A Method to Tailor Broadcasting and Multicasting Transmission in 5G New Radio

Wei Guo and Belkacem Mouhouche
Samsung R&D Institute UK
Staines-upon-Thames, United Kingdom
Email: {wei6.guo, b.mouhouche}@samsung.com

Abstract—**Broadcast and multicast will be an important feature supported in 5G New Radio. In this paper a new transmission method is proposed to improve the receiver side User Equipment (UE) resource efficiency by using redundant multicast channels at the transmitting Base Station (BS). Transmission is tailored for UEs with different channel characteristics. A sub-grouping algorithm is designed to fast allocate UEs of a multicast group to their most suitable channels. Numeric sample calculation proves the validity of the proposed method.**

Keywords—5G; New Radio; broadcast; multicast; channel allocation; optimization

I. INTRODUCTION AND BACKGOURND

Broadcast and multicast service provision will be an appealing feature in the 5th Generation mobile telecommunications (5G). Via the mobile cellular networks end users will enjoy personalized and rich contents which were only possible in television and radio networks before the convergence of broadcasting networks and telecommunication networks. Apart from the customized contents at application layer, new transmission technologies at the physical layer (PHY) and Medium Access Control (MAC) are also introduced to support broadcasting and multicasting. Back in the 4th Generation mobile telecommunication (4G) Long Term Evolution (LTE), dedicated multicast channels are already introduced in Evolved Universal Terrestrial Radio Access (E-UTRA) to support Multimedia Broadcast Multicast Service (MBMS) [1]. We expect in 5G New Radio (NR) [2] such multicast channels and transmission technologies will be further enhanced to provide more advanced broadcasting and multicasting capabilities.

As one of the most prominent standards developing organization on 5G, the 3rd Generation Partnership Project (3GPP) has defined both Single Cell Point to Multipoint (SC-PTM) and Multimedia Broadcast multicast service Single Frequency Network (MBSFN) to support broadcast and multicast [1]. In current SC-PTM transmission, the Base Station (BS) sends a unified multicast service to UEs in a same multicast group on a particular common multicast channel. On the other hand, each UE in a same cell experiences different channel quality and thus receives different quality of the multicast service signal. Primarily, the BS uses a common Modulation and Coding Scheme (MCS) and Transport Block Size (TBS) on the multicast channel, based on an assumption of the channel quality, without differentiating diversified UE receiving conditions. As a consequence, some UEs experience very good reception and achieve a good throughput while some others with inferior channel characteristics cannot achieve the same. Our pervious investigation verified the problem, where the optimal Quality of Service (QoS) can only be achieved at a particular point [3]. Elsewhere the QoS, taking the mean throughput as an example, will drop. In this situation, how to select a proper transmission scheme is a key question to achieve a fair and efficient QoS at the UE side.

In 5G NR a UE is able to report its experienced channel quality through uplink Channel State Information (CSI) [4]. The channel quality is indicated by a numeric value of Channel Quality Indicator (CQI), indexed from 0 to 15, in a quality increasing order, where CQI 15 stands for the best channel quality and CQI 0 means the UE is out of the range of the cell served by the BS. The BS may configure on which channels the UE should report back the CQI indexes. Ideally the UE will report the highest one which stands for the best quality channel available. The feedback mechanism provides a means to perceive the quality of multicast channels and help the decision on MCS and TBS selection.

In a previous work [5] we investigated a hybrid scheduling approach with a partial HARQ (Hybrid Automatic Repeat Request). Unicast retransmission is utilized in case of broadcast reception failure. The best alignment in fading between different broadcast receivers plays a fundamental part in the optimal MCS selection on a single broadcast channel. In this paper we take a different approach which is computational, by taking into account the channel quality distribution among the broadcast and multicast service receivers, and propose an optimal channel allocation and MCS/TBS selection scheme on available one or more multicast channels.

Theoretically, broadcast can be deemed as a special case of multicast, where the multicast group is all the served users. In the same way, unicast can also be deemed as a special case of multicast, where each multicast group has only one user. To simplify narration and without loss of generality, we use multicast in the paper and don't differentiate broadcast and multicast, except where explicitly expressed.

The paper is organized as follows: Section II further describes the scenario and the problem we are aiming to solve; Section III gives a detailed solution to the problem, which is called tailored multicasting; Section IV gives some preliminary results as a proof of the solution validity with discussions; Section V concludes the paper and gives our planned future work.

