Backoff HARQ for Contention-Based Transmission in 5G Uplink

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Abstract. With extraordinary growth in the Internet of Things (IoT), the amount of data exchanged between IoT devices is growing at an unprecedented scale, which is an important requirement for Fifth generation (5G) networks. Current Long Term Evolution (LTE) system is not able to efficiently support massive connectivity, especially on the uplink (UL). The contention based transmission enables to transmit data packet without waiting for dynamic and explicit scheduling grant from base station, and is more efficient for small packet transmission in terms of lower signaling overhead, lower latency and lower energy consumption. However, this may lead to high collision rates and a large amount of retransmissions. New low complexity recovery mechanism of non-successful transmissions is needed. So in this paper, a new Hybrid Automatic Repeat reQuest (HARQ) mode, called Backoff HARQ, is proposed for contention-based (CB) transmission in 5G uplink. For Backoff HARQ mode, round trip time (RTT) is set to a longer random time. We can get more HARQ processes and put off the retransmission information for the longer random backoff time as we set. We evaluate the proposed backoff HARQ mode using system simulations and show that the new mode provides superior system performance.

Keywords: Internet of Things (IoT) · Fifth generation (5G) · Contention-based access · HARQ · Back off

1 Introduction

The Internet of Things (IoT) is an intelligent infrastructure of uniquely identifiable heterogeneous computing devices capable of communicating with each other, services, and people through the Internet without human interaction. Fortunately, the fifth generation (5G) network called New Radio (NR) by 3GPP will need to efficiently support a range of new services, which is featured with small packets but massive connections and low latency, high reliability [1,2]. The 4G network known as Long Term Evolution (LTE), which adopts strict scheduling

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and control procedure, is designed to provide high data rate services for relatively small number of users. Current LTE uplink (UL) will not be sufficient to support massive connections and achieve higher spectrum efficiency as the significant signaling overhead of the scheduling. In additional, the UL scheduler's request and grant procedure introduce extra latency for the transmission.

The contention-based (CB) transmission is a promising solution for small data packets transmission in 5G UL with advantages of low signaling overhead, low latency, and support of massive connectivity [3–6]. But, the CB transmission efficiency will be limited by the packet collision rate, which is increased in proportion to the number of simultaneously transmitting packets and in inverse proportion to the transmission opportunities provided by the CB transmission channel. To further improve the transmission efficiency, nonorthogonal multiple access schemes with advanced receiver have been proposed to be employed with 5G UL CB transmission. A Non-Orthogonal Coded Access (NOCA) scheme, called ZC-NOCA, is used for CB transmission in 5G uplink. In the scheme, data bit is spread over OFDM symbols by using the non-orthogonal codes, which is generated by Zadoff-Chu (ZC) sequences [7]. The simulations in the paper is under contention-based NOCA scenario.

There are already some works on HARQ. A HARQ protocol, called Flexible HARQ, is proposed in [8], which allows flexible bandwidth allocation of retransmission data and new transmission data based on imperfect channel state information (CSI) and soft decoding information sent along with ACK/NACK feedback. [9] proposed an Adaptive HARQ (A-HARQ) scheme, where RTX are done on better quality sub-bands, with resources dynamically allocated based on Channel Quality Indicator (CQI) reports. [10] propose a novel HARQ scheme for 5G enhanced mobile broadband (eMBB) systems that also support ultra-reliable and low latency communications (URLLC). The proposed scheme performs retransmission of the lost part of a data packet when URLLC traffic, e.g., accident alert signal on the road, is transmitted immediately upon its creation by puncturing a part of the current data packet to avoid delay.

Now there are already two modes, asynchronous and synchronous HARQ mode, in LTE system. In this paper, Backoff HARQ mode is proposed for CB transmission in 5G uplink. For this mode, RTT is set to a longer random time. We can get more HARQ processes and put off the retransmission information for the longer random back-off time as we set. For stop and wait HARQ, in a HARQ process, whether the next transmission is to transmit new data or to retransmit old data is decided at a RTT after a transmission has occurred. So through a longer RTT, the interval between the same HARQ processes is increased for a random time. In general, it is important to minimize the HARQ buffer memory requirement at the UE. Similar objectives have been used in to optimize HARQ buffer memory management for a single carrier. And we evaluate the proposed backoff HARQ mode using system simulations to prove its superior system performance.

