

UL Coverage Enhancement for Massive Machine Type Communication in 5G

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Abstract—Massive machine type communication (mMTC) is one key scenario in 5G deployment. Reducing the signaling overhead and enhancing the coverage are two important targets. To reduce the signaling overhead, UL grant free transmission is considered, where one user equipment (UE) transmits data directly on one resource unit within the preconfigured resource set without eNB's scheduling. Repetition is the baseline method for coverage enhancement. To achieve efficient transmission, different repetition levels are configured for one UE and UE selects the repetition level for the transmission based on its measurement results. On the eNB side, eNB blindly decode the incoming data by assuming different repetition levels. In this case, eNB may successfully decode the data in earlier time before the repetition ends due to the inaccurately under-estimated channel estimation on the UE side and then performs the HARQ-ACK feedback earlier than the UE's expectation. In this case, unnecessary retransmissions happen at UE side due to the miss detection of the HARQ-ACK. Unnecessary retransmissions lower the spectral efficiency and consume more power on the UE side. To avoid the early termination on the eNB side, we propose to use repetition-level specific sequence to scramble the data. Simulation results show by using the proposed method, the unnecessary retransmissions are totally eliminated and the spectral efficiency is improved by around 30% and the power saving is improved by around 35%.

Keywords- 5G; mMTC; UL grant free; Repetition; Scrambling

I. INTRODUCTION

Machine type communication (MTC) is the networking of intelligent, communications-enabled remote devices to allow autonomous or semi-autonomous key information exchange between them without human intervention. MTC is drawing great interest from the telecom industry as it promises to provide revenue growth with the proliferation of MTC devices. The MTC devices will enable a wide variety of services ranging from healthcare to smart grids and sensors. It is forecasted that in the next 5-10 years, MTC related service will account for majority of operators' revenue [1][2].

In the 5G research in the 3rd Generation Partnership Project (3GPP), MTC is one of the key scenarios [3]. The feature of massive connections is the key in the 5G MTC scenario. It is expected that 1000000 connections/km will be supported [4]. Thus, MTC in the 5G uses the terminology of mMTC (massive MTC). In addition, considering MTC user equipments (UEs) are usually installed in the basements of residential buildings or locations shielded by foil-backed insulation, metalized windows. And these mMTC UEs would experience

significantly greater penetration loss on the radio interface than normal UEs, coverage enhancement should be performed for these mMTC UEs to maintain similar performance to the normal UEs. In the 5G, the coverage for mMTC devices is required extended to maximum coupling loss (MCL) of 164dB [4]. Currently, LTE decided to adopt repetitions as the baseline solution. Power saving is another target for the mMTC design. It is expected that 2AA battery could provide 10~15 years power supply [4]. In addition, to reduce the device cost, the bandwidth of the MTC device is reduced to 1.4 MHz. Related operation such as measurement is limited within 1.4 MHz.

Since there would be huge number of mMTC devices in the network and the majority traffic for these devices is small data traffic e.g., 20 bytes per packet in the uplink[5]. If reusing the existing scheduling manner, a set of signaling and procedures will be proceeded such as random access, scheduling request and uplink grant transmission. For one small packet transmission, the overhead of these assisted signaling exceeds that of the transmitted data a lot, which is not efficient at all. Furthermore, such overwhelming signaling storming from massive connections occur great challenge to the network.

To get rid of the impact of significant overhead involved in the uplink data scheduling, UL grant free scheduling is introduced to the mMTC in 5G network [6][7]. In this scheme, the transmission resource and scheduling information such as modulation and coding scheme, transmission power is preconfigured/ predefined for a group of UEs. Furthermore, the possible numbers of repetitions for different coverage enhancement levels are preconfigured as well. Once there is traffic arriving at a certain UE, the UE will proceed the data transmission on the predefined resource directly without eNB's scheduling. Regarding the exact number of repetitions, UE will determine one repetition level within the preconfigured set of repetitions based on its channel status such as reference signal receiving power (RSRP) measurement result. However, due to the limited operation bandwidth, the channel status measurement on MTC device is usually inaccurate, especially in the low SINR situation, which MTC devices often experience [8]. It is highly possible that the selected repetition level is over-set due to the under-estimated channel status. On the eNB side, eNB is unaware of the data arrival and the number of repetitions. In this case, eNB will perform blind detection during each subframe by combining different number of repetitions for decoding. Considering UEs select the number

of repetitions based on rough and inaccurate channel status measurement, it is highly likely that eNB could decode the data with repetitions less than the determined value on the UE side and perform the corresponding HARQ-ACK feedback in the earlier time than UE's expectation. Then UEs will miss detect the HARQ-ACK, which will result in unnecessary retransmissions on the UE side. The unnecessary retransmissions would decrease the spectral efficiency and consume more power on the UE side.

