

Accurate determination of transport block size for 5G new radio

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The data payload from the medium access control layer to the physical layer is referred to as the transport block (TB). In fifth-generation new radio, the TB size is determined by using a formula due to large variations of available resource elements (REs) per resource block (RB). To ensure that a matching TB size can easily be scheduled in the retransmission instance, the reference number of REs is used to determine the TB size. As a result, the actual code rate may be much higher than the target code rate. This degrades the performance of the channel coding and increases the likelihood of the decoding failure. To solve these problems, the authors quantise the number of REs within the scheduled duration that are not available for the data transmission and the demodulation reference signal transmission. The difference between the reference number of REs of the traditional scheme and the quantised number is used to determine the TB size in the proposed scheme. Compared to the traditional scheme, the proposed scheme reduces the difference between the actual code rate and the target code rate.

Introduction: The data payload from the medium access control layer to the physical layer is referred to as the transport block (TB). In fourth-generation (4G) long-term evolution, the TB size is determined by using the look-up table [1], which is derived by assuming that there are three OFDM symbols in the control region and 11 OFDM symbols in the scheduled duration. Under this assumption, the number of resource elements (REs) per resource block (RB) that are available for the data transmission does not change. And the TB size is aligned with quadratic polynomial permutation interleaver sizes to avoid the insertion of filler bits.

In 5G new radio (NR), the scheduling is extremely flexible. The number of OFDM symbols in the scheduled duration may vary dramatically. In addition, there are highly configurable control information (hybrid automatic repeat request acknowledgment, channel state information (CSI) etc.) and reference signals (sounding reference signal (SRS), demodulation reference signal (DMRS), etc.) [2]. The number of REs per RB that are available for the data transmission may vary dynamically. As a result, determining the TB size through the look-up table is not a suitable scheme. In 5G NR, the TB size is determined by using a formula [3]. The formula has the following parameters: the number of REs, the number of layers, the modulation order, the target code rate, etc. There are essentially two options to derive the number of REs. One option is to use the actual number of REs available for data transmission. The other option is to use the reference number of REs. The actual code rate is well matched to the target code rate when the first option is used. However, it is not easy for the scheduler to obtain a matching TB size for retransmission due to the time-varying signal that is rate-matched around REs used for the data transmission. To ensure that a matching TB size can easily be scheduled in the retransmission instance, the second option is used in 5G NR [4, 5]. The reference number of REs is equal to the number of scheduled REs minus the sum of the number of DMRS REs and an overhead. Since the overhead is configured semi-statically, the REs that are dynamically allocated can not be accounted for by the overhead. The reference number of REs may be much larger than the actual number of REs available for the data transmission. As a result, the actual code rate may be much larger than the target code rate [6]. Fig. 1 illustrates an example. The physical downlink shared channel (PDSCH) is used for data transmission. The physical downlink control channel (PDCCH) is used for the control signaling. The synchronisation signal block (SSB) is used for the cell search. The number of REs that are allocated to the SSB varies dynamically from slot to slot and can not be accounted for by a semi-statically overhead. The reference number of REs is 132 and the actual number of REs available for the data transmission is 84. If the target code rate is 0.60, then the actual code rate is ~ 0.94 .

Quasi-cyclic low-density parity-check (QC-LDPC) code with a rate-compatible structure is adopted in 5G NR for data channels. The parity-check matrix of the QC-LDPC code can be described by a small base graph. Two base graphs, BG1 and BG2, are supported to guarantee the performance of the channel coding over a wide range of code rates and TB sizes. BG1 is designed for large TB sizes and high code rates. BG2 is designed for small TB sizes and low code rates

[7, 8]. Figs. 2 and 3 show the difference in the required signal-to-noise ratio (SNR) between BG1 and BG2 to reach the block error ratio (BLER) of 10% in the additive white Gaussian noise (AWGN) channel. As expected, BG1 performs much better than BG2 for high code rates. The criterion of choosing a base graph depends on the target code rate for the initial transmission and the TB size [9], as illustrated in Fig. 4. If the actual code rate is much higher than the target code rate, then the appropriate base graph is not selected. This may result in a performance loss up to approximately 3 dB. As a result, it is desirable to keep the actual code rate as close as possible to the target code rate.

