(54) **Title:** Efficient Scheduling in a Wireless Communications System

Figure 2

(57) **Abstract:** Methods for transmitting downlink control information in a cellular communications network utilising an OFDM transmission format in which a DCI message is transmitted from the base station, the DCI message containing at least one additional field that dynamically allocates a number n of repetitions to be applied to a transport block to be transmitted by a UE operating in the network. The additional field may be in the TDRA or a parameter of the DCI message.

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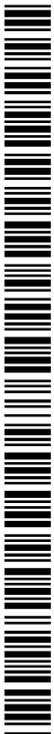
Efficient Scheduling in a Wireless Communications System

Technical Field

[1]   The following disclosure relates to scheduling communications in a wireless communications system and in particular to the efficient scheduling of multiple transport blocks with a single downlink control indicator.

Background

[2]   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) (RTM). 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.

[3]   In cellular wireless communication systems User Equipment (UE) is connected by a wireless link to a Radio Access Network (RAN). The RAN comprises a set of base stations which provide wireless links to the UEs located in cells covered by the base station, and an interface to a Core Network (CN) which provides overall network control. As will be appreciated the RAN and CN each conduct respective functions in relation to the overall network. For convenience the term cellular network will be used to refer to the combined RAN & CN, and it will be understood that the term is used to refer to the respective system for performing the disclosed function.

[4]   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. NR is proposed to utilise an Orthogonal Frequency Division Multiplexed (OFDM) physical transmission format.

[5]   The NR protocols are intended to offer options for operating in unlicensed radio bands, to be known as NR-U. When operating in an unlicensed radio band the gNB and UE must compete with other devices for physical medium/resource access. For example, Wi-Fi (RTM), NR-U, and LAA may utilise the same physical resources.

[6]   A trend in wireless communications is towards the provision of lower latency and higher reliability services. For example, NR is intended to support Ultra-reliable and low-latency communications (URLLC) and massive Machine-Type Communications (mMTC) are intended to provide low latency and high reliability for small packet sizes (typically 32 bytes). A user-plane latency of 1ms has been proposed with a reliability of 99.99999%, and at the physical layer a packet loss rate of 10^{-5} or 10^{-6} has been proposed.

[7]   mMTC services are intended to support a large number of devices over a long life-time with highly energy efficient communication channels, where transmission of data to and from each device occurs sporadically and infrequently. For example, a cell may be expected to support many thousands of devices.

[8]   The disclosure below relates to various improvements to cellular wireless communications systems.

Summary

[9]   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.

[10]   The invention is defined by the claims, in which there is provided a method of transmitting downlink control information in a cellular communications network utilising an OFDM transmission format, the method comprising: transmitting, from a base station to a UE operating in the network, a DCI message containing at least one additional field that dynamically allocates a number n of repetitions to be applied to a transport block to be transmitted by the UE.

[11]   A UE operating in the network may transmit in response to the DCI message n repetitions of the transport block.

[12]   A TDRA table contained within the DCI message may contain at least one additional field that allocates the number n of repetitions to be applied to a transport block.

[13]   The at least one additional field may include a repetitions indicator associated with at least one SLIV entry in the TDRA table.

[14]   The at least one additional field may further include a repetitions indicator associated with a plurality of SLIV entries in the TDRA table.

[15]   A plurality of SLIV entries may be allocated to a single repetition of a TB.

[16]   The at least one additional field may comprise a parameter in the DCI, which parameter indicates the number n of repetitions to be applied to a transport block.

[17]   The parameter may be an RRC parameter.

[18]   The parameter may be an existing RRC parameter extended to indicate the number n of repetitions.

[19]   Each repetition of the transport block may include a dynamically configured redundancy version transmitted by the UE to the base station.

[20]   The base station and/or the UE may be required to do a listen before transmit check.

[21]   The UE may pre-empt transmission in a slot allocated to a lower priority transmission block with additional repetitions of a higher priority transmission block.

[22]   The cellular communications network may operate in both licensed and unlicensed spectra.

[23]   The n repetitions may be scheduled as n repetitions of a transport block with n PUSCH repetitions.

[24]   The invention may further comprise a base station configured to operate according to the method described herein.

[25]   The invention may further comprise a UE configured to decode a DCI message transmitted in accordance the method described herein and transmit in response to the DCI message the n repetitions of the transport block.

