Each RLC entity is configured in one of three operating modes: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC services and functions supported by each mode is illustrated in [3]. For UM/AM mode, RLC layer segments and/or concatenates the RLC SDUs so that the UMD/AMD PDUs fit within the total size of RLC PDU(s) indicated by lower layer at the particular transmission opportunity notified by lower layer.

In this paper, we apply RLC UM mode for contention-based transmission to provide data segmentation concatenation, and reassembly functions.

A UMD (UM data) PDU consists of a data field and a UMD PDU header. UMD header consists of a fixed part (fields that are present for every UMD PDU) and an extension part (fields that are present for an UMD PDU only when the data field contains more than one SDU or SDU segment). The fixed part of the UMD PDU header consists of a Framing Information (FI) and a Sequence Number (SN). Note that the field of E is ignored to simplify and minimize the RLC PDU header. We assume only one packet arrives at UE each time, and the concatenation of SDUs is not required, i.e. that payload part of an UMD PDU is composed of only one

Table 1. Layer 2 Header

	Header length	Segmentation overhead
PDCP	8 bits	×
RLC UM	8 bits	8 bits
MAC	16 bits	16 bits
Total	32 bits	24 bits

SDU element. Therefore, UMD PDU header only includes the fixed part, and the length of fixed part is one byte.

2.2 Layer 2 Header of Contention-based Transmssion

For LTE, Layer 2 protocol stack consists of the Packet Data Convergence Protocol (PDCP), RLC and Media Access Control (MAC) sublayers. The header length of each sublayer was summarized in Table 1. The contention-based transmission scheme is applied for small data packet. The minimum header length could be applied for each sublayer under the assumption that each RLC UM PDU contains only one RLC SDU and each MAC PDU contains only one MAC SDU. The PDCP layer has no impact to RLC segmentation, only the extra header overhead from MAC and RLC UM is added for packet segmentation simulation. The header of UM mode is used for the simulation in Section 4.

3 Analysis of Collision-free Rate

We consider that the packet arrival rate of each user follows a Poisson distribution. The network traffic load λ is the total packet arrival rate per TTI. The resource pool, a fixed-size physical layer resource, is configured in each TTI for contention-based transmission in uplink. One resource pool can be further divided into one or several RUs. When packet is arrived, users randomly select a RU in the TTI for packet/segmented packet transmission. In the case that one RU is selected by more than one user for packet transmission, collision occurs, and packet transmission fails. The users perform segmentation according to the packet size (RLC SDU size) and the configured RU size (TB Size). The packet size follows a lognormal distribution [4, 5]. The lognormal distributions is characterized by two parameters: the position parameter μ, and the shape parameter σ. We set the position parameter μ to 6.7, and set the shape parameter σ to 0.2, 0.5 and 0.8 representing the traffic pattern with small, medium and large packet size variance, respectively. We limit the maximum size of the packet within 2000 bits.

Next, we derive the collision-free rate. The size of resource pool is S_{RP}. We divide one resource pool into N RUs. The probability density function of packet size is given as

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{ \frac{(\ln(x)-\mu)^2}{2\sigma^2} \right\} \quad , \ x > 0. \qquad (1)$$

Then the probability of packet size in the range of $[kS_{\mathrm{RP}}/N, (k+1)S_{\mathrm{RP}}/N], \quad k = 0, \ 1, \ \ldots, \ N-1$ can be expressed as

$$P\left\{ \frac{kS_{\mathrm{RP}}}{N} \leq X \leq \frac{(k+1)S_{\mathrm{RP}}}{N} \right\} = \int_{kS_{\mathrm{RP}}/N}^{(k+1)S_{\mathrm{RP}}/N} f(x)\,dx. \quad (2)$$

We consider segmented packet as a new packet, then the segmented packets also obey a Poisson distribution with the parameter $\overline{\lambda}$, which is calculated by

$$\overline{\lambda} = \lambda \sum_{k=0}^{N-1} (k+1) \int_{kS_{\mathrm{RP}}/N}^{(k+1)S_{\mathrm{RP}}/N} f(x)\,dx. \qquad (3)$$

When there are N resources in the system and the number of packets is Y, which is a Poisson random variable with parameter $\overline{\lambda}$:

$$P\{K = Y\} = \overline{\lambda}^{Y} \mathrm{e}^{-\overline{\lambda}} / Y!. \qquad (4)$$

