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Happy Bits Based BSR Mechanism in 5G Networks

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Abstract. Being an important part of uplink dynamic scheduling, Buffer Status Report (BSR) has theoretical and practical significance for improving the resource utilization ratio of Long Term Evolution (LTE) system. Because uplink scheduler in base station is not directly aware of the UEs buffer content, the performance of its resource allocation strategy heavily relies on the accuracy of BSR feedback. However, the currently adopted non-uniform quantization mechanism for BSR, will inevitably cause considerable quantization error, thereby lead to an enormous waste of radio resources when large buffer size is taken into account. Therefore, this paper presents a revised BSR mechanism to improve the accuracy of BSR by fully utilizing two reserved bits, so called “Happy bits”, in MAC BSR control element’s sub-headers. Besides, this paper also proposes criteria to set those Happy bits. Simulation results show that, this new mechanism tremendously improve radio resource utilization ratio without introducing additional signalling overhead.

1. Introduction
The Fifth Generation (5G) wireless communication system, which is the latest technology research project launched by the 3rd Generation Partnership Project (3GPP), supports downlink peak rates of 20 Gbps, an uplink peak rates of 10 Gbps. Besides, 5G network is designed to provide lower latency, high data rate services with more flexible spectrum usage and more improved spectral efficiency, which inevitably entails 5G network to adopt a dynamic radio resource scheduling strategy. Dynamic resource scheduling takes the two-dimension resources, time-frequency resources, into account simultaneously and dynamically allocates them to different users according to their actual requirements. Consequently, it makes the dynamic scheduling scheme to be extremely complicated. Furthermore, it is of great importance to properly design the dynamic scheduling strategy [1]. Otherwise, the network performance may be significantly degraded rather than improved.

In 5G system, the uplink scheduler resides in the medium access control (MAC) layer of eNB. The scheduler needs information about the current status of the UE buffer to manage radio resources efficiently [2]. Therefore, 3GPP introduces a Buffer Status Report procedure, which is used to provide the serving eNB with information about the amount of data available for transmission in the buffers of the UE. Consequently, the more precise buffer size information UE reports, the more accurate scheduling decisions eNB will make. Then, the trade-off is more uplink overhead to send the feedback on uplink [3]. Taking account of reporting actual buffer size directly, bit cost is too heavy for UE to afford. As a result, current BSR procedure adopts non-uniform quantization strategy to quantify the buffer size in UE side. On one hand, non-uniform quantization that uses limited discrete values to indicate continuous ones reduces the signaling overhead. On the other hand, non-uniform quantization improves the quantized signal to noise power ratio (SNR) for small buffer size at the cost of
considerable estimation deviation for large buffer size, leading to the waste of time-frequency resources.

The rest of this paper is organized as follow: In section II, we give a brief introduction to current BSR mechanism and discuss some problems existing in it. In section III, a revised BSR mechanism based on Happy bits is proposed. A simulation and conclusion are presented in section IV and V.

2. Current BSR Mechanism in 5G

A MAC Protocol Data Unit (PDU), described in figure 1, is composed of a MAC header, zero or more MAC Service Data Units (SDU), zero or more MAC control elements, and optionally padding. A MAC PDU header consists of one or more MAC PDU sub-headers. Each sub-header corresponds to either a MAC SDU, a MAC control element or padding [4]. Additionally, BSR control element is one of the MAC control elements reported by UE in the uplink.

![General MAC PDU format](image1)

**Figure1.** General MAC PDU format

2.1. Current BSR Mechanism

In current BSR procedure, served UE uses a MAC PDU to carry a BSR MAC control element. According to different requirements, BSR control elements can be categorized into three formats: Short BSR, Truncated BSR and Long BSR. For each logical channel, RRC optionally maps it to a Logical Channel Group (LCG), which has a maximum of four ranging from #0 to #3, for BSR reporting [5].

