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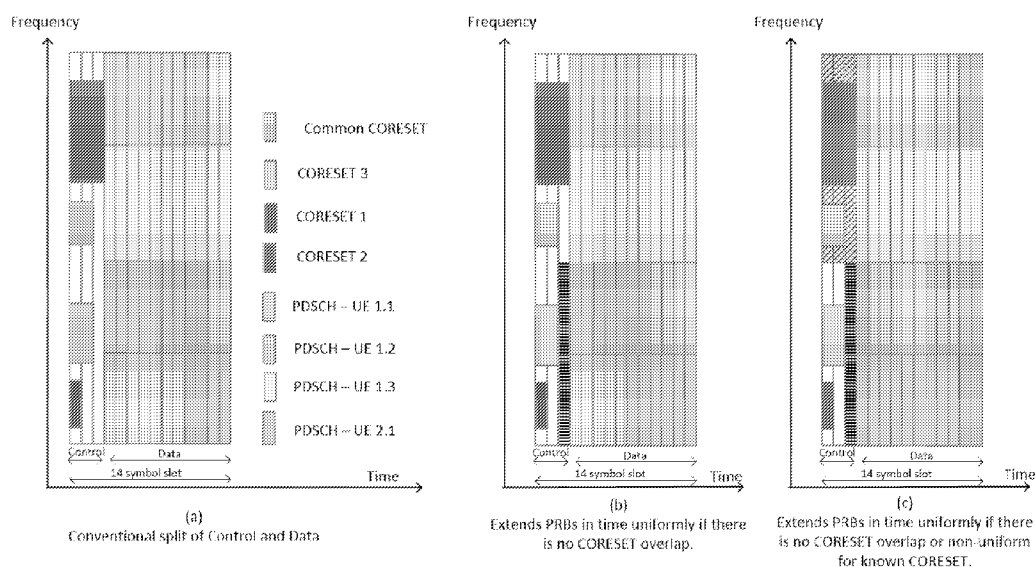


Figure 1: CORESET Level Sharing of control resources for data

(57) **Abstract:** A method for enabling a wireless communication device to access services provided by a Radio Access Network in a communication between a first and a second wireless communications device, wherein the communication includes at least one control region including a group of physical resource blocks, the method comprising: multiplexing data within at least part of the control region to liberate space in the control region, such that the liberated space can be used for data transmission.



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Multiplexing Data over Control Resources in New Radio

Technical Field

Embodiments of the present invention generally relate to wireless communication systems and in particular to devices and methods for enabling a wireless communication device, such as a User Equipment (UE) or mobile device to access a Radio Access Technology (RAT) or Radio Access Network (RAN), particularly but not exclusively multiplexing data over control Resources in New Radio (NR).

Background

Wireless communication systems, such as the third-generation (3G) of mobile telephone standards and technology are well known. Such 3G standards and technology have been developed by the Third Generation Partnership Project (3GPP). The 3rd generation of wireless communications has generally been developed to support macro-cell mobile phone communications. Communication systems and networks have developed towards a broadband and mobile system.

The 3rd Generation Partnership Project has developed the so-called Long Term Evolution (LTE) system, namely, an Evolved Universal Mobile Telecommunication System Territorial Radio Access Network, (E-UTRAN), for a mobile access network where one or more macro-cells are supported by a base station known as an eNodeB or eNB (evolved NodeB). More recently, LTE is evolving further towards the so-called 5G or NR (new radio) systems where one or more cells are supported by a base station known as a gNB.

The 5G standard will support a multitude of different services each with very different requirements. These services include Enhanced Mobile Broadband (eMBB) for high data rate transmission, Ultra-Reliable Low Latency Communication (URLLC) for devices requiring low latency and high link reliability and Massive Machine-Type Communication (mMTC) to support a large number of low-power devices for a long life-time requiring highly energy efficient communication.

To maintain varying levels of quality of service (QoS) requirements demanded by this vast number of services, the 5G standard must allow a flexible and scalable design to support those various requirements at the same time.

NR supports slot based scheduling and communication in a “flavour” very close to LTE. In addition, mini-slots have been standardized in NR to accommodate low latency and/or small packet size requirements. When data for URLLC services appears after the slot scheduling decisions have been made at the gNB scheduler (and Downlink Control Information (DCI) has been prepared), to satisfy low latency requirements this data may be sent in the form of a mini-slot along with its control information. Due to relatively small time-frequency resources available for mini-slot, multiplexing of data in the control region of mini-slot is of prime importance.

In NR systems, the use of COntrol REsource SET (CORESET) has been agreed on.

This is a group of physical resource blocks (PRBs) for a certain number of Orthogonal Frequency Division Multiplexing (OFDM) symbols, to carry control information from the gNB to users. Due to wide carrier bandwidths available for NR, time and/or frequency portions extending the CORESET can be significant and if left unused may degrade the system spectral efficiency. This necessitates the multiplexing of data (such as Physical Downlink Shared Channel (PDSCH)) over these resources to improve the spectral efficiency.

Contrary to LTE where there is a clear time split between control (Physical Dedicated Control Channel (PDCCH) region) and data (PDSCH), in NR the control information will be sent to users through different CORESETs in the control region. Due to availability of very wide-bandwidth carriers in NR, CORESET may not occupy the whole control region all the time. To achieve good spectral efficiencies, NR has already agreed to multiplex the data over the control resources. However, a user will not know the presence and precise location of CORESETs for which it is not configured. Similarly, a CORESET may consist of certain time frequency resources to accommodate potentially the control information for several users. As these users may not necessarily have relevant control information in CORESET during each scheduling interval, this will result in partially used CORESETs which also implies inefficient use of time-frequency system resources.

In NR, a slot is defined as 7 or 14 OFDM symbols for the same subcarrier spacing of up to 60kHz with a normal Cyclic Prefix (CP) and as 14 OFDM symbols for the same subcarrier spacing higher than 60kHz with a normal CP. A slot can contain all downlink, all uplink, or at least one downlink part and at least one uplink part. Slot aggregation is supported, i.e., data transmission can be scheduled to span one or

multiple slots. Mini-slots having the following lengths are also defined. At least above 6 GHz, mini-slot with length 1 symbol are supported. For lengths from 2 to slot length -1, for URLLC, at least 2 symbols are supported. Mini-slot can start at any OFDM symbol, at least above 6 GHz. A mini-slot contains a Demodulation Reference Signal (DMRS) at position(s) relative to the start of the mini-slot.

There are numerous agreements relating to CORESET and search spaces in the standards documents. These are readily available to the person skilled in the art. The agreements set out the requirements and the features which require further study. The various agreements have resulted in a number of proposals to address the various issues and problems.

The present invention is seeking to solve at least some of the outstanding problems in this domain.

An object of the present invention is to enable efficient multiplexing of data over the so-called control resources, both for slot and mini-slot based scheduling use cases, without the problems of previous methods and schemes.

Summary

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

According to a first aspect of the present invention there is provided a method for enabling a wireless communication device to access services provided by a Radio Access Network in a communication between a first and a second wireless communications device, wherein the communication includes at least one control region including a group of physical resource blocks, the method comprising: multiplexing data within at least part of the control region to liberate space in the control region, such that the liberated space can be used for data transmission.

Preferably, the group of physical resource blocks comprises a CORESET.

Preferably, the first communications device comprises a base station and the second device comprises a UE; and wherein the base station configures data for the UE in the control region of the transmission.

Preferably, the base station configures data for the UE in the control region of the transmission if all frequency carriers allocated to the UE are not configured for any CORESET.

5 Preferably, the base station configures data for the UE in the control region where a user's allocated frequency resources overlaps partially or completely with its own CORESET.

Preferably, the base station configures data for a UE in the control region where a user's allocated frequency resources may contain any number of known CORESETs including the common, group common and its assigned user specific CORESET.

10 Preferably, the base station multiplexes data for a UE extending its frequency allocation in the control part where there is a CORESET configured unknown to this specific user but currently does not contain any control data.

Preferably, the base station can configure data for a user in the control part such that user's frequency carriers are using the resources around the CORESETs of other
15 users, and gNB signals the resource occupancy of the CORESETs to the user.

Preferably, the base station configures resources for a user in the control part allowing an irregularity around unknown CORESET by conveying limited information about the boundary of the unknown CORESET.

Preferably, the limited information about the boundary of the unknown CORESET
20 comprises at least one of a last PRB of the CORESET and a first available PRB for the user; and further includes information regarding a length of the CORESET.

Preferably, information about the boundary of the unknown CORESET is sent at a granularity higher than PRB to reduce the signalling overhead.

Preferably, the information regarding the length of the CORESET comprises one of an
25 absolute length or a relative length from the start of the user's scheduled data.

Preferably, the base station uses a CORESET pattern from a set of pre-defined CORESET patterns.

Preferably, more than one pattern can be activated by the base station at the same time.

30 Preferably, the base station can further send a bitmap conveying an activation status of the CORESETs for an active CORESET pattern.

Preferably, the activation information is sent as one of cell specific or group specific data.

Preferably, the base station can configure data for a user inside a CORESET for its allocated PRBs if one or more symbols inside the CORESET for the user's frequency resources are unused in a current scheduling interval.

Preferably, the base station can configure data for a user inside a CORESET for one or more OFDM symbols for which the user's CCEs are present in a symbol.

Preferably, the CCEs can be time or frequency first mapping and localized or distributed in the CORESET.

10 Preferably, the base station can configure data for a user inside a CORESET by extending its frequency resources for one or more OFDM symbols when there are unknown CCEs from at least one user.

Preferably, the base station provides location information to a user to be able to wrap data around the CCEs of an unknown user.

15 Preferably, the base station provides limited location information indicating that a user knows a frequency location starting from which its data has been multiplexed inside a CORESET.

Preferably, the frequency location information is in terms of PRB number or on a higher granularity for a group of PRBs to reduce the signalling overhead.

20 Preferably, the Radio Access Network is a New Radio/5G network.

According to a second aspect of the present invention there is provided a base station adapted to perform the method of another aspect of the present invention.

According to a third aspect of the present invention there is provided a UE adapted to perform the method of another aspect of the present invention.

25 According to a fourth aspect of the present invention there is provided a non-transitory computer readable medium having computer readable instructions stored thereon for execution by a processor to perform the method of another aspect of the present invention.