The rest of the paper is organized as follows, Sect. 2 gives the motivation of Backoff HARQ mode. Overview of Backoff HARQ mode is presented in Sect. 3.

The link level simulation of Backoff HARQ mode are presented in Sect. 4. Finally, we conclude the paper in Sect. 5.

2 Motivation of Backoff HARQ Mode

One proven way of increasing the reliability of transmission is by using HARQ, which can be sufficient for most applications, provided the given deadline is sufficiently long. However, it is possible for the system to reach the limit of 4 HARQ RTXs if the channel conditions are poor enough. HARQ is utilised as a Stop and Wait (SAW) process in LTE.

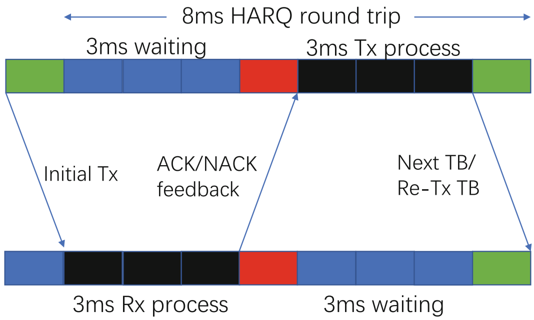

Fig. 1. The typical 8 ms LTE HARQ process.

A typical 8 ms LTE HARQ process follows as shown in Fig. 1. It involves the decoding of the received TB, Cyclic Redundancy Check (CRC), and the encoding of Acknowledgement (ACK)/Negative ACK (NACK) feedback for decoding success or failure respectively within 3 ms. The ACK/NACK feedback is then transmitted to the Tx. The Tx decodes the received ACK/NACK, constructs the next TB or RTX TB for decode success or failure respectively, and then encodes the next TB or RTX TB within 3 ms. The Tx then sends the next TB or RTX TB to the Rx to complete one LTE HARQ round trip. One problem with using a single HARQ SAW process, is that it waits for feedback for the majority of the 8 ms round trip. This is why LTE uses 8 parallel HARQ processes in the uplink (synchronous) or up to 8 in the downlink (asynchronous). However, for the contention-based transmission in 5G uplink, massive connectivity is required and they compete for the same time-frequency resources. The current LTE HARQ method can't cope well with the retransmissions of large amounts of data. So, a new method is needed.

3 Backoff HARQ Mode

HARQ uses stop-and-wait protocol to send data. In the stop-and-wait protocol, the sender sent a TB, it stopped waiting for confirmation. The receiver will acknowledge (ACK) or negate (NACK) the TB using 1-bit information. However, after each transmission, the sender stops and waits for acknowledgment, resulting in low throughput. So LTE uses multiple parallel stop-and-wait processes: when one HARQ process is waiting for acknowledgment, the sender can use another HARQ process to continue sending data. These HARQ processes jointly form a HARQ entity, which incorporates a stop-and-wait protocol while allowing continuous transmission of data. We already know that in order to make full use of 8 ms round trip time, LTE uses 8 parallel HARQ processes.

In order to deal with a large number of retransmission requests, RTT is set as a longer random time in backoff HARQ mode. For stop and wait HARQ, in a HARQ process, whether the next transmission is to transmit new data or to retransmit old data is decided at a RTT after a transmission has occurred. So through a longer RTT, the interval between the same HARQ processes is increased for a random time. And each HARQ entity has an independent backoff time.

For example in Fig. 2, if RTT is set to 10 TTIs, which means 2 TTIs longer than standard LTE RTT, the HARQ process used at TTI 1 is available at TTI 11. And we get two more HARQ processes and put off the retransmission information for two TTIs. Next, we will evaluate the proposed backoff HARQ mode using system simulations and see whether a better system performance is got.

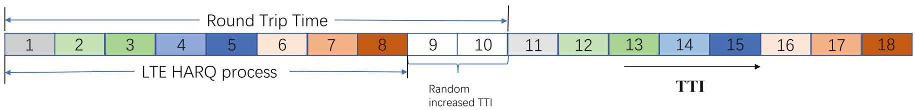

Fig. 2. Longer round trip time.

Table 1. Table captions should be placed above the tables.