Illustrated in figure 2, the Short BSR control element is 1 byte long, where the former 2 bits indicate the LCG identity, and the remaining 6 bits, that is the buffer size field in BSR control element, is used as non-uniform quantization index, which will discussed below. It indicates the amount of data available associated with that LCG. Moreover, the Long BSR control element is 3 byte long, and utilized for reporting data amount of the uplink buffers of all LCGs.

![BSR control element](image2)

**Figure2.** BSR control element

Consequently, eNB can be aware of the data amount of the uplink buffer size associated with LCG by looking up Table I. This table reflects the mapping relationship between 6-bit quantization index
and buffer size value. Since the index presents a buffer size interval, eNB will suppose to take the maximum of that interval.

2.2. Problem Caused by Non-uniform Quantization
Considering the bit cost of reporting buffer sizes for LCGs in UE side, 3GPP decides to use 6 bits to quantify the buffer sizes. That means that it supports 64 ranks of quantization step size, the step-size increases nonlinearly to grant the quantified SNR keeping the same in each quantization interval.

3GPP 5G system supports non-uniform quantization ranging from 0 to 15000 byte, so the quantization error is 17%. Take small buffer size into account, it seems that 17% is not evitable enough. Where else, when it comes to large buffer size, quantization error is very serious. For example, if a UE’s uplink buffer size is 128126 bytes, UE will set the buffer size field of the BSR control element to be 63, encoding it with other MAC SDUs to build a MAC PDU and lastly send to eNB. Consequently, when serving eNB decodes that BSR control element from the MAC PDU, it will look up Table I. Then, eNB will manage resources scheduling based on the value of the upper bound of the interval-150000Byte. Obviously, it wastes 21874 bytes, which means the ratio of resources is only 85%.

3. Happy Bits as A Complement to Current BSR Mechanism
We propose using the two currently reserved bits in the MAC PDU sub-header corresponding to the BSR control element to report the buffer size information of UEs more accurately [6]. Based on previous High Speed Uplink Packet Access (HSUPA) system nomenclature, these two unused bits in MAC PDU sub-header dedicated to BSR control element are also referred to as “Happy bits” [7]. Criteria to set those Happy bits are also proposed, which is unlike in HSUPA - allow the eNB to get more accurate buffer size information.

3.1. Happy Bits Encode Criteria in UE Side
For Long BSR control element, the MSB (Most Significance Bit) of the two-bit Happy bits represents LCG#0 and LCG#1; LSB (Least Significance Bit) represents LCG#2 and LCG#3. Since each Happy bits needs to indicate two LCGs, it prefers to modify the buffer size value of the LCG which has larger quantization error.

Take the encode criteria for MSB for example, which can be applied to LSB either.Supposed the non-uniform quantization index for LCG#0 is x, while that for LCG#1 is y.

- If the buffer sizes of LCG#0 and LCG#1 reaches the upper(lower) bound of x and y respectively, then, the MSB is set to be 1(0);
- If either of the buffer sizes of LCG#0 and LCG#1 reaches the upper(lower) bound of x and y, then, the MSB is also set to be 1(0);
- If the buffer sizes of LCG#0 reaches the upper(lower) bound of x while that of LCG#1 reaches the lower(upper) bound of y, then, set the MSB according to LCG which has higher priorities;
- If the buffer sizes of LCG#0 and LCG#1 is both between BSR_{inf} and (BSR_{inf} + BSR_{sup}) \times 0.5, then set the MSB 1;
- If the buffer sizes of LCG#0 and LCG#1 is both between (BSR_{inf} + BSR_{sup}) \times 0.5 and BSR_{sup}, then set the MSB 0;
- If the buffer sizes of LCG#0 and LCG#1 each allocated in opposite bound of the quantization interval, then, MSB will prefer to represent the LCG which has larger quantization error.
3.2. Happy Bits Decode Criteria in eNB Side