The non-transitory computer readable medium may comprise at least one from a group consisting of: a hard disk, a CD-ROM, an optical storage device, a magnetic storage

device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory and a Flash memory.

Brief description of the drawings

- 5 Further details, aspects and embodiments of the invention will be described, by way of example only, with reference to the drawings. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. Like reference numerals have been included in the respective drawings to ease understanding.

Figure 1 is a simplified diagram showing CORESET level sharing of Control Resources for data, according to an embodiment of the present invention.

Figure 2 is a simplified diagram showing enhanced CORESET level data reuse, according to an embodiment of the present invention.

Figure 3 is a simplified diagram showing an example set of CORESET patterns, according to an embodiment of the present invention.

- 15 Figure 4 is a simplified diagram showing enhancement of Control Resource usage with limited signalling, according to an embodiment of the present invention.

Figure 5 is a simplified diagram showing CCE level reuse of control resources for data including a frequency first localized mapping of CCE, according to an embodiment of the present invention

- 20 Figure 6 is a simplified diagram showing CCE level reuse of control resources for data including a time first localized mapping of CCE, according to an embodiment of the present invention.

Figure 7 is a simplified diagram showing CCE level reuse of control resources for data, according to an embodiment of the present invention.

- 25 Figure 8 is a simplified diagram showing enhanced CCE level reuse of REs for data around unknown CCEs, according to an embodiment of the present invention.

Figure 9 is a simplified diagram showing data multiplexing over control resources for mini-slots, according to an embodiment of the present invention.

- 30 Figure 10 is a simplified diagram mini-slot data multiplexing inside CORESET around unknown CCEs of other users, according to an embodiment of the present invention.

Detailed description of the preferred embodiments

Those skilled in the art will recognise and appreciate that the specifics of the examples described are merely illustrative of some embodiments and that the teachings set forth
5 herein are applicable in a variety of alternative settings.

The present invention relates to methods and a system that use unexploited control resources for data transmission which increases the spectral efficiency of the system. This may be used to improve the available resources for data transmission in for example the DL direction. In turn, this may increase the users' throughputs. Use of
10 more time-frequency resources for data can be used to lower the code rate for a given information block causing to improve reliability.

The present invention goes beyond the current state of the art on both CORESET level reuse and CCE/DCI level reuse. For CORESET level reuse, it provides techniques to use resources around the unknown CORESETs and efficient signalling to achieve this.

15 In addition, a pattern-based technique with hierarchical refinement or its variation with additional bitmap indicating configured and unconfigured CORESETs is provided. Similarly, for data multiplexing inside the CORESET at DCI/CCE level, the invention provides techniques to enable data multiplexing around other users' CCEs which are normally unknown to the UE.

20 An important part of the invention is the reuse around an unknown CORESET. To overcome the signalling burden, a signalling strategy is provided which can harness most of the multiplexing gain with a limited number of bits by indicating only the boundary of the unknown CORESET. A similar approach can be adopted at the CCE/DCI level data multiplexing. Another important feature relates to basing the
25 CORESET configuration pattern on, and sending a bitmap informing UEs about, the unoccupied CORESETs.

In 4th Generation mobile systems, such as LTE and LTE-Advanced, there is a clear split in the control region in the beginning of the sub-frame and the data region on the rest of the symbols. This control region consists of three physical control channels,
30 Physical Control Format Indicator Channel (PCFICH), Physical Hybrid ARQ Indicator Channel (PHICH) and PDCCH. PCFICH provides the size of the control region and

then within this control region, users can search for their relevant control information as a function of system configurations and their identity.

As carrier bandwidths can be extremely large in NR systems, maintaining a clear split in time between control region and data region by dedicating the first few symbols for control may incur a huge resource waste. As a result, it has already agreed that part of the control resources may be used for data transmission. There are agreements in 3GPP that each user will not be configured to search through the whole control region to find its relevant control information, rather it may be configured one or more CORESETs to look for its control information.

A CORESET is a combination of contiguous resource element group (REGs) with a time duration of 1, 2 or 3 OFDM symbols. Further there may be at least a CORESET which a user can get to know after reading a master information block (MIB). As with this common CORESET, there may be a group-common PDCCH transmission listened to by a group of users. Thus, every user in the system may be configured to listen to at least one or more CORESETs. Most likely, these CORESETs are not going to define a perfectly regular rectangle in the beginning of the slot, which means there may be time-frequency resources available in the beginning of the slot, in this so-called control region.

In accordance with 3GPP agreements on enabling the use of control resources for data transmission, multiple solutions are possible at different granularities with different gains and different signalling requirements to enable these mechanisms. For this 3GPP has already agreed to indicate the start symbol for data transmission dynamically and possibly the allocated length as well.

The first level of sharing is when the gNB configures the start of data for a user within the control region but configures this reuse only when all the PRBs allocated to this user can be time extended into the control region without any overlap to any of the configured CORESET. The next level of sharing of control resources can be achieved when the gNB configures the PRBs for a UE starting from a certain OFDM symbol where the PDSCH allocated region overlaps with one or more CORESETs known to the UE. With the knowledge of the CORESETs' resource allocations, the UE can accurately determine the time-frequency resources in the control region which may carry its data.

With respect to the figures it should be noted that for CORESETs which are contiguous (frequency localized) in the frequency domain, the ideas apply directly to the CORESETs which are non-contiguous in the frequency domain as well which means that a single CORESET which is mapped onto non-adjacent or non-contiguous frequencies.

Figure 1 shows an example where two levels of control resource sharing are illustrated. Figure 1a on the left-hand side shows the conventional setting. The slot includes a control region in the beginning followed by a data region. The control region comprises a common CORESET and three other CORESETs. There are three users configured and scheduled through CORESET1, denoted as UE 1.1, 1.2 and 1.3. CORESET2 schedules UE 2.1. No users from the CORESET3 are scheduled in this slot. In the conventional scheduling scenario, in this case the gNB has scheduled the users in the data region only.

Figure 1b shows the first level of reuse of control resources for data where the gNB indicates the first data symbol of the users which is the first symbol where its PRBs have no overlap with any CORESET. This shows that UE 1.1 and UE 2.1 gain one symbol time of resources corresponding to their assigned PRBs. Still in the time-frequency grid, there is considerable resource waste in the control region. The resources gained with this step have been horizontally shaded.

Figure 1c shows the case where the gNB configures the users with data starting at OFDM symbol where they can have overlap with any known CORESET. The gNB can choose to carry out puncturing or rate-matching around these CORESETs. For rate-matching, the gNB can choose the target code rate for PDSCH. For the puncturing case, it uses a lower code rate to compensate for the puncturing around the CORESETs. In general, puncturing may facilitate the gNB operation compared to rate-matching where it needs to carry out rate-matching as a function of what data resources it is able to multiplex in the control part for a specific user. UE 1.2 is configured by the gNB to receive PDSCH from the first symbol of the slot. Its allocated PRBs overlap with its CORESET1 so it successfully takes only the resource elements where its data is transmitted after leaving the resources of CORESET1. Similarly, UE 1.3 has been allocated PRBs that overlap in frequency with regions of CORESET1 and the common CORESET that is known to all users in the cell. The gNB has configured the PDSCH of UE 1.3 from the first symbol of the slot. Therefore, UE 1.3 may leave

out the resources occupied by CORESET1 and common CORESET and the rest of the resource elements carry its data. The resources gained by both UE 1.2 and 1.3 in this step have been vertically shaded.

It should be noted: apart from an indication on the start symbol for data (which has been agreed by 3GPP) no additional signalling is required from the network.

Figure 2 is essentially an extension of Figure 1, showing two additional settings. In Figure 2a, it is assumed that CORESET3 is either a group common CORESET known at least to UEs 1.1 and 2.1 or the gNB has informed at least these users about the resource allocation of this CORESET. Under that assumption, the gNB can configure the PDSCH start symbol of UE 1.1 and UE 2.1 as the first symbol of the slot doing the puncturing or rate-matching around CORESET3 for the data of UE 1.1 and puncturing/rate-matching around CORESET2 and 3 for the data of UE 2.1. The squared patterned PDSCH region shows the additional PDSCH resources becoming available with this enhancement.

If CORESET3 is not configured or it happens to be carrying no information during this slot, the gNB can configure the PDSCH of these UEs 1.1 and 2.1 from the first symbol of the slot without having the need to rate match around CORESET 3. This additional PDSCH resource extension is shown as crossed patterned region. The region of interest here is the region which was shown in Fig 2a occupied by CORESET 3. Here if this happens to carry nothing, the gNB can configure users over this region..

Figure 2 has demonstrated that the knowledge of CORESETs at the UE may enable efficient use of control resources for data. Unfortunately, normally each user may know only the CORESETs for which it is configured. Informing all UEs of all the active CORESETs location (time and frequency regions) may increase the signalling load significantly. Each user may need to be informed separately about the CORESETs where it may have control information plus the other UEs CORESETs just to enable data multiplexing over the control resources or common signalling may be required (at cell level or group level).

To reduce the signalling load required to enable data multiplexing in the control region, one possibility may be to pre-define a set of CORESET patterns. Then the gNB can choose one of the suitable patterns to be used as a function of network and users' dynamics. Figure 3 shows an example set of pre-defined CORESET patterns. Such

CORESET patterns may be defined for different system/carrier bandwidths. The gNB can inform the users in the cell which pattern is currently configured through common or group-common control signalling. This will enable the use of time-frequency resources for data in the control region which are not part of any CORESET.

- 5 As the requirement for size and periodicity of the CORESET configuration can have many variations, to handle such variations either the set of patterns can contain a plurality of patterns and gNB chooses in a semi-static manner the pattern which best suits the current load and dynamics. The other possibility may be to have relatively few simple patterns in the set and gNB can activate one or more patterns at the same
10 time. This may allow some flexibility when gNB needs to scale up or down the number of CORESETs without making any change to currently active CORESETs and configured users.

An enhancement to CORESET pattern idea can be to use hierarchical patterns. There are one or more base patterns and the gNB can refine or adapt these patterns. This
15 may still further reduce the amount of signalling, since the used pattern is not expected to change dramatically from one slot/sub-frame to the next. This also ensures that if the gNB needs to scale up or down CORESET resources due to change in network/users' dynamics, it does not need to de-allocate and then allocate the currently active users.