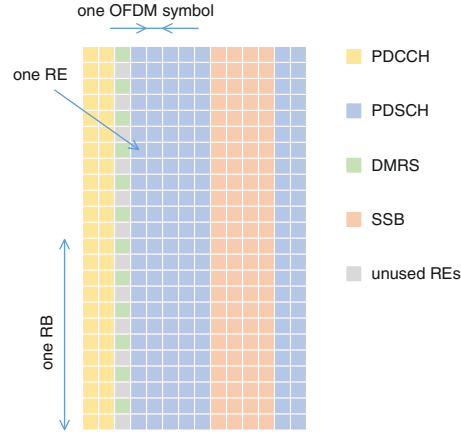


Fig. 1 Configuration for downlink physical channels

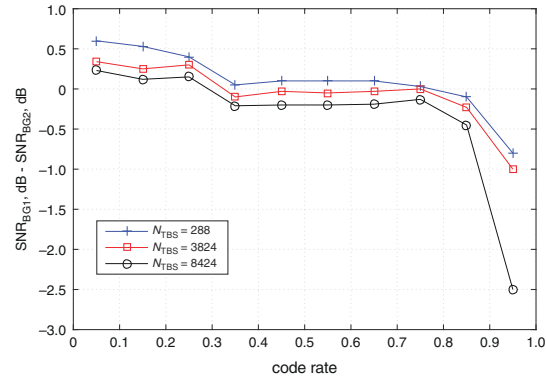


Fig. 2 The difference in the required SNR between BG1 and BG2 to reach the BLER of 10% in the AWGN channel. The decoding algorithm is layered belief propagation. The number of iterations is 12. The modulation type is QPSK. The TB sizes N_{TB} are 288, 3824 and 8424

In this letter, the procedure of the TB size determination in 5G NR is modified to reduce the difference between the actual code rate and the target code rate. We quantise the number of REs within the scheduled duration that are not available for the data transmission and the DMRS transmission. The difference between the reference number of REs of the traditional scheme and the quantised number is used to determine the TB size in the proposed scheme. Also, the scheduler of the proposed scheme can easily find a matching TB size for retransmission.

The TB size determination in 5G NR: In 5G NR, the TBS is determined as follows [3]. The reference number of REs is equal to

$$N_{RE} = \min(156, N'_{RE})n_{RB} \quad (1)$$

where N'_{RE} is the reference number of REs per RB and n_{RB} is the number of scheduled RBs. N'_{RE} is equal to

$$N'_{RE} = N_{sc}N_{sym} - N_{DMRS} - N_{oh} \quad (2)$$

where $N_{sc} = 12$ is the number of subcarriers per RB, N_{sym} is the number of OFDM symbols in the scheduled duration, N_{DMRS} is the number of REs for DMRS per RB in the scheduled duration including the overhead of the DMRS code division multiplexing groups without data and N_{oh} is the overhead. Note that N_{oh} is semi-persistent configured.

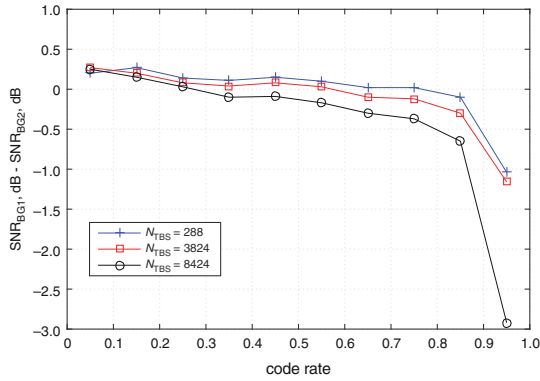


Fig. 3 The difference in the required SNR between BG1 and BG2 to reach the BLER of 10% in the AWGN channel. The decoding algorithm is layered belief propagation. The number of iterations is 12. The modulation type is 64QAM. The TB sizes N_{TBS} are 288, 3824 and 8424