[26]   The invention may further provided a method of transmitting downlink control information in a cellular communications network utilising an OFDM transmission format, the method comprising: transmitting, from the base station to a UE operating in the network, a TDRA table

contained within a DCI message containing at least one additional field that dynamically allocates a number n of repetitions to be applied to a transport block to be transmitted by the UE.

[27]   The invention may further provided a method of transmitting downlink control information in a cellular communications network utilising an OFDM transmission format, the method comprising: transmitting, from the base station to a UE operating in the network,, a parameter within a DCI message which parameter dynamically indicates a number n of repetitions to be applied to a transport block to be transmitted by the UE.

[28]   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

[29]   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.

[30]   Figure 1 shows selected elements of a cellular communications network.

[31]   Figures 2 to 7 shows scheduling of transport blocks in time slots.

Detailed description of the preferred embodiments

[32]   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 herein are applicable in a variety of alternative settings.

[33]   Figure 1 shows a schematic diagram of three base stations (for example, eNB or gNBs depending on the particular cellular standard and terminology) forming a cellular network. Typically, each of the base stations will be deployed by one cellular network operator to provide geographic coverage for UEs in the area. The base stations form a Radio Area Network (RAN). Each base station provides wireless coverage for UEs in its area or cell. The base stations are interconnected via the X2 interface and are connected to the core network via the S1 interface. As will be appreciated only basic details are shown for the purposes of exemplifying the key features of a cellular network. A PC5 interface is provided between UEs for SideLink (SL) communications. The interface and component names mentioned in relation to figure 1 are used for example only and different systems, operating to the same principles, may use different nomenclature.

[34]   The base stations each comprise hardware and software to implement the RAN's functionality, including communications with the core network and other base stations, carriage of control and data signals between the core network and UEs, and maintaining wireless communications with UEs associated with each base station. The core network comprises hardware and software to implement the network functionality, such as overall network management and control, and routing of calls and data.

[35]   In the unlicensed spectrum, a UE may have to transmit TBs with different priorities and requirements. To make the UL transmission of each TB achieve aspecified requirement, the gNB schedules each TB with a specific number of repetitions.

[36]   In uplink transmissions, one physical uplink shared channel (PUSCH) transmission instance is not allowed to cross the slot boundary for both dynamic grant (DG) and configured grant (CG) PUSCH. Therefore, to avoid transmitting a long PUSCH across slot boundary, the UE can transmit small PUSCHs in several repetitions scheduled by an UL grant or radio resource control (RRC) in the consecutive available transmission sub-slots/slots. The use of PUSCH repetitions for one transport block (TB) also reduces latency and increases reliability of PUSCH transmission where a UE can be configured to transmit a number of TB repetitions across consecutive transmission occasions without feedback. In PUSCH repetition Type A, each slot contains only one repetition and the time domain for the repetitions of a TB is the same in those slots. In PUSCH repetition Type B, the repetitions are carried out in the consecutive mini-slots so one slot might contain more than one repetition of a TB.

[37]   In the unlicensed spectrum, a transmitter is required to do listen-before-talk (LBT) to check the availability of a channel before transmission.In UL DG transmission, a UE can access channel according to Type 1 or Type 2 UL channel access procedureas indicated by UL grant DCI. When the UE has a TB to transmit, it sends Scheduling Request to the gNB. The gNB responds with DCI as an UL grant to schedule an UL transmission. This DCI provides information on the UL transmission such as time and frequency resources, number of repetitions, transmission power, modulation and coding scheme, type of channel access in unlicensed spectrum, etc. A TB is transmitted on the allocated PUSCHs and each repetition corresponds to a PUSCH. One DCI used as UL grant can schedule multiple TBs in multiple PUSCHs.

[38]   The standards (such as 3GPP Technical Standard 38.913)requires that an UL transmission of a TB is supported with multiple repetitions to achieve the strict URLLC requirements. A time domain resource assignment (TDRA) field in the DCI indicates the resource for the first "nominal'" repetition. The time domain resources for the remaining repetitions are derived from the information provided for the first repetition and UL/DL direction of symbols. The number of the repetitions represents the "nominal" number of repetitions. The dynamic indication of the number of repetitions for dynamic grant is jointly coded with start and length indicator value (SLIV),which indicates the start symbol and length of scheduled resource for PUSCH, in a TDRA table using DCI formats 0_1 and 0_2 by adding an additional column for the number of repetitions in the TDRA table. The maximum TDRA table size is 64 and for CG PUSCH transmission, if the number of repetitions is not included in the TDRA table, it is provided by RRC parameter repK.