- 20 One further strategy can enable dynamic use of control resources for data multiplexing. For the slots with only a low number of active CORESETs within the configured CORESET pattern, the gNB can send a bitmap for the configured/active CORESETs. This is more suitable in the case of a single active pattern since with more patterns the dynamic information regarding all patterns may be an issue. This information can be
25 cell specific and sent to all users. This information can also be sent in a group specific manner to a group of users or be user specific. In the latter case, for example, for the user who is currently requesting high throughputs in the DL direction and is being scheduled actively. Having informed the relevant users about the current CORESET active bitmap, the gNB can configure users from the first symbol of the slot and users
30 knowing the active CORESETs may be able to use the resource elements in the control region (which are not part of CORESETs) plus the resource elements which correspond to non-configured or non-active CORESETs. This may improve the system spectral efficiency despite the requirement for dynamic signalling.

Instead of using CORESET patterns and associated signalling to enable data multiplexing in the control region, an alternative approach may be to let the gNB configure CORESETs as it deems suitable. In this approach, data multiplexing in the control region is enabled by gNB sending limited control information to the user being scheduled whose data scheduling could be extended in the control region, overlapping some unknown CORESET(s). Instead of sending to just a single user in question, the limited information can be sent to a group of users. One example can be the group of users who are currently active. This is explained with reference to Figure 4 where for ease of description only a single scheduled user is shown.

Figure 4a shows a classic split of control and data. If the gNB allows Data resource allocation around known CORESETs, Figure 4b is the result. This is achieved by indicating the start symbol to be the second symbol of the slot. The UE knows the CORESET1 and the common CORESET around which the gNB has rate matched its data. Thus, both the gNB and the UE have a common understanding where PDSCH data is scheduled. The gNB cannot start this user's data from the first symbol as CORESET2 is unknown to this UE. Use of resources from the first symbol as shown in Figure 4c may require the gNB signalling the region of CORESET2 to this UE. This may increase the signalling overhead. Spectral efficiency close to this case can be realized by adopting a rule that the gNB may only allow a single irregularity/dent in the rectangle other than made by known CORESETs. This scenario is shown in Figure 4d. Thus, the gNB can inform this UE about the PRB position where CORESET2 ends or the first PRB that UE1.1 can use after CORESET2. To be able to use the resources properly, the UE must acquire knowledge of the time duration of the unknown CORESET in addition to its position in frequency. As the CORESET can only be configured for 1, 2 or 3 symbols in time, this information can be communicated easily with 1 or 2 bits of information. The CORESET time duration can be indicated relative to the first symbol of the slot or the PDSCH start symbol of the user who is being configured to use these resources. Figure 4d has shown one dent or irregularity in the user's PRB in addition to the known CORESET at one corner. Conveying the dent information in one corner is straightforward as only one PRB needs to be indicated. In case this dent occurs in the middle of the user's PRBs, starting and ending position or one position plus CORESET length need to be conveyed to the user. The gNB may choose to configure data on the unknown CORESETs only at the corners of allocated

PRBs, thus limiting the information which needs to be sent. One additional approach to further reduce the signalling bits required to indicate the boundary PRB is to adopt a higher granularity in terms of PRBs, by considering a certain number of adjacent PRBs forming a group. Thus instead of indicating the PRB, gNB needs to indicate the boundary of the unknown CORESET in terms of group PRB, which would require fewer bits than indication in terms of PRBs.

DCI or CCE level reuse of control resources from within a CORESET for data transmission will now be discussed.

Data multiplexing over the control resources inside CORESETs will now be discussed.

There may be common, group common and UE specific CORESETs. A user may be configured for UE specific CORESETs through higher layer signalling but it may not know if there are other users configured for the same CORESET. That also implies it may not know the detailed mapping of other users control channel elements (CCEs) in the CORESET if they happen to be present. The mapping of CCEs inside a CORESET can be time/frequency-first and localized or distributed. The location (and hopping to next CCEs) is normally a function of UE identity.

The simplest case of using control resources inside a CORESET is the setting when the gNB is configuring some users and for a specific user's allocated frequency resources, one or more symbols in the CORESET happen to be unused for CCEs. In this case, the gNB can very easily configure this data multiplexing inside a CORESET by indicating the start symbol of the user's allocation inside the CORESET (making use of the unused CORESET OFDM symbols). An example is shown in Figure 5. This figure shows a simple case where there is only one CORESET spanning three OFDM symbols. This is followed by 11 OFDM data symbols but the time durations are exemplary here and can be any allowable lengths for these regions. In figure 5, CCE mapping is frequency first and localized for both UEs. Figure 5a shows the setting such that there are OFDM symbols unused in the CORESET1 but the data of users 1.1 and 1.2 start after the CORESET. Figure 5b shows the simple multiplexing over the CORESET where the frequency allocation for both users has been extended in time over the unused CORESET symbols. The additional resource gain is shown in vertical lines patterned region.

The next level of data multiplexing inside CORESETs can be enforced when the gNB indicates the start symbol of data in a slot which even contains its own CCEs, the

location for which is certainly know to this UE. The gNB can apply puncturing/rate-matching of data resources around the CCE of the user in the CORESET, though there should be no confusion at the UE side as to which of rate-matching or puncturing is used. This is shown in Figure 5c where gNB configures both UEs 1.1 and 1.2 from the first symbol of the slot without any additional information. The frequency allocation for each UE overlaps with the location of its CCE which is known to each UE. Thus, upon getting the scheduling command from the first symbol and having knowledge of its CCE location, each user knows that the gNB has scheduled its data around its CCEs and hence is capable of successfully identifying the data resource elements from CCEs. The additional resource which becomes available for data multiplexing is shown in plus signed pattern in the first symbol of Figure 5c.

Figure 6 shows the same strategy applied to multiplex data over CORESET resources when CCEs have been mapped time first in localized manner. Figure 6a shows the classic scheduling where there is no data multiplexed over the CORESET. Figure 6b shows the case when gNB allows data scheduling over unused CORESET symbols. Due to time first mapping of CCE, CCEs occupy Resource Element Groups (REGs) in time up to the duration of the CORESET. Thus, this alternative does not permit any increase in the data resource elements for any user. Figure 6c shows the case when the gNB adopts the strategy of scheduling data around a user's known CCEs. Thus, the gNB schedules the data of each user starting from first symbol of the slot by carrying out puncturing or rate-matching around each user's CCEs. As each user knows the precise location of its CCEs, upon receiving the scheduling command from the gNB with start symbol as first symbol of the slot, it knows the multiplexing of its data around its CCEs without any signalling requirement. This may improve the spectral efficiency of the system. The additional resource which becomes available through this is shown in plus sign pattern in Figure 6c.

Figure 7 shows the case of distributed mapping for CCEs. The top figures show the frequency first and the bottom figures show the time first mappings. Figure 7a show the scenario where CORESET contains CCEs for UE 1.1 and 1.2 for which these users have been scheduled outside of the CORESET. Figure 7b show the scenarios where the gNB is allowed to do the CORESET reuse for data of a specific UE if all PRBs for this user are unused over one or more symbols of the CORESET. For the case of frequency first mapping, this allows the gNB to schedule the data of both users two

symbols in the CORESET, shown vertical lined pattern symbols in the figure. In the contrary, this brings no improvement for time first mapping case as CCEs extend and use all the CORESET symbols. Figure 7c show the case when the gNB does the scheduling for the users over known CCEs. This allows additional control resource
5 usage for UE 1.2 as for its frequency resources; only own CCEs are present in the CORESET. This additional area is shown with horizontal lines patterns.

Enhanced CCE Level Reuse of control resources from within a CORESET for Data Transmission will now be discussed.

The case of aggressive multiplexing of data over the CORESET resources which may
10 have overlap with CCEs that are unknown to the user who is being scheduled around those CCEs is now considered. This may be enabled by the gNB conveying some information to the user.

One approach to enable such resource sharing around unknown users' CCE may be to enforce some CCE patterns, similar to what was proposed in Figure 3 for
15 CORESETs. These patterns may be different for different system bandwidths. To enable data multiplexing of a specific user around CCEs of another user, the gNB may inform the former regarding the pattern of the latter and may schedule the data by puncturing or rate-matching around this CCE pattern. Once the pattern is known, the user is able to retrieve the data multiplexing around the CCEs of other users.

Another approach is to inform the user being scheduled regarding the location of other
20 users CCEs. This may require additional signalling if there is only one or two other users' CCEs are present in a user's frequency resources in a localized fashion but conveying the complete information if distributed mapping may put a burden on the DL signalling. As a result, the use of such multiplexing may not be optimal. The DL
25 signalling burden to inform the users about other unknown CCEs can be contained by sending only limited information regarding the boundary of other users CCEs.

Figure 8 shows the above approaches applied to the resource elements inside a CORESET. Figure 8a shows the classic setting where CORESET contains localized
30 time-first mapped CCEs for two users who are assigned data resources outside of the CORESET. Figure 8b shows the reuse of control resources for data when UE 1.2 is scheduled from the first symbol of the slot without any additional information. Figure 8c shows the case when the gNB schedules even UE 1.1 from the first symbol of the

slot and carries out the puncturing or rate-matching of data of UE1.1 around the CCEs of UE 1.2. To enable this, the gNB informs UE 1.1 about the precise location of CCEs of UE 1.2. The additional resource which becomes available for UE 1.1 through this aggressive reuse is shown in +sign pattern.

5 Sending complete information to a user about the unknown CCEs of other users may be optimal from the perspective of spectral efficiency, this may result in a control overhead issue when there are CCEs for multiple users in the CORESET that have been mapped in a distributed manner. The signalling overhead can be contained if the gNB only uses one side of resources around unknown CCEs for a specific user. An
10 example is shown in Figure 8d where the gNB schedules the data of UE 1.1 from the first symbol of the slot and only indicates the first PRB after the unknown CCE. This informs UE 1.1 that in such a setting it may use the PRBs in the first symbol starting from this PRB to its last PRB. Figure 8d shows that there are some unused resource elements which cannot be used through this limited signalling, though considering the
15 limited signalling necessary to enable such data multiplexing this strategy seems to offer a very reasonable trade-off. One important aspect is the fact that gNB does not need to inform the UE about the number of symbols in time that CCEs of others users occupy. A CORESET can have either time first or frequency first mapping so in case of time first mapping, UE knows that all symbols inside the CORESET would be
20 occupied by other users CCEs in the form of resource element groups. Similarly for frequency first mapping case, it would know that next symbols would be empty, unless there are some users CCEs which are embedded after the first symbol and then gNB may need to send some information about the time boundary of unknown CCEs.