In this paper, we will address this issue. By scrambling a repetition-level specific sequence on the transmitted data to avoid eNB's early termination, the unnecessary retransmissions can be avoided totally. To the best of our knowledge, this paper is the first one to address the ambiguous detection of repetitions for mMTC in 5G network design.

The reminder of the paper is organized as follows. Section II introduces related basic concepts and states the problem. In section III, a smart scrambling method to guarantee the spectral efficiency and save power will be elaborated. Numerical simulations and related analysis are to be carried out in section IV to verify the effectiveness of proposed method. At last, we conclude this paper in section V.

II. ANALYSIS OF THE PROBLEM

In this section, we will firstly provide some introductions on the related basic concepts to facilitate the problem explanation. And then we move to the problem statement part.

2.1 Basic concept

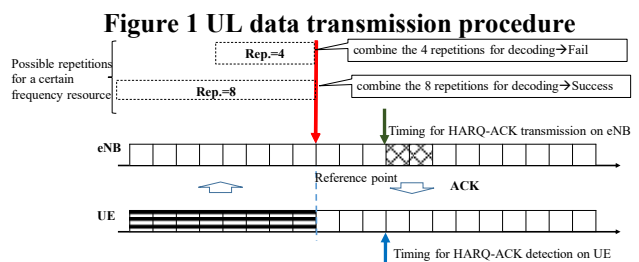
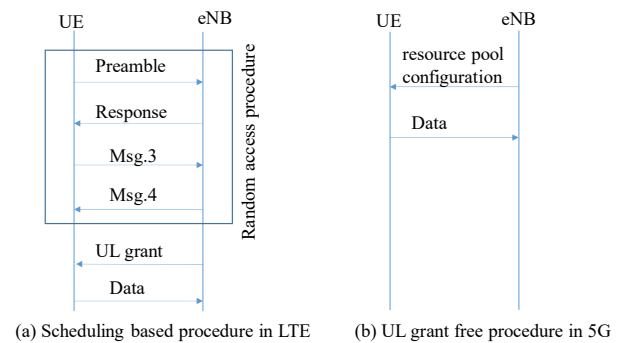
(1) Coverage enhancement solution

As explained in section I, to compensate the coverage loss caused by significant penetration loss, repeating the same content across multiple subframes should be applied to the transmitted data. Since the channel status for different UE are various, different levels of repetitions are supported in the network to ensure efficient transmission.

(2) UL grant free transmission

In LTE system, multiple DL/UL signaling would be involved for the UL scheduling as shown in Figure 1 (a). For human type communication, this kind of scheduling is feasible since the UL packet size is large (e.g., 2M bytes per packet) and multiple rounds of scheduling are needed. However, for mMTC, where the UL packet is usually small (e.g., 20 bytes per packet) and one-shot transmission is sufficient, the situation is quite different. If reusing the LTE scheduling procedure, the signaling overhead would become significant compared with the data amount tend to transmit, which would incur heavy signaling load in the network considering massive connections. For example, to transmit one data packet of 20 bytes, additional overhead of 53 bytes will be transmitted. To avoid this situation, UL grant free scheduling as shown in Figure 1 (b) is considered for the mMTC in the 5G study. Firstly, eNBs

broadcast the resources used for the uplink data transmission and a set of supported repetitions. On the UE side, once there is data arriving, UEs will select one resource for the data transmission. Then based on current channel measurement result, mMTC UE will determine the number of repetitions for the subsequent data transmission. The eNB will blindly detect data by assuming different repetitions as shown in Figure 2. In the example, 4 repetitions and 8 repetitions are the possible numbers of repetitions for this resource. In each subframe, eNB will firstly combine the previous 4 subframes for decoding and continue to combine the previous 8 subframes for decoding if previous combining fails. After the data decoding, HARQ-ACK feedback will be proceeded. As shown in the Figure 2, on the eNB side, if data is decoded successfully in subframe n , then subframe n is set as the reference timing point and ACK is to be transmitted 4 subframes later relative to the determined reference timing point. Otherwise, no feedback is performed. On the UE side, the reference point is the end of data transmission, UE would try to receive the HARQ feedback 4 subframes later relative to the reference timing point. If ACK is detected, UEs interpret the recent transmission successful. Otherwise, retransmission will be triggered.