3.2.1. Decode Criteria for Short BSR and Truncated BSR.

| Happy bits value | Estimated buffer size                                      |
|------------------|------------------------------------------------------------|
| 00               | [BSR_{inf} \times 0.75 + BSR_{sup} \times 0.25]           |
| 01               | [BSR_{inf} \times 0.75 + BSR_{sup} \times 0.25, (BSR_{inf} + BSR_{sup}) \times 0.5] |
| 10               | [(BSR_{inf} + BSR_{sup}) \times 0.5, BSR_{inf} \times 0.25 + BSR_{sup} \times 0.7] |
| 11               | [BSR_{inf} \times 0.25 + BSR_{sup} \times 0.75, BSR_{sup}] |

3.2.2. Decode Criteria for Long BSR.

For Long BSR, if the MSB of the Happy bits reported in BSR control element is 1(0), then buffer size of LCG#0 and LCG#1 is BSR_{inf}(BSR_{sup}) respectively, which is true to LCG#2 and LCG#3 according to the LSB of the Happy bits.

4. Simulations

In this section, we present a simulation which is strictly based on the 3GPP traffic model and LTE protocol stack. Simulation scenarios are based on ten users simultaneously launching data uploading application. Assume that the FTP traffic flow is 3M.

As we aim to investigate the performance of uplink resource schedule algorithm, we adopt the uplink-downlink configuration 0, in which the uplink sub-frames is more than downlink sub-frames in a radio frame.

In the first scenario, we simulate the current BSR procedure, while, in second scenario, we simulate BSR procedure complemented by Happy Bits. The simulation parameters are in table 2.

| Parameter                      | Value                                      |
|--------------------------------|--------------------------------------------|
| Uplink Traffic Type            | 3M FTP                                     |
| TDD configuration              | Configuration 0                            |
| Channel Model                  | 3GPP Spatial Channel Model(SCM)            |
| Antenna configuration          | 1 Tx, 1 Rx                                 |
| Path loss                      | L = 128.1+37.6*log(d), d = distance in km  |
| Shadow fading                  | Log-normal, 8dB standard deviation          |
| Bandwidth                      | 20MHz                                      |
| Cell layout                    | Single-cell                                |
| Link to system mapping         | EESM                                       |
| UE Number                      | 10                                         |
4.1. Ratio of PRB Utilization
The ratio of PRB utilization is expressed as a ratio between PRB numbers distributed by eNB and those used by UE actually.

As illustrated in figure 3 and figure 4, in current BSR procedure, the average PRB utilization ratio of four users is 88%, comparing to that of 93% when promoted BSR mechanism is applied. The average ratio of PRB utilization is expected to raise 5%.

4.2. Throughput of TCP
As can be seen from figure 5 and figure 6, in current BSR procedure, the average time spent on FTP upload is \((6.2 + 6.5 + 5.0 + 8.4)/4 = 6.5s\), the average start time is 0.4s. Therefore, we can come to the result that the total throughput of TCP is \(4 \times 3 \times 8/(6.5 - 0.4) = 15.7Mbps\). While, after adopted promoted BSR procedure complemented by Happy bits, the average time spent on FTP upload is \((5.6 + 6.0 + 4.8 + 7.0)/4 = 5.9s\) and the initial time is still 0.4s. So the throughput of TCP is \(4 \times 3 \times 8/(5.9 - 0.4) = 17.6Mbps\). In sum, the throughput of TCP has been increased by 12.1%.
5. Conclusion

Non-uniform quantization is adopted in current BSR mechanism. Compared to reporting buffer size with actual occupied bits, six quantization bits enormously reduce the overhead. However, it sacrifices the BSR accuracy, and results in the waste of resources, which may outweigh the benefit from the reduction of signalling overhead when it comes to large buffer size. Therefore, we propose a revised BSR mechanism that is based on Happy bits as a complement. Since the Happy bits are the two reserved bits in MAC PDU sub-header corresponding to BSR control element, it is not carrying additional signalling overhead. Theoretical analysis and simulation results indicate that revised BSR mechanism can improve the spectrum efficiency and system throughput in consideration of reporting large buffer size.

6. Acknowledgments

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