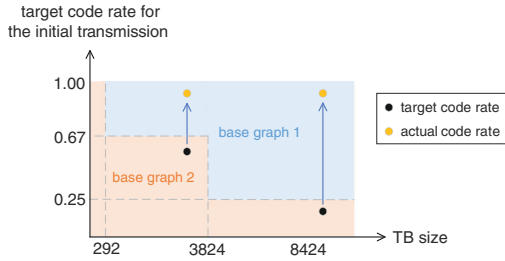


Fig. 4 The criterion of choosing a base graph depends on the TB size N_{TBS} and the target code rate for the initial transmission R . If the actual code rate is much higher than R , then the appropriate base graph is not selected

The intermediate number of information bits is equal to $N_{info} = N_{RE}QL$, where R is the target code rate, Q is the modulation order and L is the number of layers.

If $N_{info} \leq 3824$, then the quantised intermediate number of information bits is equal to

$$N'_{info} = \max\left(24, 2^n \left\lfloor \frac{N_{info}}{2^n} \right\rfloor\right) \quad (3)$$

where $n = \max(3, \lfloor \log_2(N_{info}) \rfloor - 6)$. N_{TBS} is equal to

$$N_{TBS} = \min\{\psi : \psi \in T, \psi \geq N'_{info}\} \quad (4)$$

where the values of T are listed in Table 5.1.3.2-1 of [3].

If $N_{info} > 3824$, then the quantised intermediate number of information bits is equal to

$$N'_{info} = \max\left(3840, 2^n \text{round}\left(\frac{N_{info} - 24}{2^n}\right)\right) \quad (5)$$

where $n = \lfloor \log_2(N_{info} - 24) \rfloor - 5$. N_{TBS} is equal to

$$N_{TBS} = 8C \left\lceil \frac{N'_{info} + 24}{8C} \right\rceil - 24 \quad (6)$$

where

$$C = \begin{cases} \lceil (N'_{info} + 24)/3816 \rceil & R \leq 1/4 \\ \lceil (N'_{info} + 24)/8424 \rceil & R > 1/4, N'_{info} > 8424 \\ 1 & R > 1/4, N'_{info} \leq 8424 \end{cases} \quad (7)$$

The proposed scheme: In this section, we modify the procedure of the TB size determination in 5G NR to reduce the difference between the actual code rate and the target code rate. The proposed scheme and the traditional scheme only differs in how the reference number of REs is calculated.

Let $N_{\diamond}$ be the number of REs within the scheduled duration that are not available for the data transmission and the DMRS transmission. $N_{\diamond}$ is quantised as

$$n_{\diamond} = \text{round}\left(\frac{N_{res}}{N'_{RE}}\right) \quad (8)$$

where $N_{res} = N_{\diamond} - N_{oh}n_{RB}$. The reference number of REs of the proposed scheme is equal to

$$N_{RE}^* = \min(156, N'_{RE}) \max(1, n_{RB} - n_{\diamond}) \quad (9)$$

The following steps of determining the TB size are the same as those in the traditional scheme. The proposed scheme is a compromise between the two options mentioned in the introduction. By quantising $N_{\diamond}$, the time-varying signals that are rate-matched around REs used for the data transmission can be counteracted by changing the number of scheduled RBs. The scheduler does not need to carefully determine the location of RBs to find a matching TB size for retransmission.

Let us consider an example. In the initial transmission, all REs in the system are only used for the PDCCH, the PDSCH and the DMRS. The configurations in the initial transmission are the same as those in the retransmission, except that γ REs used for the PDSCH in the initial transmission are changed to the SSB in the retransmission. If N_{oh} is set to 0, then the scheduler only needs to allocate $\text{round}(\gamma/N_{RE})$ additional RBs in the retransmission to find a matching TB size for retransmission.

