

Capacity and Throughput Enhancements for Non-Terrestrial Networks

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Abstract—Non-terrestrial networks (NTNs) are considered a key feature of 5G communications. In new radio (NR) release 19 (Rel-19) of the Third Generation Partnership Project (3GPP), an Orthogonal Cover Code (OCC) scheme was introduced for the Physical Uplink Shared Channel (PUSCH) to enhance uplink (UL) capacity and throughput. In this paper, we explore the newly introduced OCC mechanism for 3GPP Rel-19 NTN and discuss potential enhancements for future evolution.

Index Terms—NTN, OCC, 3GPP, 5G, NR

I. INTRODUCTION

Non-terrestrial networks (NTNs) are considered a key feature in 5G communications. Within the Third Generation Partnership Project (3GPP), NTNs have been studied as part of the 5G New Radio (NR) [1], [2]. Standardization of NTN began with Release 17 (Rel-17), referred to as NTN Phase 1 followed by NTN Phase 2 in Rel-18. Currently, NTN Phase 3 is in progress in Rel-19 [3].

In Rel-19 NTN Phase 3, several improvements were introduced, including downlink (DL) coverage enhancements, support for (e)RedCap user equipment (UE), and uplink (UL) capacity and throughput enhancements. Notably, as part of the UL enhancement agenda [4]–[8], agreement was reached on the introduction of orthogonal cover codes (OCCs) on the physical uplink shared channel (PUSCH), which represents a major difference compared to Rel-18 NTN Phase 2.

In this paper, we review PUSCH OCC mechanism introduced in Rel-19 NTN Phase 3 and identify potential enhancement for future evolution.

II. PUSCH OCC IN 3GPP REL-19 NR NTN

The overall Rel-19 NR NTN PUSCH OCC scheme is illustrated in Fig. 1, referred to [4]–[8]. According to Fig. 1, OCC scheme introduced in Rel-19 NR NTN consists of 4 steps, each of which is as follows.

- Step 1: UE reports OCC capability to the network through UE capability report.
- Step 2: Network configures the UE with OCC scheme(s) via radio resource control (RRC).

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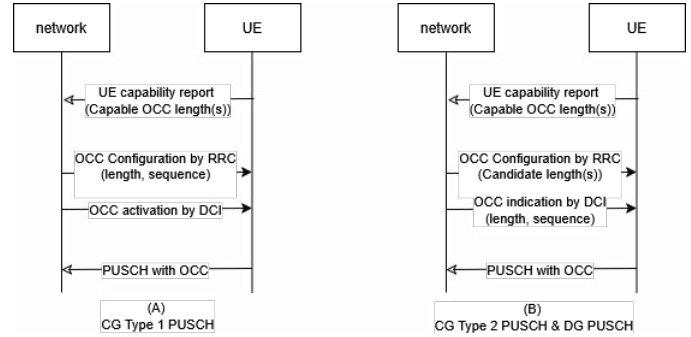


Fig. 1. Overview of Rel-19 NR NTN PUSCH OCC

- Step 3: Network indicates one of the OCC scheme(s) to the UE
- Step 4: UE transmits PUSCH with OCC scheme indicated by the network.

In addition, the OCC scheme in Rel-19 NR NTN varies depending on the grant method (configured grant (CG) or dynamic grant (DG)). Accordingly, 2 separate OCC schemes have been developed: 1) OCC for CG Type 1 PUSCH and 2) OCC for CG Type 2 PUSCH and DG PUSCH.

A. OCC for CG type 1 PUSCH

In step 1, a new field (capable OCC length) is introduced in the UE capability report, through which the UE reports its OCC capability to the network. Separate capability fields would be defined for capable OCC lengths 2 and 4, with capable OCC length 2 being a pre-requisite for capable OCC length 4. In step 2, new fields (OCC length, OCC sequence) in the RRC configuration for CG type 1 PUSCH are introduced, and the network configures OCC length and OCC sequence (index) to be applied to the PUSCH to the UE through those 2 fields (OCC length, OCC sequence). In step 3, the network indicates the activation/deactivation of the configured OCC scheme to the UE through activation/deactivation downlink control information (DCI). In step 4, a new OCC mechanism (inter-slot time-domain OCC) is introduced, designed to be applied with PUSCH repetition type A as described in Fig. 2. When the network configures the UE with an OCC length (L), an OCC sequence ($w = [w_0 \ w_1 \ \dots \ w_{(L-1)}]$), and the number