II. PROBLEM DESCRIPTION

A. Available Multicast Channels

In Next Generation Radio Access Networks (NG-RANs), during a scheduling period, each multicast channel is using a designated MCS/TBS together with other associated transmission parameters. The waveform is such configured to achieve a most efficient channel usage. On the other hand, the UEs may report different CQIs to the BS. Suppose there are *s* CQIs reported by a group of UEs. The BS needs to select the most efficient MCS/TBS for the multicast channel(s).

The first case is that there is only one multicast channel available. To ensure a fully satisfying reception by all UEs in a multicast group, as a straightforward solution, the BS may select MCS/TBS against the lowest CQI reported by group UEs. E.g. we have 100 UEs reporting different CQIs that may range from 1 to 15. Then we use CQI 1 as the perceived channel quality and use, for example, QPSK and a code rate 78/1024, as specified by 3GPP TS 38.214 [4]. All UEs will use same MCS including those even reporting a CQI as high as 15, who should tune themselves downwards to match the low rate. Alternatively, according a Service Level Agreement (SLA) signed with the users, an MCS against higher CQI could be selected, while scarifying the poor channel quality UEs and achieving an overall satisfying reception.

The next case, which is the main topic of this paper, is there is more than one available channel. This is the case where the BS has redundant resources that can be employed to transmit the multicast service. The BS has more choices in using different MCS/TBS for different channels. For a simple example, if some UEs report CQI 1, while the other UEs report CQI 15, then the BS can use QPSK and code rate 78/1024 on one channel, and use 64QAM and code rate 948/1024 on another. Then the UEs reporting CQI 1 tune themselves to the QPSK channel and UEs reporting CQI 15 tune themselves to the 64QAM channel to achieve the best receiving efficiency.

B. UE Subgrouping and Channel Allocation

Suppose the BS keeps an integer *ch* to indicate the number of current available downlink (DL) channels. In NG-RAN where multicast is supported, $ch \geq 1$, at least 1 channel is reserved for multicast service. If $ch \geq 15$ then we can use up to 15 channels. We might not need that much, depending on how many we require. If *s* CQIs are reported, then ideally we need *s* channels, where each channel can use the correspondent MCS/TBS for a specific CQI:

If $s \leq ch$, then we comfortably allocate *s* channels;

If $s > ch$, the available channels are not enough to accommodate all the UEs, then we need to reduce *s* to *s'* (compromising the requirement) and make the new $s' \leq ch$.

The question coming up is how to allocate the UEs into the *s* channels. We need to subgroup the UEs and each subgroup is allocated into a dedicated separate channel. The term “subgroup” is used because all the UEs in question are already in a same multicast group.

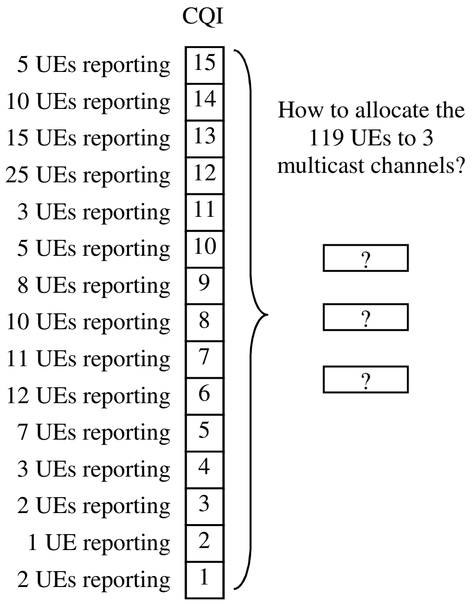

Fig. 1. Example of the problem of subgrouping UEs and channel allocation

We put UEs with same CQI into a subgroup. If s > ch, then we need to put UEs with different CQIs into a same subgroup, so as to reduce s to s’ and make $s' \leq$ ch.

Some UEs with smallest CQI could be “abandoned”, in order to achieve an overall maximum throughput. The abandoned UE can still try to use a higher rank MCS but will expect higher Block Error Rate (BLER). Even though with abandoned UEs, the agreed service coverage will still be satisfied (e.g. at least 95% of UEs are well served). We trade off the throughput to guarantee the service coverage.