The difference between the actual code rate and the target code rate: In this section, we show that the proposed scheme reduces the difference between the actual code rate and the target code rate compared to the traditional scheme. N'_{RE} is smaller than or equal to 156 in most scenarios [3]. To simplify the analysis, we assume that 156 imposes no constraint on the value of N_{RE} . Let N_{act} be the actual number of REs available for the data transmission. The actual code rate of the traditional scheme R_{act} is approximately equal to

$$R_{act} \simeq \frac{N_{RE}QLR}{N_{act}QL} = \frac{N_{RE}}{N_{act}}R \quad (10)$$

The actual code rate of the proposed scheme R_{act}^* is approximately equal to

$$R_{act}^* \simeq \frac{N_{RE}^*QLR}{N_{act}QL} = \frac{N_{RE}^*}{N_{act}}R \quad (11)$$

If $|N_{RE}^* - N_{act}|$ is smaller than or equal to $|N_{RE} - N_{act}|$, then R is closer to R_{act}^* than to R_{act} . In the following of this section, we prove that this statement is true.

In the traditional scheme, N_{RE} is equal to

$$N_{RE} = N_{act} + N_{\diamond} - N_{oh}n_{RB} = N_{act} + N_{res} \quad (12)$$

$N_{\diamond}$ may vary dynamically from slot to slot. Since N_{oh} is configured semi-statically, $N_{\diamond}$ can not be counteracted by N_{oh} . In the traditional scheme, the deviation between the reference number of REs and the actual number of REs may be large.

If $n_{RB} = n_{\diamond}$, then N_{RE} is equal to N'_{RE} and

$$\begin{aligned} |N_{RE}^* - N_{act}| &= |N'_{RE} - N_{act}| \stackrel{(i)}{\leq} |N'_{RE}n_{RB} - N_{act}| \\ &= |N_{RE} - N_{act}| \end{aligned} \quad (13)$$

where step (i) follows since

$$N_{act} = N_{RE} - N_{res} = N'_{RE}n_{RB} - N_{res} \stackrel{(ii)}{\leq} 0.5N'_{RE} \quad (14)$$

and step (ii) follows since $N'_{RE}(n_{RB} - 0.5) \leq N_{res}$ when $n_{RB} = n_{\diamond}$.

If $n_{RB} \neq n_{\diamond}$, then N_{RE}^* is equal to

$$\begin{aligned} N_{RE}^* &= N'_{RE}(n_{RB} - n_{\diamond}) \\ &= N_{act} + N_{res} - N'_{RE} \text{round}\left(\frac{N_{res}}{N'_{RE}}\right) \end{aligned} \quad (15)$$

It is clear that $|N_{\text{res}} - N'_{\text{RE}} \text{round}(N_{\text{res}}/N'_{\text{RE}})| \leq N'_{\text{RE}}/2$. As a result, the deviation between the reference number of REs and the actual number of REs is not larger than $N'_{\text{RE}}/2$ in the proposed scheme. If $n_{\text{RB}} \neq n_{\diamond}$ and $|N_{\text{res}}| < N'_{\text{RE}}/2$, then

$$\begin{aligned} |N_{\text{RE}}^* - N_{\text{act}}| &= |N_{\text{res}} - N'_{\text{RE}} \text{round}(N_{\text{res}}/N'_{\text{RE}})| = |N_{\text{res}}| \\ &= |N_{\text{RE}} - N_{\text{act}}| \end{aligned} \quad (16)$$

If $n_{\text{RB}} \neq n_{\diamond}$ and $|N_{\text{res}}| \geq N'_{\text{RE}}/2$, then

$$\begin{aligned} |N_{\text{RE}}^* - N_{\text{act}}| &= |N_{\text{res}} - N'_{\text{RE}} \text{round}(N_{\text{res}}/N'_{\text{RE}})| \leq \frac{N'_{\text{RE}}}{2} \\ &\leq |N_{\text{RE}} - N_{\text{act}}| \end{aligned} \quad (17)$$

From (13), (16) and (17), we see that $|N_{\text{RE}}^* - N_{\text{act}}|$ is smaller than or equal to $|N_{\text{RE}} - N_{\text{act}}|$.