The discussion and the figure shown here are for a localized mapping case but it is
25 equally valid for the case of distributed CCE mapping and for both time and frequency first cases. The principle to use some part of control resources around unknown CCEs by indicating a single boundary of the unknown CCEs is also perfectly applicable to distributed mapped CCE cases. The signalling bits required to indicate a boundary of unknown CCEs can be reduced by informing the boundary over a granularity higher
30 than PRBs.

DCI and CCE Level Reuse of control resources from within a CORESET for Mini-Slots will now be discussed. This discussion is related to mini-slots which have both control and data parts. Such mini-slots may be destined to URLLC users. The use of control

resources outside of CORESET and inside the CORESET around CCEs is more important for mini-slots than to slot based scenarios. Due to their smaller size, spectral efficiency of the mini-slots can be significantly improved by data multiplexing over the control resources.

- 5 Figure 9 shows the previously described ideas applied to the case of mini-slots. Figure 9a shows two mini-slots with control scheduled in a slot over different time and frequency resources. Each mini-slot control region is shown to have one CORESET which is shown to contain CCEs of a user which is scheduled for PDSCH. Here PDSCH length is shown to be only one symbol, but this is not a limitation and the
- 10 approach applies equally to mini-slots having a data duration of more than one symbol. In Figure 9a, data is not scheduled over the CORESET although CORESET2 has been configured for a smaller number of frequency resources than it configures for PDSCH of UE y (shown with no hatching). Figure 9b shows the case when the gNB schedules the control resources for data around the CORESET. This allows more data resource
- 15 elements for UE y around CORESET2 but does not help UE x. In Figure 9c, the gNB configures the data of the users from the start of the mini-slot and carries out puncturing/rate-matching around the CCEs present within. As users know their own CCEs, they can perfectly retrieve their data resource elements from within the CORESET. This resource increase is shown by +-sign pattern in this figure 9c.
- 20 Figure 9 shows the case of two mini-slots where there were CCEs for only one user inside a CORESET. Although several URLLC users may be allocated the same CORESET where its periodicity is more frequent than the slot based CORESETs (for example every symbol or every two symbols etc.). The chances that multiple users need to communicate with low latency at the same precise instant becomes low. Thus,
- 25 the scenario seems to be typical for mini-slots.

Nevertheless, there may be situations when the gNB scheduler receives data from higher layers for multiple URLLC users at the same time. For the case of multiple CORESETs or multiple users' CCEs inside each CORESET, the above approach stays valid. Using the control resources inside a CORESET around unknown CCEs may be

30 very relevant for mini-slot scenarios. This is shown by way of example in Figure 10. Figure 10 a, b and c on the left are for distributed cases and Figure 10 a, b and c on the right are for the localized mapping case. Figures 10a show that CORESETs containing CCEs of two users where only UE x PDSCH is shown on same PRBs. To

keep the discussion simple it is assumed that UE y is being scheduled on different time-frequency resources or at least on the frequency resources which are completely disjoint from the ones shown in the figure. The gNB does not schedule data of UE x in the CORESET due to unknown CCEs of UE y. In Figures 10b, the gNB schedules the data of UE x in the CORESET around UE y's CCEs. This may require informing UE x about the CCE placement of UE y. The required signalling may be moderate for localized mapping but very burdensome for distributed mapping case. Figure 10c show the application of a limited signalling approach where the gNB informs UE x about the boundary of UE y's CCE. This may leave some resource elements unused in the CORESET but considering the limited signalling it requires, spectral efficiency gains for data are significant.

Puncturing or Rate-Matching around CORESETs or DCIs/CCEs is now discussed.

Many of the approaches presented herein for data multiplexing in the control region, at CORESET or DCI/CCE level, may result in different length PRBs allocated to a user in the slot, due to use of resources around or at the edges of active control resource elements. If the gNB applies rate matching, this makes the gNB processing more complicated as it needs to perfectly rate match. This can be simplified to some extent by assigning a granularity to PRB group level.

Puncturing is relatively easy to apply for such non-uniform lengths. The gNB can encode the user's data with a slightly lower code rate and then carry out the puncturing around the control resources. Although relatively simple to apply, puncturing can degrade the performance for large puncturing blocks even if the code rate has been lowered. One approach is to apply a rate matching at the CORESET level as CORESETs are semi-statically configured and hence the gNB may know the amount of control resources it can use for data before scheduling DCI/CCEs in the CORESETs. For DCI/CCE level reuse where mostly moderate resources will be available, puncturing can facilitate the gNB operation. One approach is to also apply rate matching inside CORESET for CCE level data multiplexing when this CORESET has CCEs for a single user. This may be helpful for mini-slots where a single active user per mini-slot is expected to be a typical use case.

A CORESET on Non-Contiguous Frequency Resources may also be of interest, since NR allows a single CORESET to have either frequency resources that are contiguous or non-contiguous. The present invention generally makes reference to the case of

frequency contiguous CORESETs. However, the approaches are equally valid for other cases, such as for example for the CORESETs which are non-contiguous in frequency. Each single distributed CORESET can be viewed as multiple CORESETs which are either known to the user (being common, group common or user assigned
5 CORESET) or unknown and then the approach apply as a function of user knowledge about these CORESETs.

The invention has been described with reference to frequency localized PDSCH assignments. however all of the approaches associated with CORESET level sharing and DCI/CCE level sharing are applicable to distributed assignment as well.

10 An interesting situation may arise when the CORESET is configured on non-contiguous frequency resources and PDSCH allocation is also distributed in frequency. If a similar granularity is allowed for distributed CORESET and the distributed PDSCH, and they share the full or partial PRBs, that may facilitate the application of data multiplexing over control resource ideas presented in this invention.

15 Multiple DCIs (CCEs) for one UE have been used to keep the explanation simple, for example the case where there is one DCI (set of CCEs) allocated to a user but a UE can have multiple DCIs in one or different CORESETs received in the same slot. Multiple DCIs can be due to DL+UL control, DL+common, UL+common etc. All of the approaches described above apply also to these scenarios.

20 Slot aggregation or Cross-Slot Scheduling has already been standardized by 3GPP. The present invention has used the general case with same slot scheduling but the ideas stay widely applicable to slot aggregation or cross-slot scheduling use cases of all types. For the PDSCH data scheduled in a slot later than the current slot or the slot aggregation part in the next slots, the gNB may not know the DCI/CCE size for the
25 upcoming slots. Therefore, the DCI level sharing inside the CORESETs can be harder to enforce. On the other hand, CORESETs are configured semi-statically so all the ideas for CORESET level sharing can be used for future PDSCH multiplexing for slot aggregation or cross-slot scheduling.

Many other alternatives and variations may apply to the use and functionality of the
30 various approaches presented herein.

Although not shown in detail any of the devices or apparatus that form part of the network may include at least a processor, a storage unit and a communications

interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method of any aspect of the present invention. Further options and choices are described below.

5 The signal processing functionality of the embodiments of the invention especially the gNB and the UE may be achieved using computing systems or architectures known to those who are skilled in the relevant art. Computing systems such as, a desktop, laptop or notebook computer, hand-held computing device (PDA, cell phone, palmtop, etc.), mainframe, server, client, or any other type of special or general purpose computing device as may be desirable or appropriate for a given application or
10 environment can be used. The computing system can include one or more processors which can be implemented using a general or special-purpose processing engine such as, for example, a microprocessor, microcontroller or other control module.

The computing system can also include a main memory, such as random access memory (RAM) or other dynamic memory, for storing information and instructions to
15 be executed by a processor. Such a main memory also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor. The computing system may likewise include a read only memory (ROM) or other static storage device for storing static information and instructions for a processor.

20 The computing system may also include an information storage system which may include, for example, a media drive and a removable storage interface. The media drive may include a drive or other mechanism to support fixed or removable storage media, such as a hard disk drive, a floppy disk drive, a magnetic tape drive, an optical disk drive, a compact disc (CD) or digital video drive (DVD) read or write drive (R or
25 RW), or other removable or fixed media drive. Storage media may include, for example, a hard disk, floppy disk, magnetic tape, optical disk, CD or DVD, or other fixed or removable medium that is read by and written to by media drive. The storage media may include a computer-readable storage medium having particular computer software or data stored therein.

30 In alternative embodiments, an information storage system may include other similar components for allowing computer programs or other instructions or data to be loaded into the computing system. Such components may include, for example, a removable storage unit and an interface, such as a program cartridge and cartridge interface, a

removable memory (for example, a flash memory or other removable memory module) and memory slot, and other removable storage units and interfaces that allow software and data to be transferred from the removable storage unit to computing system.

The computing system can also include a communications interface. Such a communications interface can be used to allow software and data to be transferred between a computing system and external devices. Examples of communications interfaces can include a modem, a network interface (such as an Ethernet or other NIC card), a communications port (such as for example, a universal serial bus (USB) port), a PCMCIA slot and card, etc. Software and data transferred via a communications interface are in the form of signals which can be electronic, electromagnetic, and optical or other signals capable of being received by a communications interface medium.

In this document, the terms 'computer program product', 'computer-readable medium' and the like may be used generally to refer to tangible media such as, for example, a memory, storage device, or storage unit. These and other forms of computer-readable media may store one or more instructions for use by the processor comprising the computer system to cause the processor to perform specified operations. Such instructions, generally referred to as 'computer program code' (which may be grouped in the form of computer programs or other groupings), when executed, enable the computing system to perform functions of embodiments of the present invention. Note that the code may directly cause a processor to perform specified operations, be compiled to do so, and/or be combined with other software, hardware, and/or firmware elements (e.g., libraries for performing standard functions) to do so.

The non-transitory computer readable medium may comprise at least one from a group consisting of: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory and a Flash memory

In an embodiment where the elements are implemented using software, the software may be stored in a computer-readable medium and loaded into computing system using, for example, removable storage drive. A control module (in this example, software instructions or executable computer program code), when executed by the

processor in the computer system, causes a processor to perform the functions of the invention as described herein.