[39]   Transmission of multiple PUSCHs of different TBs scheduled by a single DCI format 0_1 is supported in unlicensed spectrum. The same DCI format 0_1 can schedule a single PUSCH or multiple PUSCHs. The maximum number of PUSCHs scheduled by a DCI is 8. The TDRA table is extended so that each row indicates multiple PUSCHs. Each PUSCH has a separate SLIV. The number of scheduled PUSCHs is signalled by the number of indicated valid SLIVs in the row of the TDRA table.

[40]   However, the transmission of multiple PUSCHs scheduled by a single DCI in the unlicensed spectrum does not support the transmission of PUSCH with repetitions in the URLLC licensed spectrum. The incompatibility between two transmission schemes with two different TDRA table types causes issues in supporting URLLC operation in the unlicensed spectrum. A PUSCH transmission without repetitions for each PUSCH reduces reliability and increases latency of the transmission. A long PUSCH transmission cannot be transmitted across slot boundary or in resources fragmented by DL symbols in TDD configuration. In those cases, the short PUSCH repetitions are required to transmit a TB where the repetitions can be fragmented by slot boundary or DL symbols. On the other hand, using a DCI to schedule each PUSCH increases DCI overhead and LBT latency.

[41]   Figure 2, scenario 1 shows a gNB issuing a DCI to schedule 8 PUSCHs of 8 TBs in succession. Figure 2, scenario 2shows a gNB issuing PUSCHs for a TB with 4 repetitions, followed by 3 more PUSCHsfor 3 more TBs. The repetitions of TB1 are considered as PUSCHs of different TBs and are therefore indicated by different SLIVs in the TDRA table, leading to an increase of DCI overhead and latency due to LBT at the gNB. The current TDRA table for multiple TB scheduling is shown below:

TDRA Index	SLIV	Mapping Type
1	SLIV1 SLIV2	{MT1, MT2}
2	SLIV1 SLIV2 SLIV3 SLIV4	{MT1, MT2, MT3, MT4}
3	SLIV1 SLIV2 SLIV3 SLIV4 SLIV5 SLIV6 SLIV7 SLIV8	{MT1, MT2, MT3, MT4, MT5, MT6, MT7, MT8}
:	:	:

TABLE 1

[42]   Multiple TBs with repetitions for each TB are scheduled by a single DCI to reduce control overhead and LBT latency. The number of repetitions for each TB in the group of the scheduled TBs might be different based on the priority, reliability and latency requirements of each TB.The 4 repetitions of TB 1 in figure 2, scenario 2 correspond to SLIV1, SLIV2, SLIV3 and SLIV 4 in the TDRA Index 3 of Table 1. TB1 alone uses 4 out of 8 SLIVs so there are only 4 SLIVs left for other TBs. TB2-5 uses SLIV5-8, respectively. Therefore, only 5 TBs instead of 8 TBs are scheduled by a single DCI.

[43]   The number of repetitions is indicated dynamically to the UE, by extending the standard TDRA table with a column to indicate the number of repetitions for each entry of SLIV of a TB, as shown in Table 2 below. TDRA field in the UL grant DCI indicates the value of TDRA index so the UE knows the entry that is used in the table. For example, if UL grant indicates TDRA index 1, there are 2 TBs scheduled. The first TB corresponds to SLIV1 and Rep1. The second TB corresponds to SLIV2 and Rep2.

TDRA Index	SLIV + Number of Repetitions	Mapping Type
1	SLIV1 Rep 1 SLIV2 Rep2	{MT1, MT2}
2	SLIV1 Rep1 SLIV2 Rep2 SLIV3 Rep3 SLIV4 Rep4	{MT1, MT2, MT3, MT4}
:	:	:

TABLE 2

[44]   The number of entries in the new TDRA table is increased to indicate both SLIV and the number of repetitions. If the number of entries in the current TDRA table is 2^a where a is the number of bits in TDRA field of DCI, the number of entries in the new TDRA table is 2^{a+N*b} where N is the number of the scheduled TBs, b is the number of bits to indicate the number of repetitions for each TB. Based on the maximum allowed number of repetitions, b might be 2 or 3 bits.