Meaning	Symbol	Simulation parameter
Carrier frequency	**W**	4 GHz
Bandwidth	**B**	10 GHz
SubCarrier BW	**K**	15 kHz
Receiver in UL	**M**	LMMSE SIC
Modulation	**S**	QPSK
TTI duration	**T**	1 ms

4 Simulation Results

In this section, we analysis the performance of proposed Backoff HARQ mode using a detailed system simulator that used contention-based NOCA for 5G uplink transmission. In our simulations, UEs experience distance-dependent pathloss, shadow fading, and fast fading as per commonly-used 3GPP simulation assumptions. Each HARQ entity can experience independent round trip times for 8 to 12 TTIs. And we have tabulated the simulation parameters used in our simulation in Table 1.

4.1 Frame Error Rates (FER)

As shown in Figs. 3 and 4, in the NOCA scenario, when the number of receive antenna is one or two, and the max number of retransmissions is 6, the FER of asynchronous and synchronous HARQ mode are the same. Because when the arrival rate is high, the empty process does not exist, so there is no difference between the asynchronous and synchronous HARQ. And whatever the number of receive antennas and the packet arrive rate (PAR) of UEs are, the FER of Backoff HARQ mode is always lower than other modes. When the PAR is 200, the biggest difference among different HARQ modes is about 2.68%.

In Fig. 5, we observe FER of all the modes as we vary the max number of retransmissions when the PAR of UE is 100 and there is one receive antenna. As we can see, Backoff HARQ mode also shows its better performance. We find that the larger the max number of retransmissions is, the larger the gap is, as expected. And the biggest difference among different HARQ modes is 1.44%.

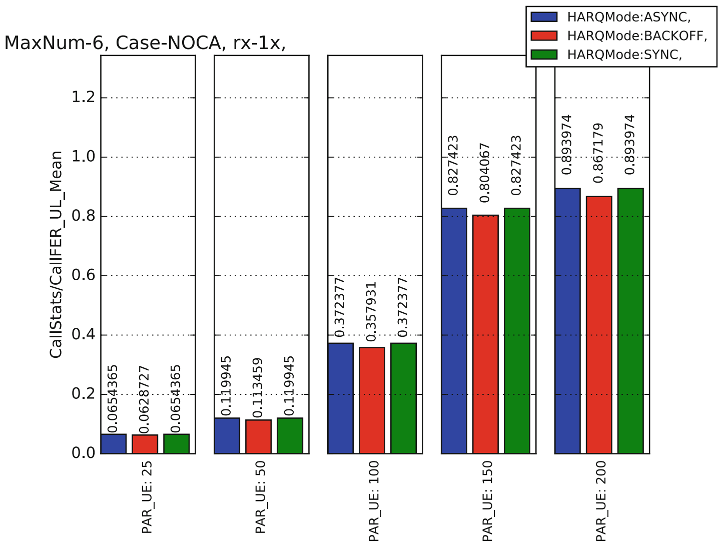

Fig. 3. FER of different HARQ mode under different PAR of UE when rx-1x.

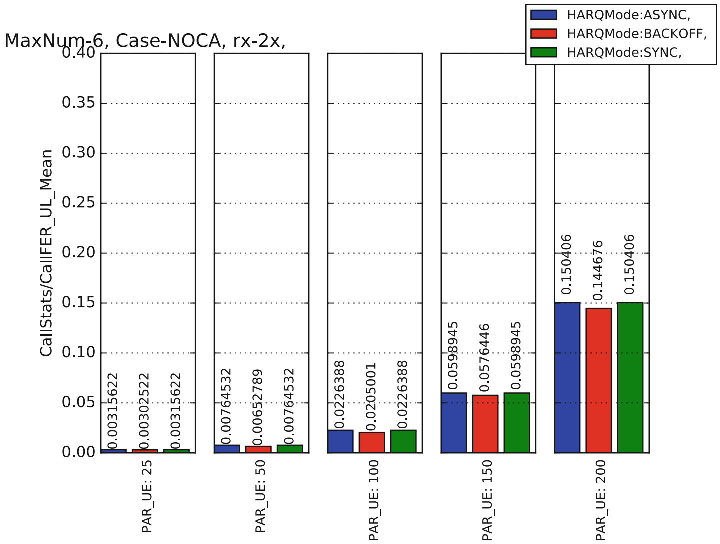

Fig. 4. FER of different HARQ mode under different PAR of UE when rx-2x.