Furthermore, the inventive concept can be applied to any circuit for performing signal processing functionality within a network element. It is further envisaged that, for example, a semiconductor manufacturer may employ the inventive concept in a design of a stand-alone device, such as a microcontroller of a digital signal processor (DSP), or application-specific integrated circuit (ASIC) and/or any other sub-system element.

It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to a single processing logic. However, the inventive concept may equally be implemented by way of a plurality of different functional units and processors to provide the signal processing functionality. Thus, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organisation.

Aspects of the invention may be implemented in any suitable form including hardware, software, firmware or any combination of these. The invention may optionally be implemented, at least partly, as computer software running on one or more data processors and/or digital signal processors or configurable module components such as FPGA devices. Thus, the elements and components of an embodiment of the invention may be physically, functionally and logically implemented in any suitable way. Indeed, the functionality may be implemented in a single unit, in a plurality of units or as part of other functional units.

Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein.

Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognize that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term 'comprising' does not exclude the presence of other elements or steps.

Furthermore, although individually listed, a plurality of means, elements or method steps may be implemented by, for example, a single unit or processor. Additionally, although individual features may be included in different claims, these may possibly be

advantageously combined, and the inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather indicates that the feature is equally applicable to other claim categories, as appropriate.

- 5 Furthermore, the order of features in the claims does not imply any specific order in which the features must be performed and in particular the order of individual steps in a method claim does not imply that the steps must be performed in this order. Rather, the steps may be performed in any suitable order. In addition, singular references do not exclude a plurality. Thus, references to 'a', 'an', 'first', 'second', etc. do not preclude
10 a plurality.

- Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with
15 particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term 'comprising' or "including" does not exclude the presence of other elements.

Claims

1. A method for enabling a wireless communication device to access services provided by a Radio Access Network in a communication between a first and a second wireless communications device, wherein the communication includes at least one control region including a group of physical resource blocks, the method comprising:

multiplexing data within at least part of the control region to liberate space in the control region, such that the liberated space can be used for data transmission.
2. The method of claim 1, wherein the group of physical resource blocks comprises a CORESET.
3. The method of claim 1 or claim 2, wherein the first communications device comprises a base station and the second device comprises a UE; and wherein the base station configures data for the UE in the control region of the transmission.
4. The method of claim 3, wherein the base station configures data for the UE in the control region of the transmission if all frequency carriers allocated to the UE are not configured for any CORESET.
5. The method any one of claims 3 to 4, wherein the base station configures data for the UE in the control region where a user's allocated frequency resources overlaps partially or completely with its own CORESET.
6. The method any one of claims 3 to 5, wherein the base station configures data for a UE in the control region where a user's allocated frequency resources may contain any number of known CORESETs including the common, group common and its assigned user specific CORESET.
7. The method any one of claims 3 to 6, wherein the base station multiplexes data for a UE extending its frequency allocation in the control part where there is a CORESET configured unknown to this specific user but currently does not contain any control data.
8. The method any one of claims 3 to 7, wherein the base station can configure data for a user in the control part such that user's frequency carriers are using

the resources around the CORESETs of other users, and gNB signals the resource occupancy of the CORESETs to the user.

9. The method any one of claims 3 to 8, wherein the base station configures resources for a user in the control part allowing an irregularity around
5 unknown CORESET by conveying limited information about the boundary of the unknown CORESET.
10. The method claim 9 wherein the limited information about the boundary of the unknown CORESET comprises at least one of a last PRB of the CORESET and a first available PRB for the user; and further includes
10 information regarding a length of the CORESET.
11. The method claim 9 or claim 10, wherein information about the boundary of the unknown CORESET is sent at a granularity higher than PRB to reduce the signalling overhead.
12. The method claim 9, wherein the information regarding the length of the
15 CORESET comprises one of an absolute length or a relative length from the start of the user's scheduled data.
13. The method any one of claims 3 to 12, wherein the base station uses a CORESET pattern from a set of pre-defined CORESET patterns.
14. The method of claim 13, wherein more than one pattern can be activated by
20 the base station at the same time.
15. The method any one of claims 3 to 14, wherein the base station can further send a bitmap conveying an activation status of the CORESETs for an active CORESET pattern.
16. The method of claim 15, wherein the activation information is sent as one of
25 cell specific or group specific data.
17. The method of any one of claims 3 to 16, wherein the base station can configure data for a user inside a CORESET for its allocated PRBs if one or more symbols inside the CORESET for the user's frequency resources are unused in a current scheduling interval.

18. The method of any one of claims 3 to 16, wherein the base station can configure data for a user inside a CORESET for one or more OFDM symbols for which the user's CCEs are present in a symbol.
19. The method of claim 18, wherein the CCEs can be time or frequency first mapping and localized or distributed in the CORESET.
20. The method of any one of claims 3 to 19, wherein the base station can configure data for a user inside a CORESET by extending its frequency resources for one or more OFDM symbols when there are unknown CCEs from at least one user.
21. The method of any one of claims 3 to 20, wherein the base station provides location information to a user to be able to wrap data around the CCEs of an unknown user.
22. The method of any one of claims 3 to 21, wherein the base station provides limited location information indicating that a user knows a frequency location starting from which its data has been multiplexed inside a CORESET.
23. The method of claims 22, wherein the frequency location information is in terms of PRB number or on a higher granularity for a group of PRBs to reduce the signalling overhead.
24. The method of any one of the preceding claim wherein the Radio Access Network is a New Radio/5G network.
25. A user equipment, UE, apparatus comprising a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method as claimed in any one of claims 1-24.
26. A base station, BS, apparatus comprising a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method as claimed in any one of claims 1-24.
27. A non-transitory computer readable medium having computer readable instructions stored thereon for execution by a processor to perform the method according to any of claims 1-24.