Simulations: In this section, numerical results are given. There are total δ OFDM symbols in the slot. The control resource set (CORESET) is located at the beginning of the slot. And the duration of the CORESET is two OFDM symbols. The resources of the CORESET are not reused for data transmission. The scheduled duration avoids these 2 symbols. Thus, N_{sym} is equal to $\delta - 2$. The mapping type A of the DMRS is used in the slot. The structure of the DMRS is the double-symbol. There is only one DMRS occasion in the scheduled duration. All other REs of DMRS symbols are occupied by co-scheduled users. Thus, N_{DMRS} is equal to 24. CSI reference signal (CSI-RS) is configured to acquire channel characteristics. The CSI-RS is transmitted over the entire bandwidth and in each scheduled RB. The number of CSI-RS antenna ports is 16. The transmission of the CSI-RS is aperiodic and is signalled using the PDCCH. Thus, N_{oh} should be set to 0. Table 5.1.3.1-2 in [3] is used as the MCS table. There is a total of 32 entries in the table, 28 of which are used to indicate R and Q , whereas four of which are reserved. If a matching TB size can not be scheduled in the retransmission, then the reserved entries are used to implicitly indicate the TB size. The number of layers L is 1. The number of RBs available for scheduling n_{avi} is 273.

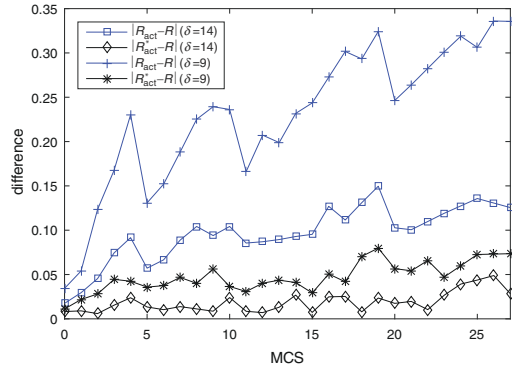


Fig. 5 $|R_{\text{act}} - R|$ and $|R_{\text{act}}^* - R|$ are plotted as a function of the index of the MCS for different δ . Here n_{RB} is equal to 6. $|R_{\text{act}} - R|$ is larger than $|R_{\text{act}}^* - R|$

Figures 5 and 6 compare the difference between the actual code rate and the target code rate of the traditional scheme and the proposed scheme, where $|R_{\text{act}} - R|$ and $|R_{\text{act}}^* - R|$ are plotted as a function of the index of the MCS for different δ . From the figures, we see that $|R_{\text{act}} - R|$ is larger than $|R_{\text{act}}^* - R|$. Compared to the traditional scheme, the proposed

scheme reduces the difference between the actual code rate and the target code rate. This verifies and validates the analysis in the preceding section. Note that the difference between the actual code rate and the target code rate reduced by the proposed scheme decreases with δ .

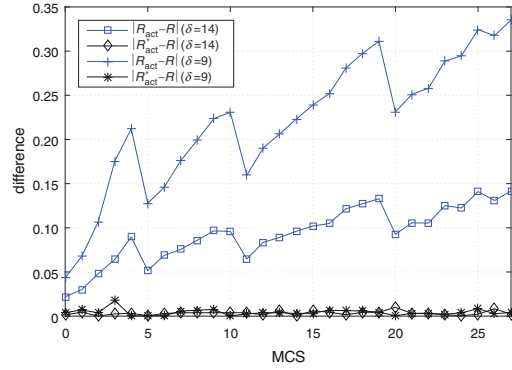


Fig. 6 $|R_{\text{act}} - R|$ and $|R_{\text{act}}^* - R|$ are plotted as a function of the index of the MCS for different δ . Here n_{RB} is equal to 60. $|R_{\text{act}} - R|$ is larger than $|R_{\text{act}}^* - R|$

Conclusion: In this Letter, the procedure of the TB size determination in 5G NR is modified to reduce the difference between the actual code rate and the target code rate. As a result, the performance of the channel coding is improved and the latency of the data transmission is reduced. In the proposed scheme, the time-varying signals that are rate-matched around REs used for the data transmission are counteracted by changing the number of scheduled RBs. The scheduler does not need to carefully determine the location of RBs to find a matching TB size for retransmission.

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One or more of the Figures in this Letter are available in colour online.

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