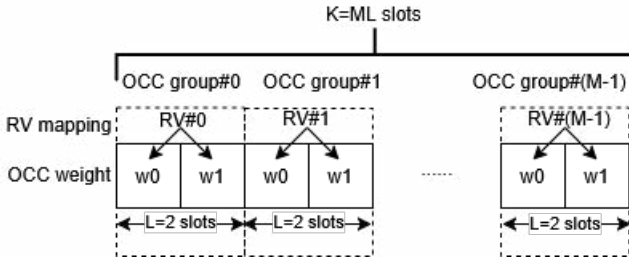


Fig. 2. Example of Rel-19 NR NTN PUSCH OCC (OCC length = 2)

of PUSCH repetitions (K), each OCC group is defined as a set of L consecutive PUSCH repetitions. The number of OCC group is then determined as $M=K/L$, where M must be an integer. This implies that the number of PUSCH repetitions is adjusted to be a multiple of L by the new OCC mechanism as described in Fig. 2. Within an OCC group, each weight of the OCC sequence is applied to the corresponding slot. Specifically, each weight (w_l , where $l = 0, \dots, (L - 1)$) is applied to the l -th slot within the group. This process is repeated for each OCC group until the final one as presented in Fig. 2. The new OCC sequence w for PUSCH is based on a Hadamard code (e.g., one of $\{[1 \ 1], [1 \ -1]\}$ for $L=2$ or one of $\{[1 \ 1 \ 1 \ 1], [1 \ -1 \ 1 \ -1], [1 \ 1 \ -1 \ -1], [1 \ -1 \ -1 \ 1]\}$ for $L=4$). The OCC sequence is applied after the modulation mapper. Regarding the redundancy version (RV), the same RV is maintained within each OCC group, referred to as "RV# m " for OCC group# m in Fig. 2, while RV values are cycled across OCC groups according to one of the pre-defined sequences: (e.g. $\{[0 \ 2 \ 3 \ 1], [0 \ 3 \ 0 \ 3], [0 \ 0 \ 0 \ 0]\}$). This indicates that the new OCC mechanism adjusts the RV value such that it changes only at the boundaries of OCC groups (i.e. every L slots).

B. OCC for CG type 2 PUSCH and DG PUSCH

This section focuses on the major differences from CG type 1, specifically step 2 and step 3, while omitting details that are similar to those of CG type 1. In step 2, a new column (candidate OCC length) in the time domain resource allocation (TDRA) table in the RRC is introduced in order to configure candidate OCC length(s). In step 3, the network indicates the OCC scheme to be actually applied on PUSCH in terms of (OCC length and OCC sequence index). The OCC length and OCC sequence index are implicitly indicated by the DCI, through the association with the TDRA field and the antenna port field, respectively.

III. POTENTIAL ENHANCEMENT FOR FUTURE EVOLUTION

According to [3], the primary objective behind introducing the Rel-19 NR NTN OCC scheme was to increase resource usage per UE to enhance system capacity and throughput, particularly within the constraints of limited spectrum resources. As an emerging network topology, NTN faces several conflicting challenges: On one hand, higher resource usage is required to overcome the worse S(I)NR in NTN compared to terrestrial

networks (TN). On the other hand, lower resource usage is needed to accommodate a significantly larger number of UEs, resulting from the much wider coverage area inherent in NTN compared to TN. These two opposing situations, maximizing resource allocation for each UE while also minimizing the usage of resources to serve more UEs, present a significant challenge to the effective operation of NTN. To address these conflicting situations, the OCC scheme was introduced in Rel-19 NTN, as the total resources available with OCC are L times greater than those without it, due to the orthogonality of OCC. This means that OCC enables a higher number of resources to be utilized by effectively expanding the resource pool through multiplexing. This approach could offer a solution to the trade-off between capacity and UE accommodation.

In Rel-19 NTN, OCC for UL (especially PUSCH) was considered as a top priority because of worse S(I)NR in the UL compared to the DL. Although the S(I)NR in the DL is generally better than in the UL, considering the limited visible time of satellites (especially LEO) and the situation that the more data is typically required in the DL rather than the UL, the resource usage per UE in the DL may not be sufficient to accommodate all the UEs within the NTN coverage during the visible time of NTN. Furthermore, OCC for the DL could become even more crucial in geostationary earth orbit (GEO) because the S(I)NR in GEO is even worse than LEO.

Given these considerations, it may be unrealistic to assume that OCC for DL is unnecessary simply because the S(I)NR in the DL is better than in the UL. Thus, similar to how OCC is introduced in the UL, the introduction of OCC in the DL, particularly for the physical downlink shared channel (PDSCH), may be needed, and OCC for the DL (especially PDSCH), like its counterparts in the UL, could also be essential for enhancing capacity and throughput in the NTN.

IV. CONCLUSION

This paper presents an overview and a detailed explanation of the Rel-19 NR NTN PUSCH OCC scheme, while also identifying the potential enhancement for future evolution. In 3GPP Rel-19, the OCC scheme for the UL was introduced as a top priority due to the more challenging conditions in the UL compared to the DL. However, considering the factors (such as the limited visible time of NTN, the higher data demands in the DL, and the GEO scenario), the need for OCC in the DL may be as critical as in the UL. Therefore, further research for DL OCC (especially PDSCH OCC) might be essential in the future evolution of NTN systems.

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