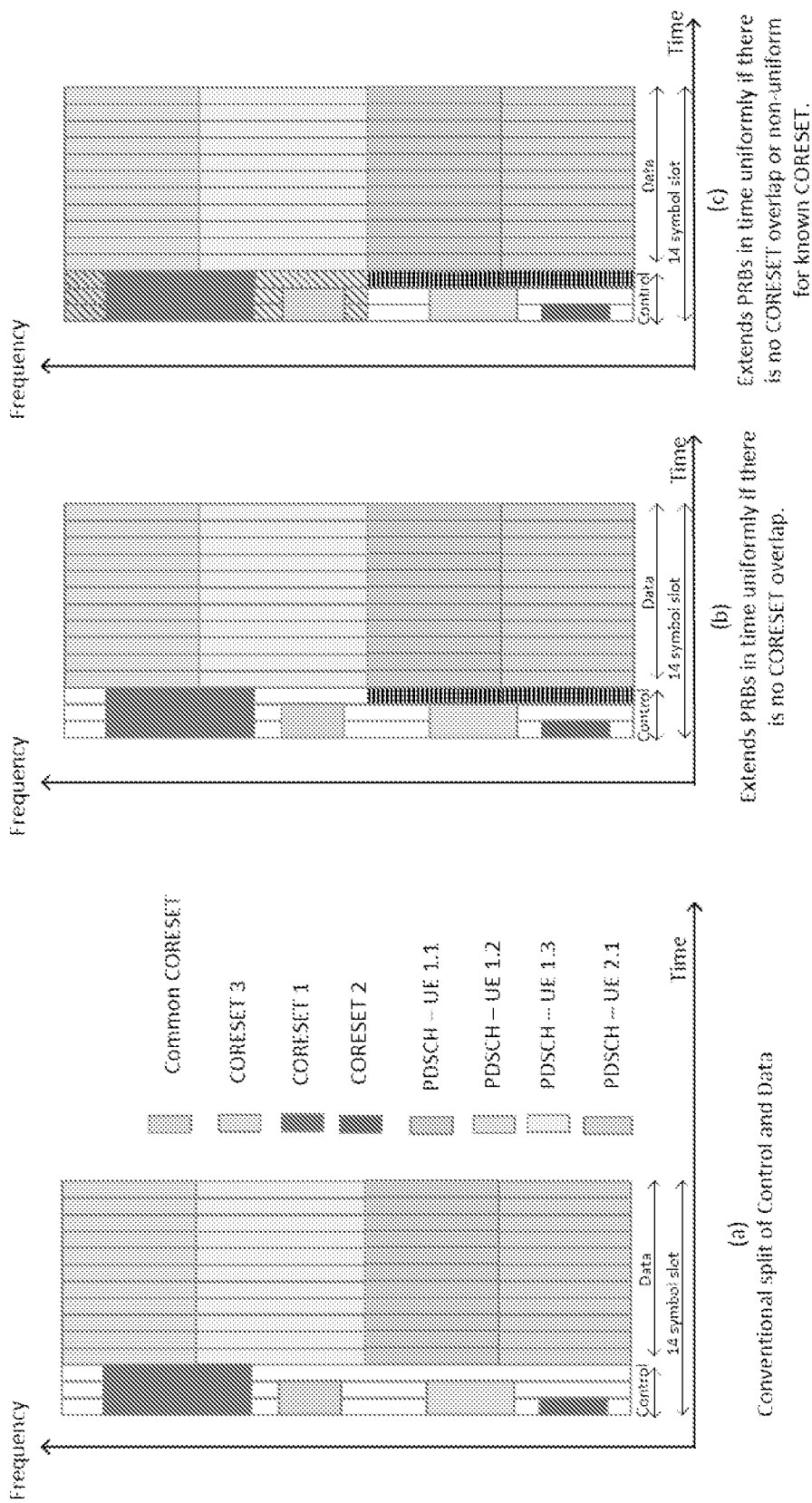


Figure 1: CORESET Level Sharing of control resources for data

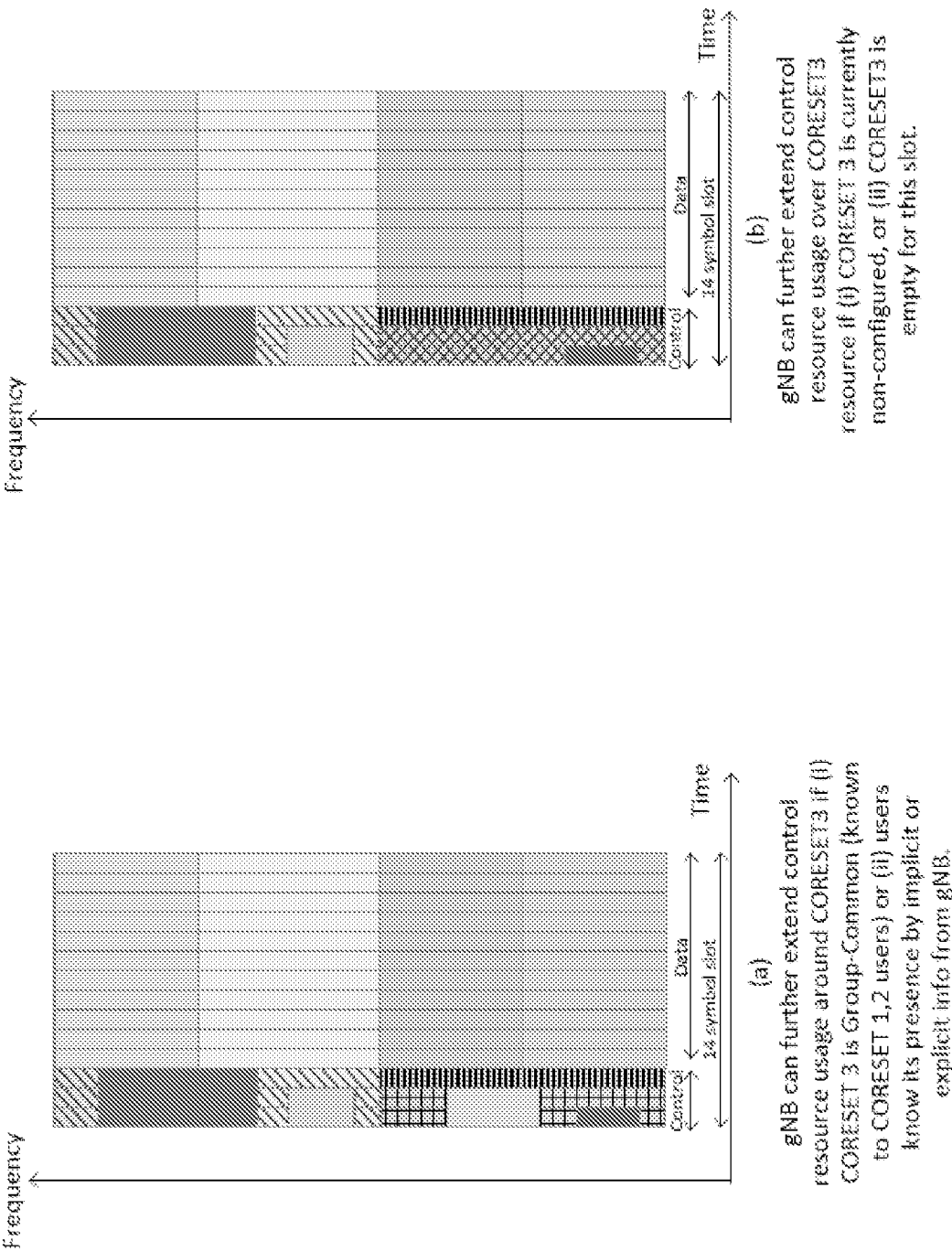


Figure 2: Enhanced CORESET level data reuse

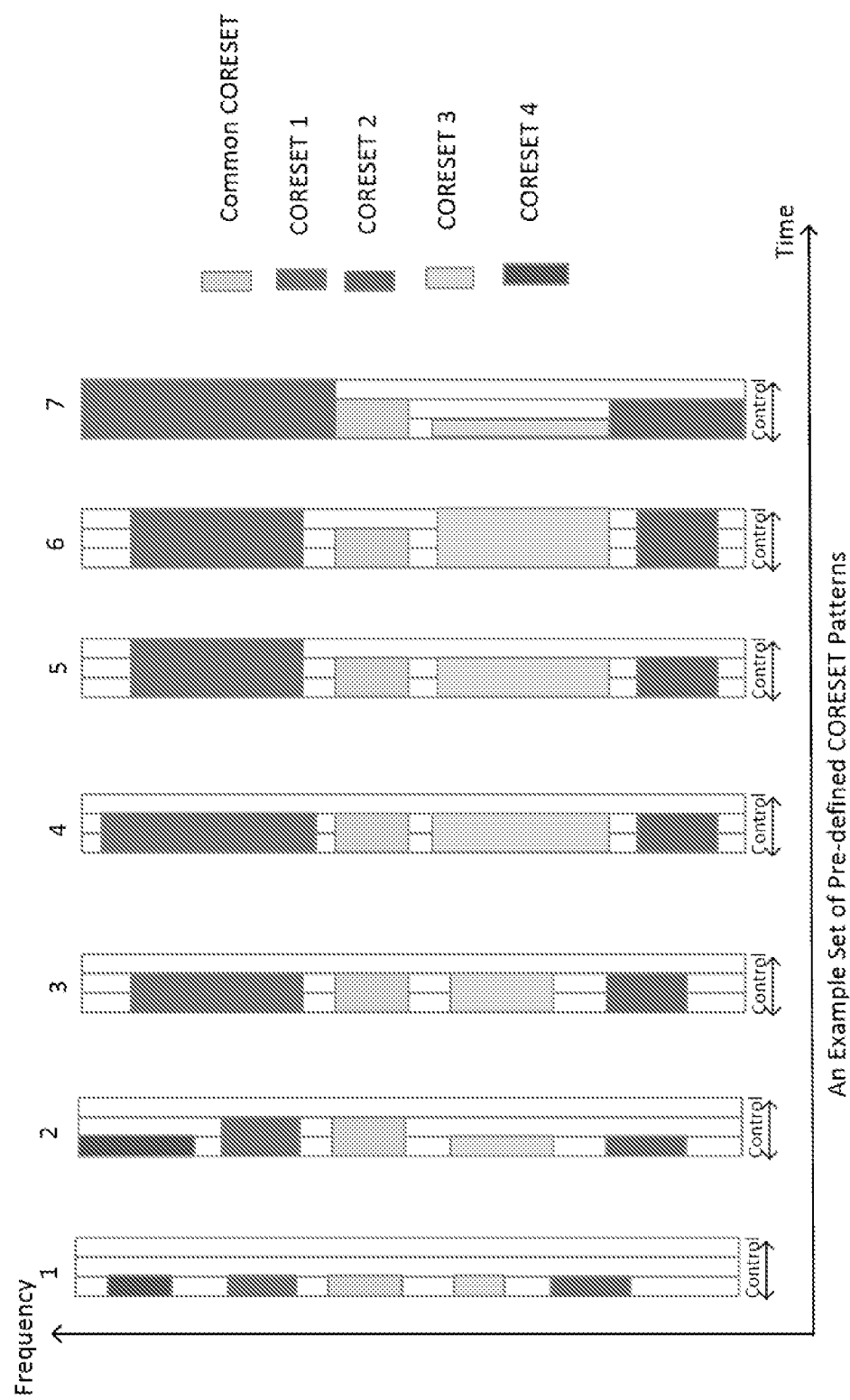


Figure 3: An Example set of CORESET Patterns

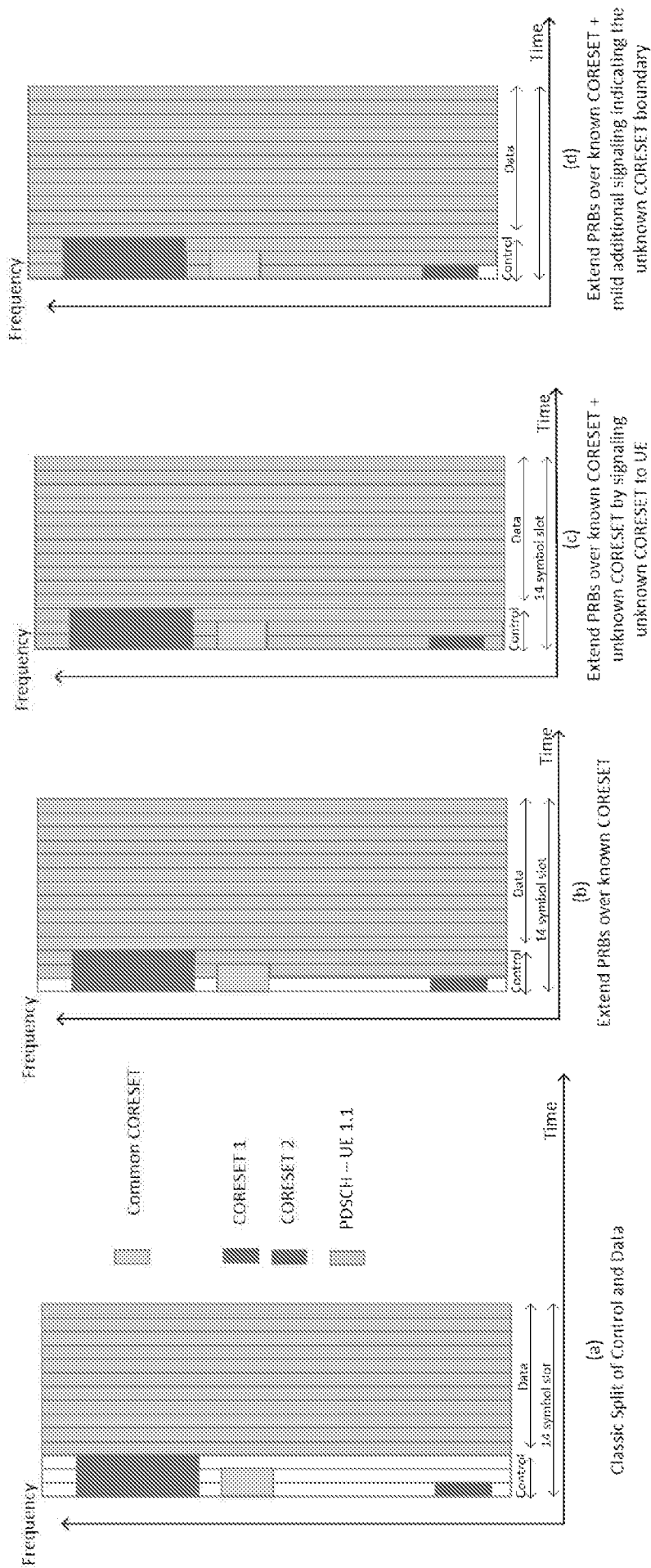