2.2 Problem statement

In the UL grant free transmission, UEs transmit data automatically. eNBs are not aware of the data arrival and the associated repetition level. The eNB can only detect the data by assuming different numbers of repetitions blindly. Since the mMTC UEs determine the number of repetitions based on very rough and inaccurate channel status due to the low complexity feature, then the repetition level may be over-set. According to our system-level evaluation, the possibility of over-setting the number of repetitions is higher than 10% depending on

different UE implementations. Hence, it is likely that eNB will successfully decode the data earlier than the end of the repetitions. As shown in the example of Figure 3. UE1 determines to repeat the data for 8 times, while, eNB successfully decodes the data just by combining the previous 4 repetitions. After eNB successfully decodes the data, it will perform the corresponding ACK feedback 4ms later. However, UE1 doesn't know the situation of early termination on the eNB side and it will complete the transmission based on the determined repetitions and wait for the HARQ-ACK feedback 4ms after the end of transmission. Definitely, UE1 can't detect the HARQ feedback on that subframe and then retransmission will be triggered.

Such retransmissions are unnecessary since eNBs have successfully decoded the data. Unnecessary retransmissions would consume more resources in the network and decrease the spectral efficiency. In addition, more retransmissions would prolong the active time of UEs and consume more power. On the other hand, such retransmissions create more connections in the network and increase the risk of colliding with transmissions from other UEs as shown in Figure 4. The unnecessary retransmission of UE1 collide with the transmission from UE2. The collisions will aggravate the problem of spectral efficiency decreasing and power consumption.

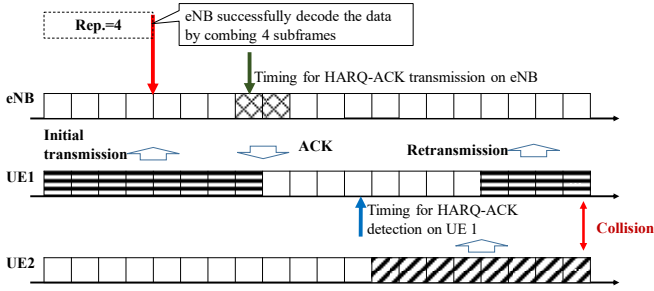


Figure 3 Problem of early termination

III. PROPOSED METHOD

We propose one mechanism in this section to avoid the ambiguity on the eNB side. The key principle of the proposed method is to scramble a repetition-level specific sequence on the data to eliminate the risk of early termination and early HARQ-ACK feedback on the eNB side.

A. Sequence Definition

In LTE system, Gold sequence is employed for the data scrambling. In our design, we reuse this principle. The scrambling sequence is defined by a length-31 Gold sequence. The output sequence $c(n)$ of length M_{PN} , where $n = 0, 1, \dots, M_{PN} - 1$, is defined by

$$\begin{aligned} c(n) &= (x_1(n + N_C) + x_2(n + N_C)) \bmod 2 \\ x_1(n + 31) &= (x_1(n + 3) + x_1(n)) \bmod 2 \\ x_2(n + 31) &= (x_2(n + 3) + x_2(n + 2) + x_2(n + 1) + x_2(n)) \bmod 2 \end{aligned}$$

where $N_C = 1600$ and the first m-sequence shall be initialized with $x_1(0) = 1, x_1(n) = 0, n = 1, 2, \dots, 30$. The initialization of the second m-sequence is denoted by $c_{init} = \sum_{i=0}^{30} x_2(i) \cdot 2^i$, where

$$c_{init} = n_{Rep} \cdot 2^{14} + \lfloor n_s / 2 \rfloor \cdot 2^9 + N_{ID}^{cell}$$

In the equation, n_{Rep} represents the number of repetitions for the transmission block, n_s is the slot number within the radio frame and N_{ID}^{cell} is the cell ID.

B. Processing on UE side

Figure 4 shows the procedure on the UE side. After the channel coding, For a codeword q , the block of bits $b^{(q)}(0), \dots, b^{(q)}(M_{bit}^{(q)} - 1)$, where $M_{bit}^{(q)}$ is the number of bits transmitted in codeword q on the physical uplink shared channel in one subframe, shall be scrambled with the repetition level scrambling sequence w prior to modulation, resulting in a block of scrambled bits $\tilde{b}^{(q)}(0), \dots, \tilde{b}^{(q)}(M_{bit}^{(q)} - 1)$ according to