[45]   The table does not need to carry all possibilities for number of TBs and number of repetitions. One approach can be that overall a given number of bits are used for TDRA table, say n, then TDRA table can have 2^n entries. The base station can configure the TDRA table with the suitable entries that it intends to use. This can be used to have the design of TDRA table for a desired number of bits, and then only the entries which are possible with this number of bits are configured by the base station.

[46]   A TB is indicated by one SLIV and the number of repetitions. In other words, a SLIV only corresponds to a TB instead of a PUSCH repetition of a TB. For example, in Table 2, TB1 is indicated by SLIV1 and Rep1. SLIV1 indicates the start symbol and length of the first repetition of TB1. The resource for the repetitions after the first repetition is derived based on the number of repetitions Rep1, length of one repetition, slot boundary and UL/DL symbol configuration.

[47]   Alternatively, the a slightly modified version of the TDRA table of Table 2 may be usedwith the number of repetitions for each SLIV indicated by a new field, as shown in Table 3 below.

TDRA Index	SLIV	Number of Repetitions	Mapping Type
1	SLIV1 SLIV2	Rep1 Rep2	{MT1, MT2}
2	SLIV1 SLIV2 SLIV3 SLIV4	Rep1 Rep2 Rep3 Rep4	{MT1, MT2, MT3, MT4}
:	:		:

TABLE 3

[48]   The number of repetitions indicated is the nominal number of repetitions for each TB. The actual number of repetitions for each TB can be bigger if a nominal repetition encounters slot boundary or DL symbols in TDD configuration and this repetition is fragmented into multiple repetitions.With these extended TDRA tables, even if each TB has several repetitions, there are still maximum 8 TBs corresponding to 8 SLIVs in a row of the TDRA table that can be scheduled by a single DCI.

[49]   These extended tables can be also used to schedule TBs with repetitions in URLLC licensed spectrum. This avoids using two different TDRA table for different cases: one table for multiple TBs in unlicensed spectrum and one table for multiple repetitions of a TB in URLLC licensed spectrum.

[50]   Alternatively, the TDRA table illustrated in Table 1 is used to schedule multiple TBs in unlicensed spectrum and the number of repetitions is indicated by a separate field in DCIas shown in figure 3.

[51]   A SLIV in the TDRA table corresponds to a TB and indicates the first repetition of the TB. Resources for the following repetitions are derived from the number of repetitions indicated in the new field added to the UL grant DCI, along with information on the length of one repetition, slot boundary and UL/DL symbol configuration. The length of repetition indication field depends on the number of the scheduled TBs and the number of repetitions of each TB. This brings flexibility in the length of DCI when the repetition indication field can be removed if there is no repetition for the scheduled TBs (each TB is only transmitted one time on one PUSCH), which helps to reduce the number of DCI bits and increase DCI reliability.

[52]   Alternatively, the number of repetitions of each TB in multiple TB transmission by a can be indicated by anRRC parameter. RRC parameter *pusch-AggregationFactor*may be extended to indicate the number of repetitions of multiple scheduled TBs. TDRA table for multiple PUSCH

transmission in the unlicensed spectrum is the same as that illustrated in Table 1. When *pusch-AggregationFactor* is configured and the UE obtains the number of repetitions of the TBs from *pusch-AggregationFactor*, the UE uses the SLIV as the indication of the first repetition of a TB and derives the resources for the rest of repetitions.

[53]   When a TB is transmitted with several repetitions, the redundancy version (RV) sequence must be indicated so that the RV of each repetition is determined. However, in the current standard, if a single DCI schedules multi-PUSCH where each PUSCH corresponds to a SLIV, there is only 1 RV bit per PUSCH. Therefore, in multiple TBs transmission with repetitions, there is only 1 RV bit per TB because a TB corresponds to a SLIV. 1 RV bit is not enough to indicate RV sequence of several repetitions of a TB. For example, a TB with 4 repetitions needs 2 bits to indicate RV sequence: {0, 0, 0, 0}, {0, 3, 0, 3) or {0, 2, 3, 1}.