Figure 4: Enhancement of Control Resource usage with limited signalling

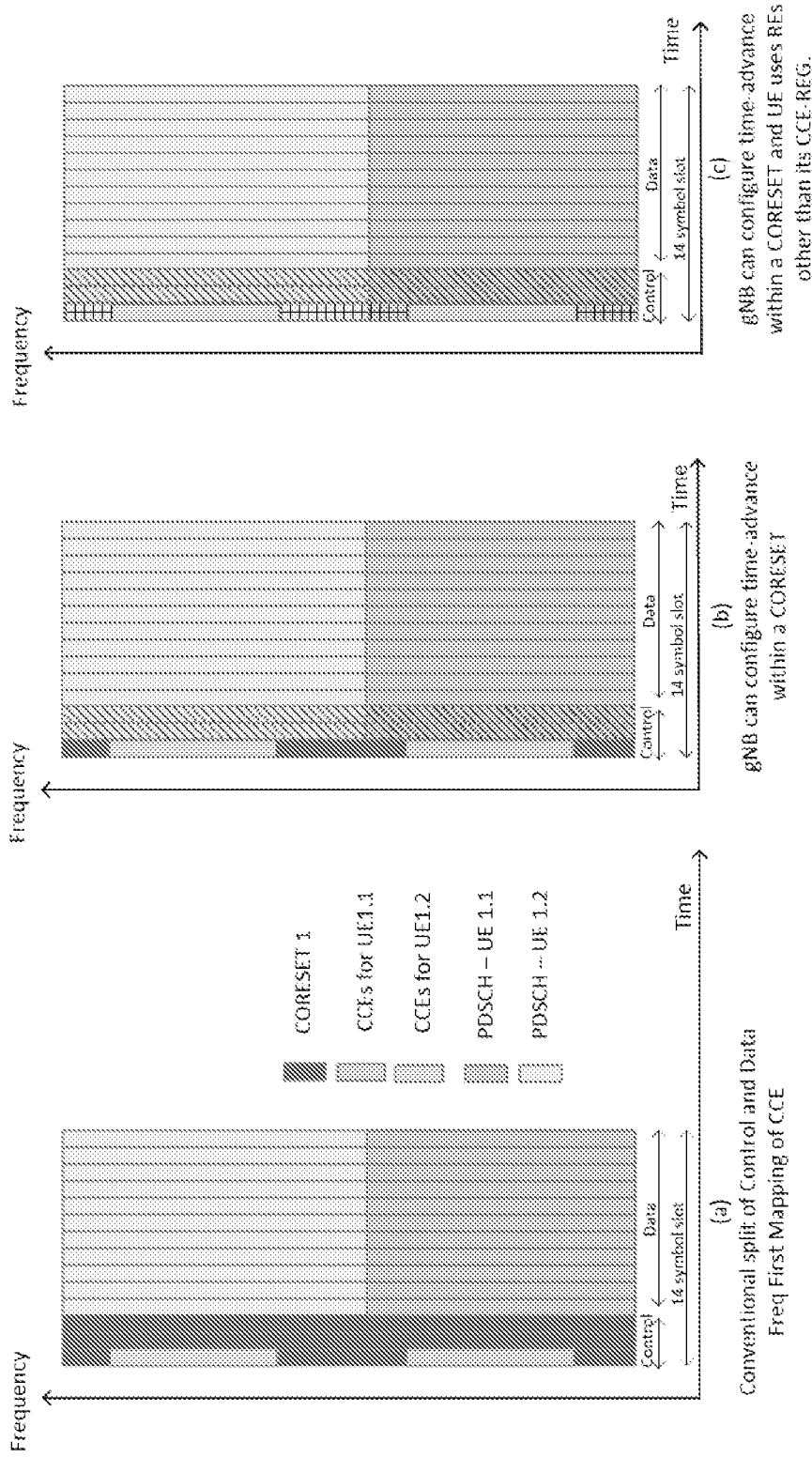


Figure 5: CCE Level Reuse of control resources for Data (PDSCH) – Freq first localized mapping of CCE

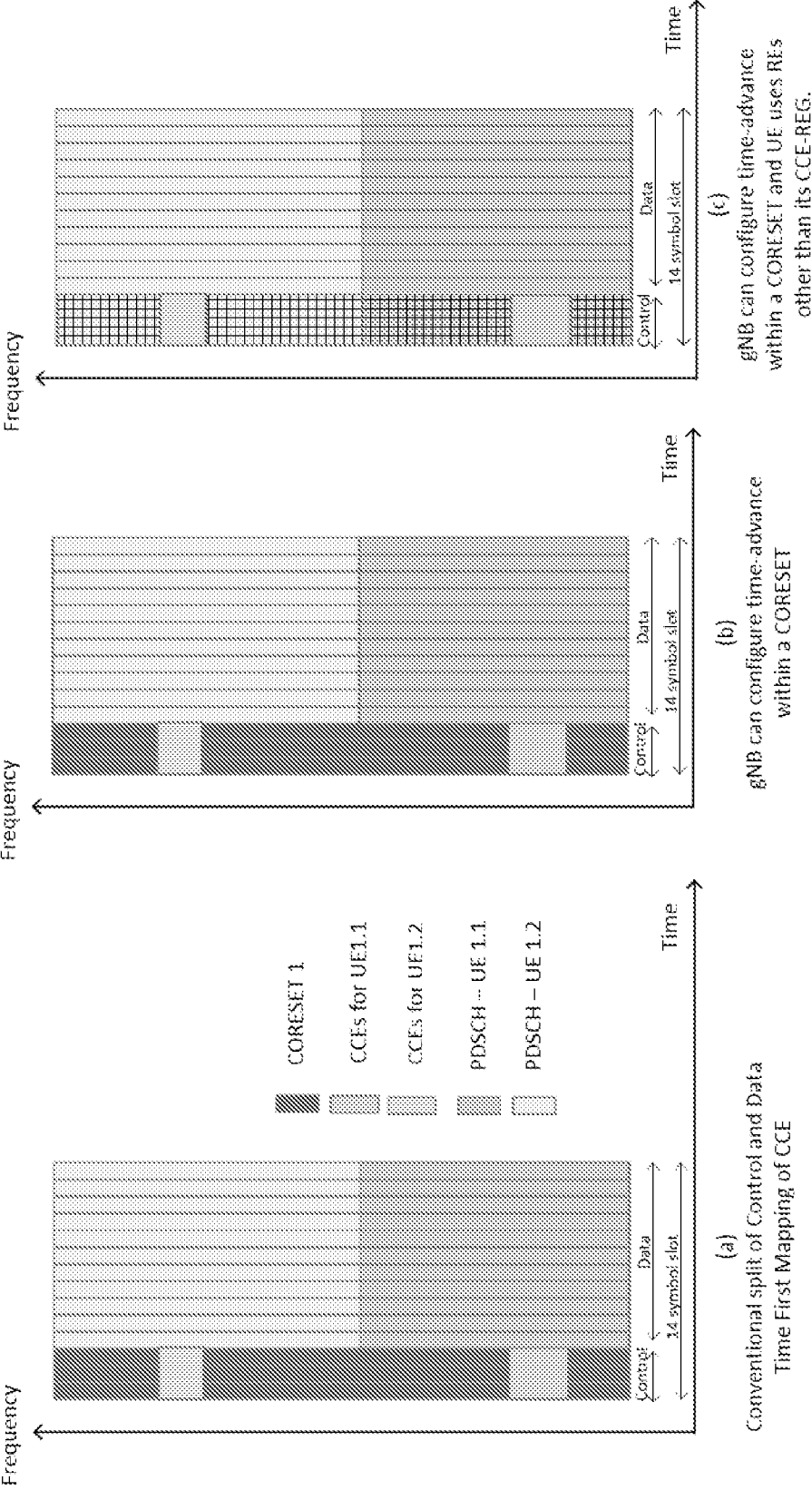


Figure 6: CCE Level Reuse of control resources for Data (PDSCH) – Time first localized mapping of CCE