$$\tilde{b}^{(q)}(i) = (b^{(q)}(i) + c^{(q)}(i)) \bmod 2$$

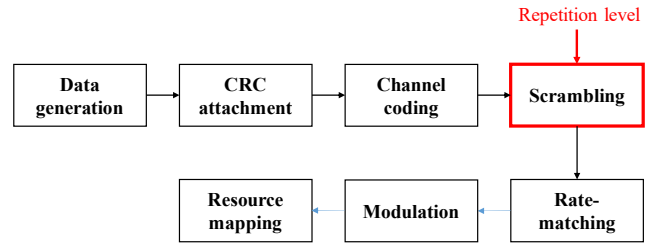


Figure 4 Processing of proposed method on UE side

C. Decoding on the eNB side

As we explained in section 2.2, eNBs blindly decode the data by assuming different number of repetitions. For the case illustrated in Figure 3, when eNBs try to decode data by combining previous 4 subframes, eNB will firstly de-scramble the demodulated data with the sequence derived based on 4 repetitions. And then perform the channel decoding. If the actual repetition number for this codeword is 8, and it is scrambled with sequence derived based 8 repetitions. Then using sequence derived from 4 repetitions for de-scrambling will result in wrong bit stream and the data will not be decoded successfully. Therefore, early termination situation can be avoided and the issue of misalignment in the transmission ending between eNB and UE can be solved.

IV. PERFORMANCE EVALUATION

In this section, numerical simulations are performed to verify the effectiveness of the proposed method. For comparison, the baseline method with different possibility of early termination (Pe) is to be evaluated as well.

A. Metric and parameters

Firstly, the total number of retransmissions is to be counted. Then, to further display the side effect of the retransmissions, the active time and consumed resource for one successful packet transmission are to be calculated as well. The active time is defined as the sum of transmission time for both initial transmission and retransmissions. Long active time will consume more power. Hence, this metric could reflect the power consumption situation. Similarly, the consumed resources are the sum of resources consumed by both initial transmission and retransmission. For a specific packet, more consumed resources lower the spectral efficiency. Thus, it could represent the spectral efficiency performance.

In the evaluation, several UEs share a set of resources and the packets arrive based on the Poisson distribution. Once there are packets in the buffer, UEs will randomly select resource for the transmission. Packet collision and transmission failure will trigger retransmission on the UE side. In addition, for the baseline method, there is possibility of early termination. If early termination happens, retransmission will be triggered on the UE side as well. Table.1 shows detailed parameter setting.

TABLE I. PARAMETERS FOR SIMULATION

Parameters	Values
Number of UEs	5
Number of resource unit	3
Configured repetition	{1, 2, 4, 8}
Distribution of possible repetition	{20%,40%,30%,10%}
Possibility of early termination (Pe)	{10%, 20%}
Possibility of transmission error	10%
Simulation time	10000 subframes

B. Evaluation results

Figure.5 shows the total number of retransmissions in the cell by varying the data arriving rate. In the figure, retransmissions caused by different reasons are shown respectively. Figure.6 and Figure.7 exhibit the average consumed resource and average active time for one successfully delivered packet respectively. Table 2 summarizes the exact performance gap between baseline method and proposed method. Generally, in the proposed method, the retransmissions due to early termination are eliminated and the retransmissions due to collision with retransmissions caused by early termination are removed accordingly. Due to less retransmissions, the performance of average consumed resources and active time is improved by around 30% and around 35% respectively when Pe is 10%.