[54]   To deal with this, the number of RV bits per TB can be configured flexibly. The number of RV bits of a TB corresponds to the number of repetitions of a TB as shown in Table 4. If the number of repetitions of a TB is 1 or 2, the number of RV bits for that TB is 1. If the number of repetitions is 1, RV field indicates {0, 2}. If the number of repetitions is 2, RV field indicates {(0, 2), (0, 3)}. This means that 2 PUSCH repetitions of a TB might have RVs of 0 and 2 or 0 and 3. On the other hand, if the number of repetitions of a TB is bigger than 2, the number of RV bits for that TB is 2.For example, with 4 repetitions, 2 bits are needed to indicate RV sequence. The UE decodes the number of repetitions of TBs in the TDRA table or the repetition indication field or RRC parameter to determine the number of RV bits in the RV field for the corresponding TBs.

NoRep1 : 1 Repetition	NoRep2 : 2 Repetitions	NoRep3 : 4 Repetitions	NoRep4 : 8 Repetitions
RV1 : 1 bit	RV2 : 1 bit	RV3 : 2 bits	RV4 : 2 bits

TABLE 4

[55]   When a gNB schedules multiple TBs with repetitions in the unlicensed spectrum by a single DCI, if there are URLLC TBs in the group, a latency budget of 1 ms for URLLC TBs must be guaranteed. However, different channel access priority classes give different channel access latencies. This can make URLLC transmissions unable to achieve a specified latency requirement. Therefore, in the scheduling DCI, a field with two bits is added to indicate channel access priority class of the multiple-TB transmission (2 bits correspond to 4 channel access priority classes). A channel access priority class is chosen and indicated to the UE to ensure that URLLC TBs with their repetitions are transmitted in the latency budget. The chosen channel access priority class depends on channel condition, location of URLLC resources, number of repetitions of each URLLC TB.

[56]   Alternatively, TBs with the same quality of service (QoS) are typically scheduled together by a single DCI and the number of repetitions is kept the same for all TBs. In other words, a single DCI schedules multiple TBs with the same number of repetitions.

[57]   In UL scheduling, when a single DCI schedules multiple TBs, the reliability of multiple-TB transmission is also related to the scheduling DCI. When the gNB allocates resources to multiple TBs, the exact order of the TBs because the TB order at the UE depends upon the packet arrival and the MAC layer procedures/implementation. If PUSCH repetitions are used for the all the TBs in the group, the gNB can schedule the same number of repetitions for all TBs in that group, thereby reducing the overhead of DCI and increasing DCI reliability sincefewer bits are needed to indicate the number of repetitions.

[58]   To make a single DCI schedule multiple TBs with the same number of repetitions for each TB, the TDRA table of Table 5 may be used.

TDRA Index	SLIV	Mapping Type	Number of Repetitions
1	SLIV1 SLIV2	{MT1, MT2}	Rep1
2	SLIV1 SLIV2 SLIV3 SLIV4	{MT1, MT2, MT3, MT4}	Rep2
:	:	:	

TABLE 5

[59]   This can be used for both multiple-TB scheduling in unlicensed spectrum and TB with repetitions in URLLC licensed spectrum.

[60]   Each TB corresponds to one SLIV that indicates resource of the first repetition and then further resource for the following repetitions, if any, is derived by the UE based on the nominal number of repetitions indicated in the Number of Repetitionscolumn of the TDRA Table5, which is applied to all TBs scheduled by a single DCI. The actual number of repetitions can be bigger if a nominal repetition encounters slot boundary or DL symbols in TDD configuration and this repetition is fragmented into multiple repetitions.

[61]   As an alternative, the number of repetitions for the TBs in a group is defined by using a new field in DCI while the TDRA of Table 1as described above is used. This field contain 2 or 3 bits depending on the set of the allowed number of repetitions for the TBs. The number of repetitions indicated in this new field of the scheduled DCI is applied to all TBs in the group.

[62]   Also as described above, the repetitions of multiple TBs scheduled by a single DCI may be indicated by an RRC parameter. The RRC parameter *pusch-AggregationFactor* indicates the number of repetitions of a TB and the value in *pusch-AggregationFactor* is applied to all TBs in a group scheduled by a single DCI. The TDRA of Table 1may be used for multiple PUSCH transmission in the unlicensed spectrum. When *pusch-AggregationFactor* is configured and the UE obtains the number of repetitions of the TBs from *pusch-AggregationFactor*, the UE uses SLIV as the indication of the first repetition and derives the resources for the rest of repetitions.

[63]   Also as described above, 2 RV bits may be used to indicate the RV sequence of the repetitions of each TB if the number of repetitions is bigger than 2. Otherwise, 1 RV bit is used. The UE finds the number of repetitions by decoding DCI or RRC and can then determine the corresponding number of RV bits from which to extract RV information.