Here we give an example illustrating the problem. Suppose we have 119 UEs reporting CQIs ranging from 1 to 15. At the BS side we have 3 available multicast channels. Also we have additional objectives to guarantee at least 95% of the UEs’ (equivalent 114 UEs’) reception, and maximize the whole multicast group’s throughput. As shown in Fig. 1, the question is how to allocate the 119 UEs into the 3 channels, i.e. against which CQIs to select the MCS/TBS. The question is formalized as (1) below:

$$\mathrm{T} = \sum_{cqi=1}^{15} \mathrm{f}(cqi) \cdot \mathrm{N}_{cqi} \qquad (1)$$

where N_{cqi} is the number of UEs reporting *cqi*, and *f(cqi)* is the weight function, meaning that for a UE using a channel correspondent to *cqi*, its gain is *f(cqi)*. Here the UE’s real channel quality must be equal to or greater than *cqi* so as to achieve the full capacity of the channel. In this case *f(cqi)* is the throughput gained by the UE. T is the valuation function and the question is to maximize T. Alternatively there can be other valuation functions, such as BLER in average.

III. COMPUTATIONAL SOLUTION FOR CHANNEL ALLOCATION

In this section we devise an optimizing algorithm to decide when and how many subgroups or channels are needed. We compute the most cost-effective channel scheme, employ the resulting additional channels over a scheduling period, perform

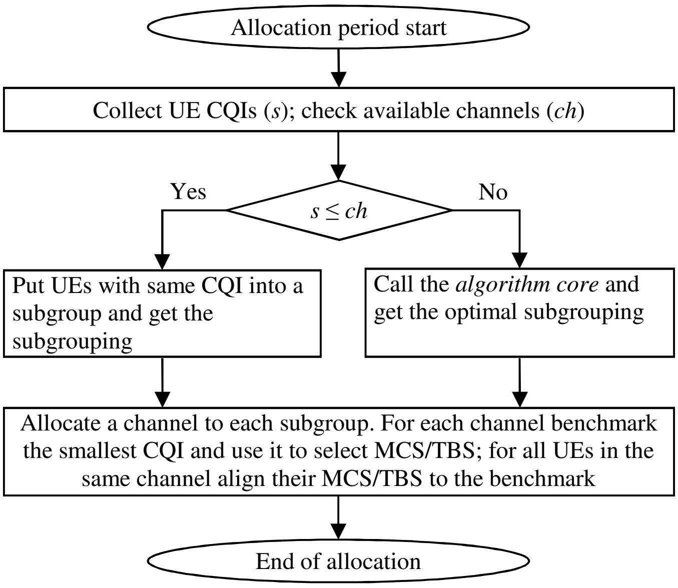

Fig. 2. General channel allocation algorithm flow chart

1) Use *gr* as iterator with initialized value1, 1 ⩽ *gr* ⩽ *ch*.
2) Consider there are only *gr* CQIs to subgroup, there can only be *gr* subgroups.
3) Suppose we have got the optimal subgrouping for *n*-1 CQIs, solve the case *n*:
4) Memorize optimal subgrouping with each CQI as highest one, thus we have memorized *n-gr* subgroupings, starting from *gr*, *gr*+1, *gr*+2, …, *n*-1.
5) If CQI *n* will be selected, then we need to use the optimal *n*-1 subgrouping with *gr*-1 subgroups.
6) If CQI *n* will not be selected, then we need to get the best from the *n*-1 subgrouping with *gr* subgroups.
7) Compare the results of 5) and 6), the better is the optimal *n*-subgrouping.
8) Incrementally execute from step 2) and get the optimal subgrouping.

Fig. 3. Core algorithm of UE subgrouping

rate matching between different channels in the same multicast session to achieve synchronization, and optimize the use of radio resource while ensuring the multicast QoS.

Fig. 2 illustrates the flow chart of the general channel allocation algorithm, previously introduced in subsection II.B. The left fork (‘Yes’ branch) illustrates the simple case where s ≤ ch; the right fork (‘No’ branch) does the optimal core algorithm to allocate the UEs into ch subgroups. Once the subgrouping is done, a channel is allocated to each subgroup. Each channel uses the smallest CQI correspondent MCS/TBS. Other UEs with greater CQIs in the same channel, if any, down select MCS/TBS and match the low code rate.