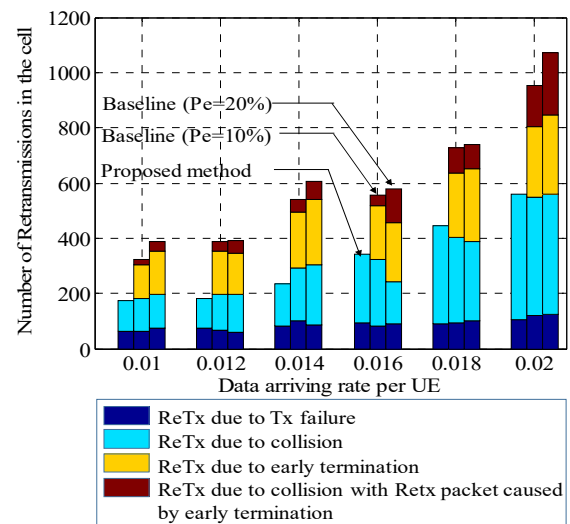


Figure 5 Total number of retransmissions in the cell

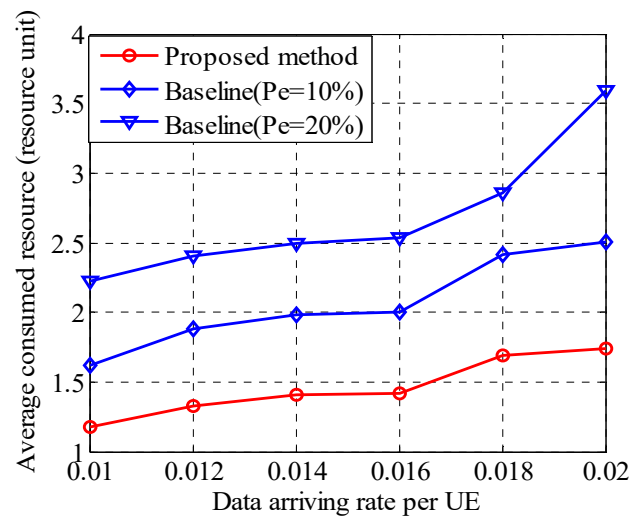


Figure 6 Average consumed resource

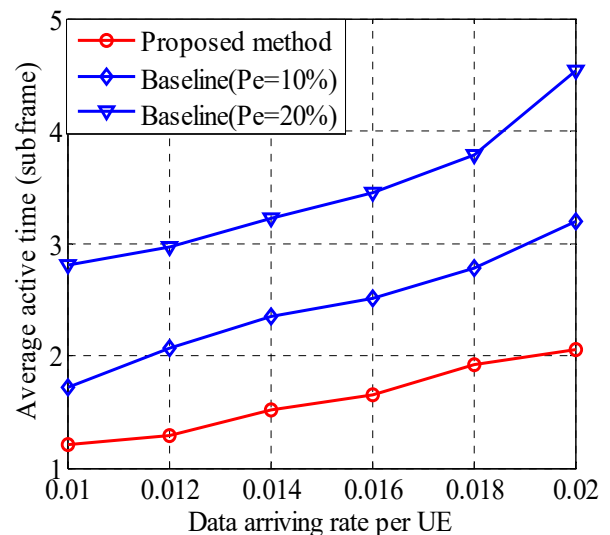


Figure 7 Average active time

TABLE II. PARAMETERS GAP BETWEEN BASELINE AND PROPOSED METHOD

Case of $P_e=10\%$ in baseline

Arriving rate	Average active time (subframe)	Average consumed resource (resource unit)
0.01	0.51666	0.4368
0.012	0.771625	0.551077
0.014	0.832321	0.574727
0.016	0.84826	0.583214
0.018	0.852617	0.721577
0.02	1.141405	0.773583

Case of $P_e=20\%$ in baseline

Arriving rate	Average active time (subframe)	Average consumed resource (resource unit)
0.01	1.048235	1.601573
0.012	1.074775	1.679364
0.014	1.089081	1.706111
0.016	1.122156	1.791548
0.018	1.161441	1.8649
0.02	1.855694	2.486568

C. Discussion

Some observations and analysis based on simulation results are summarized.

- (1) According to Figure 6 and Figure 7, it is observed that both the average consumed resources and active time increase with the increase of the arriving rate in baseline method and proposed method. One reason is the packet collisions increase due to more connections in high arriving rate for both methods as shown in Figure 7. In addition, for the baseline method, the potential collisions between one normal packet and a retransmission packet due to early termination increases as well as shown in Figure.7.
- (2) In Figure 6 and Figure 7, the proposed method outperforms the baseline method significantly in both average consumed resource and average active time. The performance gain mainly comes from two aspects. One aspect is that the retransmissions due to early termination is removed in the proposed method. Another reason is the additional collision caused by retransmissions due to early termination are eliminated as well in the proposed method.
- (3) According to the performance gap summary in Table.2, it can be observed that under one specific P_e , the performance gap between proposed method and baseline

method in both average consumed resource and average active time increases with the increase of data arriving rate. As analyzed in the aforementioned item (2), the performance gap mainly comes from two aspects. Under a specific possibility of early termination, the performance gap caused by retransmissions due to early termination will be enlarged due to more transmitted packets. Moreover, more retransmission packets due to early termination and more packets to be transmitted due to higher data arriving rate would create more collisions and retransmissions accordingly. Then, the performance gap will be further enlarged.

- (4) By comparing the performance gap with different P_e under specific data arriving rate in Table 2, the performance gap between proposed method in both average consumed source and average active time increases with the increase of possibility of early termination. Similarly, the difference in performance gap also comes from the retransmission due to collision with the retransmission packets caused by early termination. Under fixed traffic load, high possibility of early termination would increase more retransmission packets for this reasons and these retransmission packets would block other transmission with higher possibility.

V. CONCLUSION

In this paper, we investigate the early termination issue in the UL grant free transmission for mMTC in 5G . To avoid the ambiguity in the repetition level determination caused by the early termination, we propose to use repetition level specific scrambling sequence on the UL data. Simulation results clearly show that proposed method could improve the spectral efficiency and reduce the power consumption significantly.

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