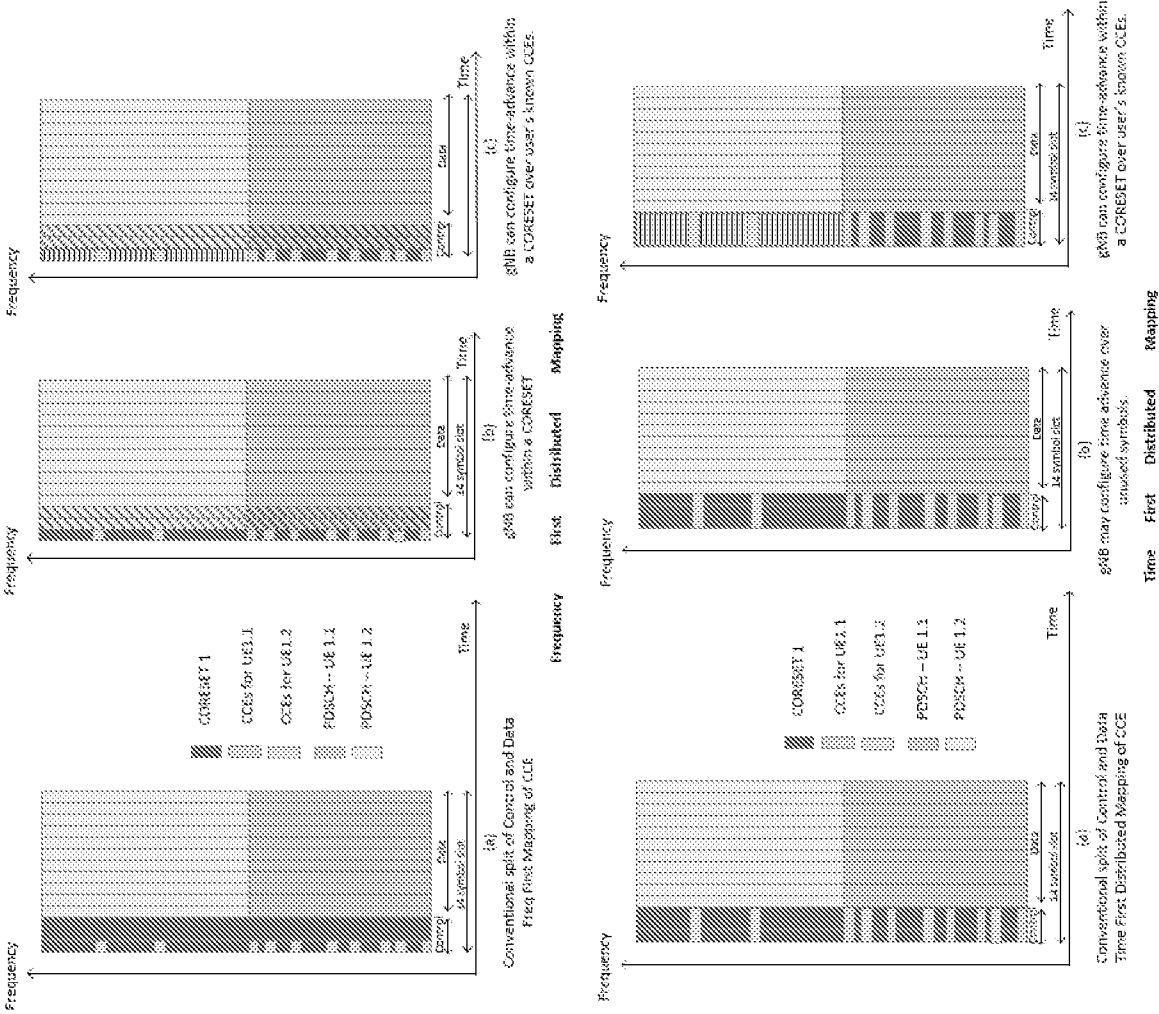


Figure 7: CCE Level Reuse of control resources for Data (PDSCH) –

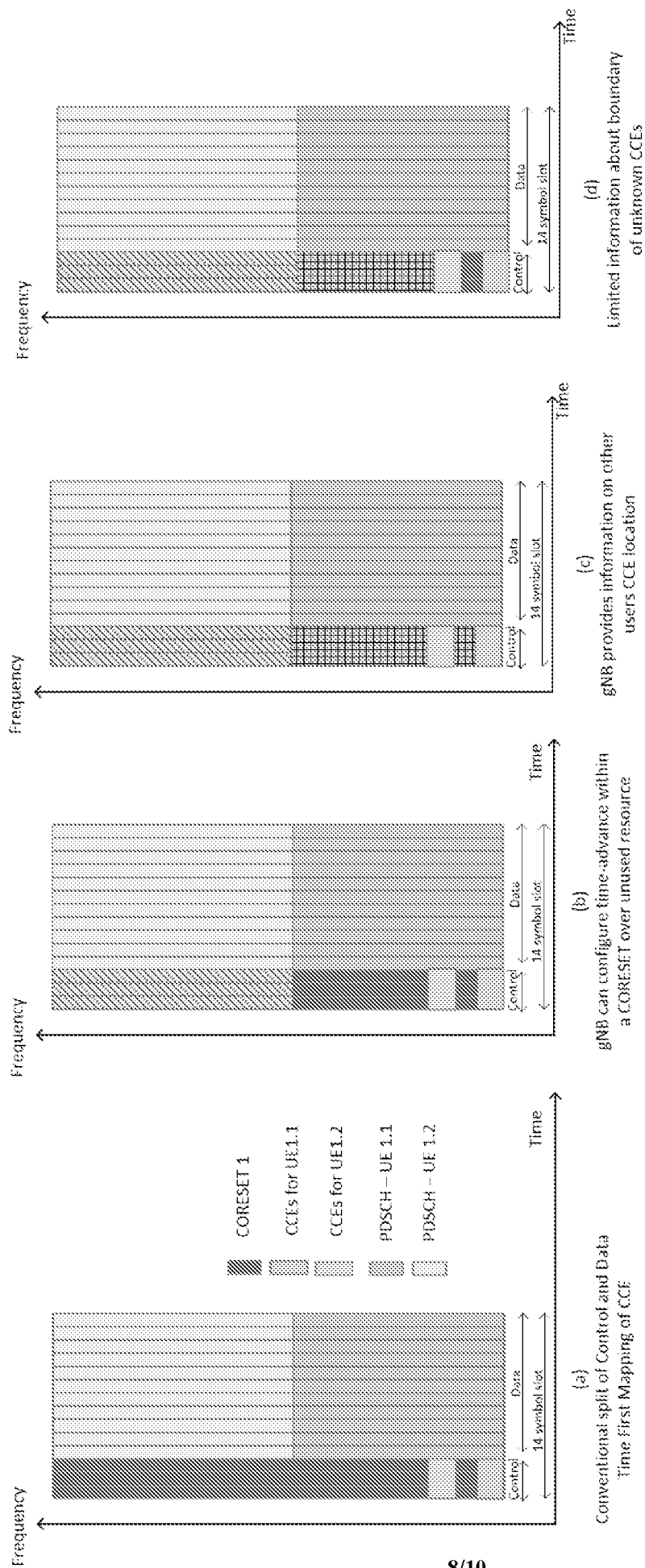


Figure 8 : Enhanced CCE Level Reuse of REs for Data Around Unknown CCEs

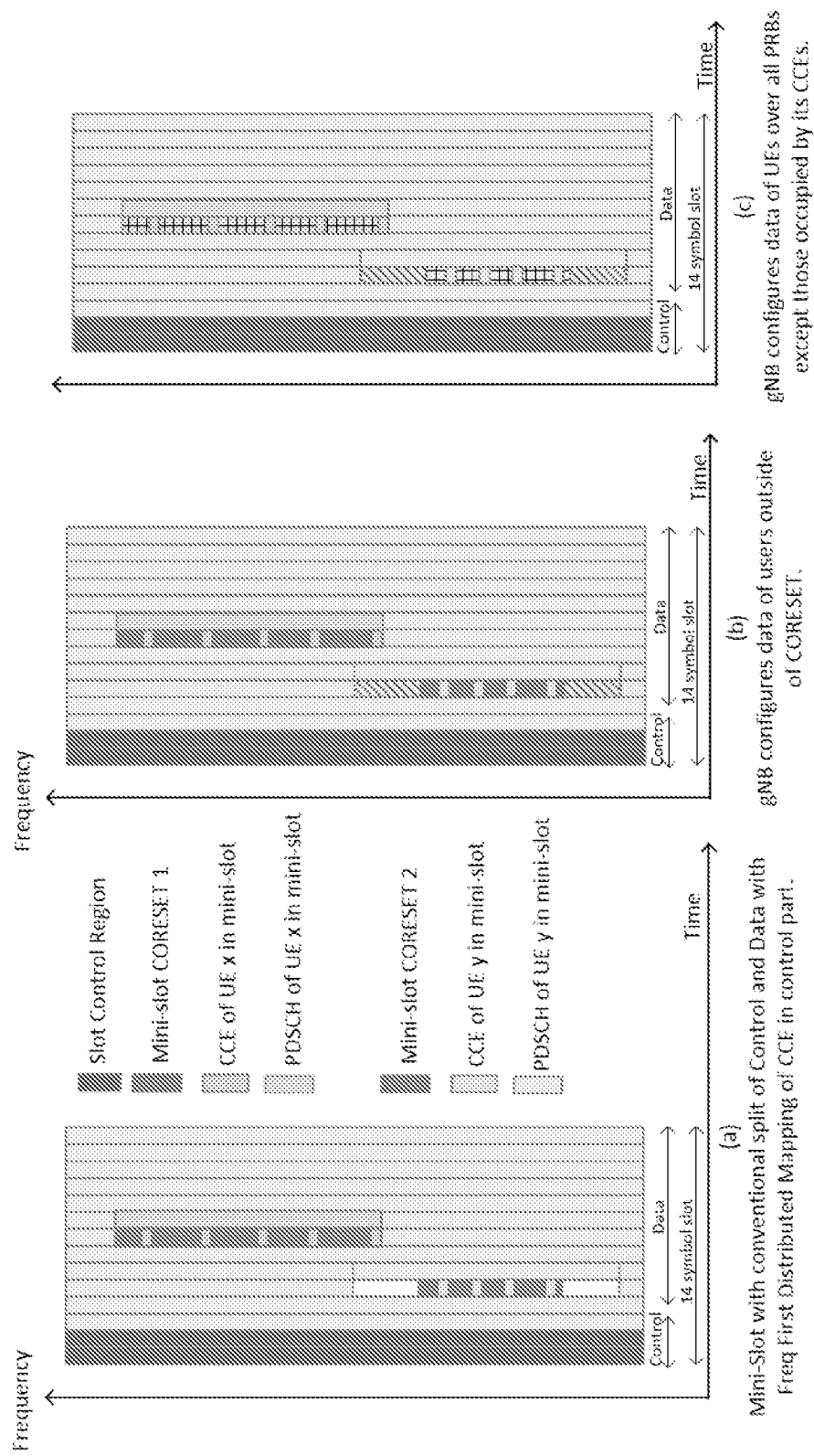


Figure 9: Data Multiplexing over control resources for Mini-Slots



Figure 10: Mini-Slot Data multiplexing inside CORESET around Unknown CCEs of other users

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2018/099868

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/04(2009.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W; H04Q; H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS, CNTXT, CNKI, VEN, USTXT, WOTXT, EPTXT, IEEE, 3GPP: control resource set, control signal, control region, multiplex, data, CORESET, carrier, frequency, overlap, allocation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017150486 A1 (QUALCOMM INC) 25 May 2017 (2017-05-25) description, paragraphs [0007], [0037]- [0041], [0049] - [0108]	1-27
A	US 2009069023 A1 (KOREA ELECTRONICS TELECOMM) 12 March 2009 (2009-03-12) the whole document	1-27
A	US 2013107861 A1 (FUTUREWEI TECHNOLOGIES INC.) 02 May 2013 (2013-05-02) the whole document	1-27
A	CN 103220102 A (HUAWEI TECHNOLOGIES CO LTD) 24 July 2013 (2013-07-24) the whole document	1-27

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

19 October 2018

Date of mailing of the international search report

26 October 2018

Name and mailing address of the ISA/CN

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