Allocating *m* UEs into *n* subgroups with constraint conditions is a typical combinatorial optimization problem and can be solved with dynamic programming. Suppose we need to allocate UEs of *s* CQIs ($1 \leq s \leq 15$) into *ch* subgroups ($1 \leq ch \leq s$), we call it a 15-subgrouping problem. Fig. 3 gives a step by step description of the core algorithm. To give complete details of the algorithm, we also publish a code snippet and some samples written for Microsoft Visual C++ implementing the core algorithm at GitHub [6]. The algorithm gives the optimal solution with a desirable time complexity O(15×15×15), which can be implemented in hardware with minimum cost and best performance. If CQI 0 needs to be considered (UE is out of reach at all, but still counted in), then that is a 16-subgrouping problem and the solution is same. The time complexity for the 16-subgrouping is O(16×16×16).

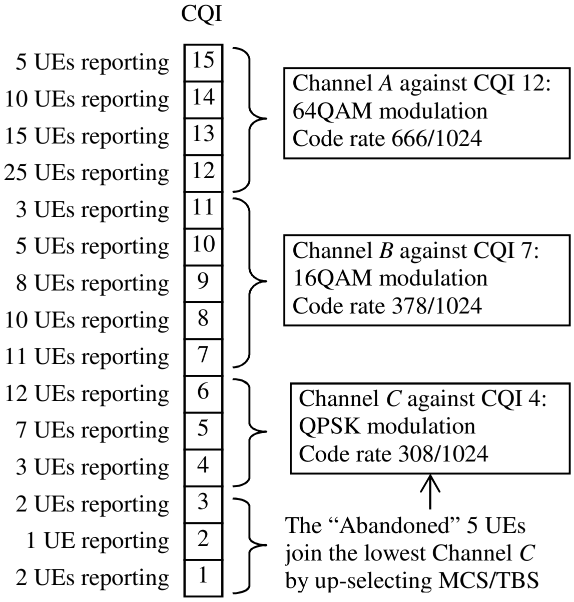

Fig. 4. Solution to the example of the 15-subgrouping channel allocation

Coming back to the example problem in Fig. 1, for simplicity, with regard to (1), we arbitrarily define

$$f(cqi) = cqi \qquad (2)$$

That can be redefined to make the valuation function more realistic, which is less significant and not further discussed in this paper. The results by executing the algorithm are presented in Fig. 4. The 119 UEs are allocated into 3 subgroups plus a subgroup of “abandoned” ones, with the latter meaning that we cannot guarantee the QoS. Channels *A*, *B* and *C* are allocated to the 3 subgroups with correspondent MCS and other parameters to the smallest CQI of each subgroup. For the UEs with poorest CQIs 1, 2 and 3 they can use Channel *C* by up-selecting MCS but will expect to experience a high BLER. After all, the valuation function T in (1) achieves its maximum of 1007 under the definition in (2). The QoS guaranteed UEs percentage is 114/119 = 95.8%, satisfying the SLA (≥ 95%) set in section II.

IV. VALIDATION AND DISCUSSION

To further validate the effectiveness of the proposed method, we conduct calculations with comparisons to an ordinary single multicast channel allocation without any optimization. TABLE I. gives all the possible MCS selections

TABLE I. ORDINARY SINGLE CHANNEL MULTICASTING TRANSMISSION

CQI corresponding	**Ordinary single multicast channel**			
	MCS	***Code rate × 1024***	***Valuation T***	***UE Coverage***
1	QPSK	78	119	100%
2	QPSK	120	234	98.3%
3	QPSK	193	348	97.5%
4	QPSK	308	456	95.8%
5	QPSK	449	555	93.3%
6	QPSK	602	624	87.4%
7	16QAM	378	644	77.3%
8	16QAM	490	648	68.1%
9	16QAM	616	639	59.7%
10	64QAM	466	630	52.9%
11	64QAM	567	638	48.7%
12	64QAM	666	660	46.2%
13	64QAM	772	390	25.2%
14	64QAM	873	210	12.6%
15	64QAM	948	75	4.2%