From [8], the probability of successful transmission of u packets among Y packets can be calculated as

$$p(u|Y) = \begin{cases} \mathrm{C}_N^u Y! m(u)/N^Y & , \quad 0 \leq u < \min(Y-1, N) \\ \mathrm{C}_N^u Y!/N^Y & , \quad u = Y \text{ and } N \geq Y \\ 0 & , \quad \text{otherwise} \end{cases} \qquad (5)$$

where

$$m(u) = \sum_{k=1}^{q} \mathrm{C}_{N-u}^{k} \sum_{a_1 \geq 2, \ a_2 \geq 2, \ \ldots, \ a_k \geq 2}^{a_1+a_2+\ldots a_k = Y-u} \frac{1}{\prod_{i=1}^{k} a_i!}, \qquad (6)$$

$$q = \min\{\lfloor (Y-u)/2 \rfloor, \ N-u\}, \qquad (7)$$

$$\mathrm{C}_N^u = N!/(u!(N-u)!). \qquad (8)$$

Here, $m(u)$ shows the failed attempts of $Y-u$ packets to transmit in $N-u$ resources that after u packets have succeed in transmitting.

Since Y is a Poisson random variable with parameter $\overline{\lambda}$, the collision-free rate v is defined by the number of packets transmitted successfully divided by the total number of packets, which is given by

$$v = 1 - \frac{\sum_{Y=1}^{+\infty} \sum_{u=0}^{Y} \mathrm{P}\{K=Y\} \cdot \mathrm{P}(u|Y) \cdot (Y-u)}{\sum_{Y=1}^{+\infty} Y \cdot \mathrm{P}\{K=Y\}} \qquad (9)$$

The header overhead and retransmission is not considered in the analysis, which will be studied in the simulation in Section 4.

4 Simulation Results

The simulation follows the system described in Section 3. A fixed-size resource pool is configured in each TTI. We consider all users apply the same modulation and coding scheme (MCS), the resource pool can deliver a Layer 2 PDU no larger than 2000 bits and ignore the concrete physical layer configuration. One resource pool is further divided into 1, 2, 4, 8 and 16 RUs. Correspondingly, the RU size is 2000, 1000, 500, 250 and 125 bits. When a packet arrives at a user, the user performs segmentation according to

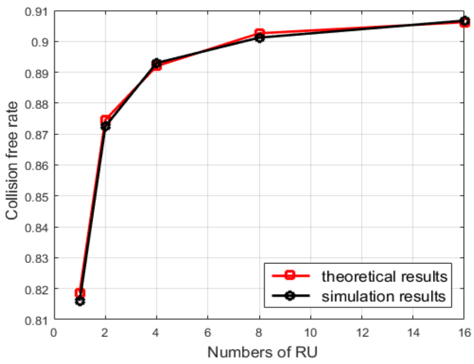

Figure 1. Collision-free rate vs. Numbers of RU (case 1).

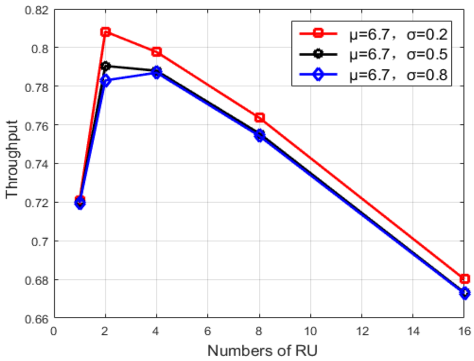

Figure 2. Throughput vs. Numbers of RU (case 2).

the packet size and the RU size configured in the simulation. The sum of segmented packet size and related header should not exceed the RU size. In the simulation, we assume correct packet transmission guaranteed by channel coding. In the case packet is segmented by several small packets, the segmented packets will be successively sent in following TTIs, until all the segmented packet are sent out. The packets failure occurs in the case any segmented packet is collided.

To further study the impact of the factors as distribution of packet size, traffic load and HARQ for the results, four simulation cases were defined in Table 2. The parameters of the simulation are given in Table 3.

Case 1: The collision-free rate is evaluated with the fixed load without considering of overhead and HARQ. In Figure 1, it shows the simulated collision-free rate curves, which is compared with theoretical analysis described in Section 3. From the Figure 1, the simulation results and theoretical results are consistent. The collision rate decreases when N increases. It means that without the header overhead, collision rate is reduced by using smaller size Layer 2 PDU. With N increasing from 1 to 16, the number of segmented packet increasing from 1 to 7.88, which is far more less than the increasing of N, thus the collision rate reduces. Meanwhile, smaller RU size provides a better granularity and reduces the bits waste for padding as the packets size is

Table 2. Simulation Cases

Case 1	Traffic pattern 2($\mu = 6.7, \sigma = 0.5$) network load $\lambda = 0.2$, no header overhead and HARQ
Case 2	Three traffic patterns with small, normal and large packet size variance ($\mu = 6.7, \sigma = 0.2, 0.5, 0.8$), network load $\lambda = 0.3$,consider the header overhead, no HARQ
Case 3	Traffic pattern 2($\mu = 6.7, \sigma = 0.5$), network load λ=0.1, 0.2, 0.3, 0.4, 0.5. consider the header overhead,no HARQ
Case 4	Traffic pattern 2 ($\mu = 6.7, \sigma = 0.5$), network load $\lambda = 0.3$, consider the header overhead, HARQ with maximum transmission number 0, 1 and 3