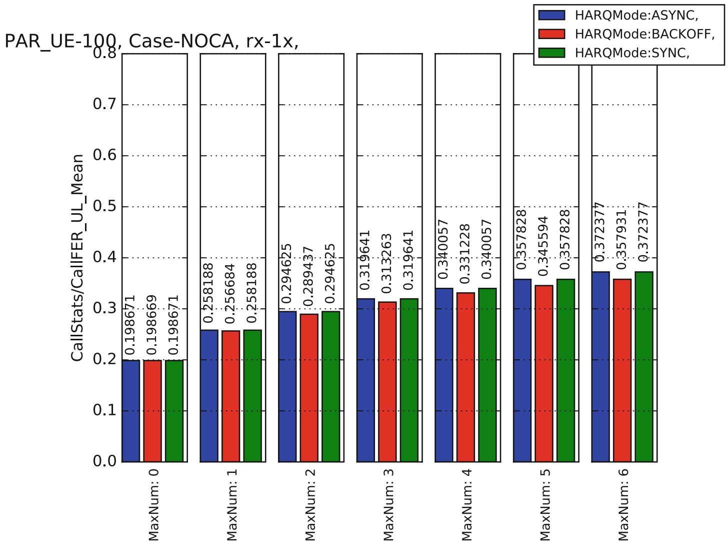

Fig. 5. FER of different HARQ mode under different max number of retransmissions.

As for when the number of receive antennas is two, the difference of all the HARQ modes is small, the next we will focus on the simulation results of one receive antenna. And for the similar reason, we will only observe asynchronous and Backoff HARQ mode.

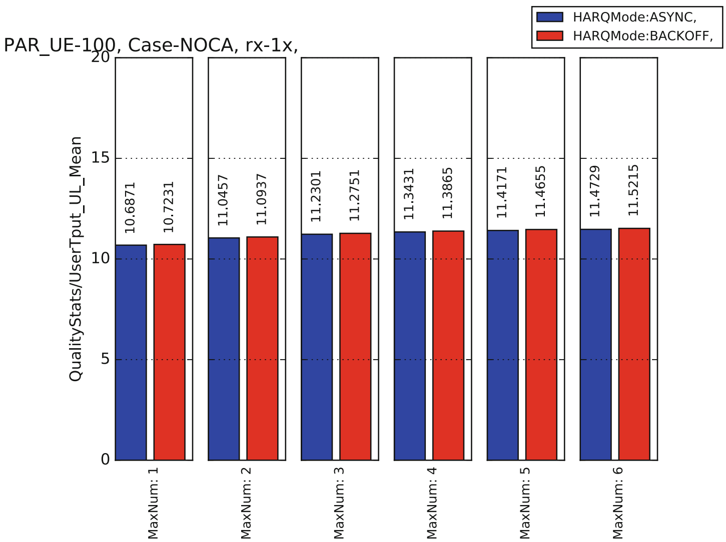

Fig. 6. Throughput of different HARQ mode.

4.2 Throughput

Next, our proposed Backoff HARQ mode is compared to the asynchronous HARQ mode in terms of user throughput of mean value. As we can see in the Fig. 6, The results are very close, but we can also find that the throughput of Backoff HARQ mode is always larger. And the bigger the max number of retransmissions is, the larger the throughput is. The biggest difference between the average of user throughput is 48.6 kbps.

5 Conclusion

In this paper, Backoff HARQ mode is proposed for CB transmission in 5G uplink. In contention-based access, because multiple users share the same time-frequency resource, non-orthogonal collisions of arriving signals at the receiver may be caused by the users. And collisions will be more serious when a large number of users access. In the stop-and-wait protocol, multiple parallel stop-and-wait processes are used. We try to solve the problem by increasing the RTT by a random back-off time (0 to 4 TTIs), for which we called Backoff HARQ mode. The link level simulation of Backoff HARQ mode has been implemented. The simulation results show the FER and throughput of our proposed Backoff HARQ are proved to be better than synchronous and asynchronous HARQ mode. The pursuit of better performance is the future work.

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