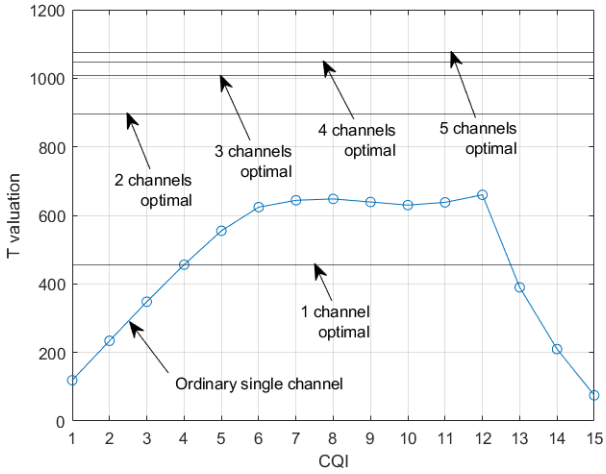

Fig. 5. The T valuation for optimal multiple channel transmission vs. ordinary single channel transmission

for the ordinary single channel and the associated gains represented in T valuation. As can been seen, neither high end nor low end CQIs give a satisfying gain. The results further verify the observation we obtained in previous work [3]. The acceptable effects come from the middle CQIs, as plotted in Fig. 5, for the sample we use, between 4 and 12. However, as CQI against which we select MCS increases, we are losing QoS for UEs with low CQIs. The covered UEs drop from 95.8%to 46.2% for the CQIs from 4 to 12. Although the proposed tailoring method is for multiple channel multicasting, it also works well for the single channel. We plotted the horizontal line which stands for the best T value we can obtain with one channel (labeled “1 channel optimal”), which is for CQI 4 and the T value is 456, where 95.8% UEs’ service is guaranteed.

As the proposed tailoring multicast’s aiming at using multiple channels, we also plot the optimal T values for 2, 3, 4 and 5 channels in Fig. 5. As shown, 2 channels outperform all possible ordinary single channel configurations, with a T value 896 and the coverage of 95.8% UEs. Interestingly, the gains do not increase linearly with the number of employed channels. The extra gains brought in by a 4th or 5th channel become very marginal, where T value is 1046 for 4 channels and 1076 for 5 channels. In view of the minor profit of more extra channels, we recommend using the minimum amount of channels that just outperforms the ordinary method. This also depends on the CQI distribution among the UEs. The shape of the CQI distribution and its impact will be our future investigation.

Obviously we employ more channels for a same multicast service at BS side and at the transmission side more resources are occupied. But that is a worthy cost we pay for the very desirable gain at the UE side, which is proved by the results represented by the T valuation. Furthermore, tuning into a most suitable channel for a UE saves energy and active time when receiving multicast service, especially when the UE is in a dual connectivity or multiple connectivity mode when it needs to allocate more receiving resources for other services, and even with other BS(s).

V. CONCLUSION AND FUTURE WORK

Thanks to the available uplink feedback to the BS in 5G New Radio, the UE is able to report its channel quality via CQI, so that the BS understands well how the UE experiences the Quality of Service. That enables the BS to tailor its multicast transmission against UEs with different channel characteristics. We propose to use more than one channel when receiving multicast services. For each channel a dedicated MCS/TBS (mainly MCS is exemplified in this paper) targets a specific UE subgroup. In order to subgroup UEs and allocate a most proper channel to them, we design a general channel allocation algorithm and an efficient and concise core to fast calculate the optimal subgrouping. The initial validation proves the effectiveness of the method. We also find that more extra channels don’t bring in extra proportional gains for UEs, and a number just above ordinary is sufficiently efficient.

Next we will refine the T valuation function and make it more realistic. Furthermore, we’ll use the SRUK 5G network system level simulator we used in previous work [3] to carry out more investigation on the method.

ACKNOWLEDGMENT

This work was supported in part by the European Commission under the 5G-PPP project 5G-Xcast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this paper are those of the authors and do not necessarily represent the project.

REFERENCES

[1] 3GPP TS 36.300 “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 15)”.

[2] 3GPP TS 38.300 “NR; NR and NG-RAN Overall Description; Stage 2 (Release 15)”.

[3] Wei Guo, Manuel Fuentes, Louis Christodoulou and Belkacem Mouhouche, “Roads to Multimedia Broadcast Multicast Services in 5G New Radio”, IEEE BMSB, June 2018.

[4] 3GPP TS 38.214 “NR; Physical layer procedures for data (Release 15)”.

[5] Belkacem Mouhouche, Louis Christodoulou and Manuel Fuentes, “Partial HARQ Retransmission For Broadcast in Fading Channels”, CS & IT, October 2017.

[6] https://github.com/gguowei/Channel-Allocation.