Table 3. Simulation Parameters

Parameter	Sysmol	Value
The size of RP	S_{RP}	2000 bits
The size of header overhead	H	24 bits
The number of RU in each TTI	N	1, 2, 4, 8, 16
The backoff window	W	10 TTI
Network load	λ	0.1, 0.2, 0.3, 0.4, 0.5
The maximum number of retransmissions	R	0,1,3

smaller than RU.

Case 2: We consider the header overhead. The header overhead for segmentation is described in Section 2. We use the normalized throughput, which is defined by the throughput of the successful transmission divided by the total throughput, as the key performance indicator. In Figure 2, there is a peak in the throughput, which is different from the monotonic increase of collision-free rate for case 1. When the cost of the segmentation header exceeds the benefit of collision reduction from the segmentation, the peak exists. For the traffic pattern with larger packet size variance (σ=0.8), the maximum throughput rate is achieved with the TB size S_{TB}, of 500 bits. For the traffic pattern with small and normal packet size variance ($\sigma = 0.2, 0.5$), the maximum throughput rate is achieved with the $S_{TB} = 1000$ bits.

Case 3: The performance of packet segmentation impacted by traffic load was studied. From the Figure 3, when the network load is high ($\lambda = 0.4, 0.5$), the maximum throughput is achieved when $S_{TB} = 500$ bits. With load decreasing ($\lambda = 0.1, 0.2, 0.3$), the maximum throughput is achieved with the TB size of 1000 bits. When load in the network is higher, more segmentation is the preferred choice. Otherwise, with lighter network load (fewer collisions), the less segmentations is the preferred choice. This is because the benefit of collision reduction from the segmentation is small when the network load is light.

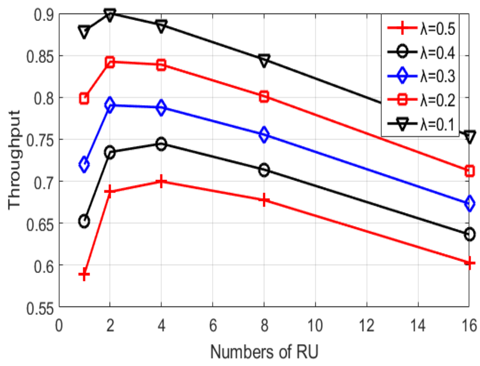

Figure 3. Throughput vs. Numbers of RU (case 3) .

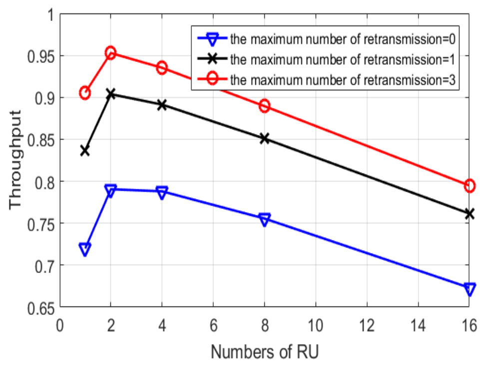

Figure 4. Throughput vs. Numbers of RU (case 4) .

Case 4: Numbers of retransmission's impact for packet segmentation is cautiously studied. For the failure packet retransmission, we set a backoff window $W$and the maximum number of retransmission R. When the retransmission times of packet are less than R, the failure packet will be retransmitted by choosing a TTI randomly within the backoff window. In Figure 4, compared with no retransmission (R=0), the throughput was significantly improved from 0.791 to 0.904 at optimal TB setting ($S_{\mathrm{TB}} = 1000$ bits), when R=1. Thus, the fewer segmentations will be preferable in the case that retransmission is enable.

5 Conclusions

In the paper, the impact of packet segmentation on the network throughput is analyzed and evaluated considering the header overhead of the segmentation, network traffic load and HARQ. The results show that packet segmentation is necessary for the traffic with large packet size variance. From the comparison with the theoretical derivation in case 1, simulation results validate the analysis of collision-free rate. From the simulation case 2 to case 4, We can conclude that: 1) packet segmentation improves throughput with the proper RU size setting. With the larger packet size variance, more segmentation is preferred. 2) With the increase of traffic load in the network, more segmentation can effectively improve the throughput. 3) The fewer segmentations is preferable in the case of retransmission. These conclusions are benificial for the design of packet segmentation in contention-based transmission.

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