[64]   In the unlicensed spectrum, the UE must do LBT before transmitting data on the UL, and as a consequence the LBT result is uncertain. If LBT succeeds before the starting symbol of the scheduled resources, the UE can transmit TB on the UL resources. In contrast, if LBT initially fails and then only succeeds after the starting symbol of the scheduled resources, the scheduled transmission is not started and PUSCH is dropped. The gNB will have to reschedule the resources of this PUSCH, which in turn adds latency and is harmful to the QoS of the URLLC.

[65]   When a transmission is not able to start at the scheduled location because of channel access uncertainty, the UE should transmit on the scheduled resources after getting the channel access. This may lead to insufficient number of resulting repetitions for an initial TBwhen the UE gets later access to the channel, as it leaves a smaller number of repetitions than scheduled for a given TB. This may be harmful to the performance of URLLC with high reliability requirement.

[66]   As shown in scenario 1 of figure4, a single DCI schedules 2 TBs with 4 repetitions for each TB. LBT succeeds before S1 so the UE can transmit TB1 with 4 repetitions from S1 to S4 and TB2 with 4 repetitions from S5 to S8 (S1, ..., S8 are sub-slots or slots depending on mapping and repetition types). However, in scenario 2 of figure4, LBT fails before S1 and only succeeds before S2 so the UE only can transmit 3 repetitions of TB 1 from S2 to S4 instead of 4 repetitions as scheduled. It might be harmful if TB1 has high reliability requirement.

[67]   To address this issue, a UE may override the base station (gNB)scheduling to use additional resources for the repetitions of a transport block, when some of its repetition resources have been lost due to a delay in acquisition and when a channel is acquired after the nominal start instant.

[68]   The high priority TB may use the resources of low priority TB so that the reliability of high priority TB is guaranteed in case of LBT failure. A PUSCH transmission can be scheduled with multiple starting points by using multiple SLIVs in the proposed TDRA table. Multiple SLIVs are associated with a PUSCH and each SLIV indicates a potential starting point.

[69]   As shown in figure5, 4 repetitions of TB1 are scheduled from S1 to S4 and 4 repetitions of TB2 are scheduled from S5 to S8. However, in scenario 2, LBT fails before S1 and the UE cannot start the transmission. The UE only can start the transmission at S2 after the transmission. TB1 has higher priority than TB2 so the UE pre-emptsS5 from TB2 and allocates it to TB1 to transmit the fourth repetition so that all 4 configured repetitions are transmitted to achieve reliability of a high priority transmission. While TB2 has lower priority, the transmission of TB2 is offset from S5 to S6. Only 3 repetitions of TB2 are transmitted from S6 to S8. On the other hand, in scenario 3, TB2 has higher priority than TB1 so the transmission of TB 2 still starts at S5 as scheduled in SLIV so that 4 repetitions of TB2 are ensured and only 3 repetitions of TB1 are transmitted.

[70]   If LBT only succeeds at the beginning of the second scheduled TB and the priority of the first scheduled TB is higher than the second TB, the UE may transmit the first TB and drop the second TB. For example, in scenario 4 of figure5, if LBT succeeds at S5 and TB1's priority is higher than TB2's priority, the UE transmits TB1 instead of TB2 from S5 to S8.

[71]   The gNB can determine the result of LBT and the decision of the UE to offset the start symbol of low priority TB by decoding UCI multiplexed with PUSCH repetitions. UCI contains a bit to indicate the offset at the intended sub-slot/slot. As an alternative, the UCI may contain a HARQ ID corresponding to a TB being transmitted so the gNB can determine the offset.For example, in scenario 2 of figure 5, 4 repetitions of TB1 have HARQ ID 1, 4 repetitions of TB2 have HARQ ID 2. In case of overriding as scenario 2, S5 contains a repetition of TB1 instead of TB2 as configured at the beginning. Therefore, the UCI at S5 contains HARQ ID of TB 1 instead of HARQ ID of TB2 as expected from the scheduling. The gNB recognises this HARQ ID and can determine that S5 contains a repetition of TB1 instead of a repetition of TB2. Therefore, the gNB can do soft-combining among the repetitions of TB1. The gNB can also determine that the UE has offset the transmission of TB2 to the next transmission occasion S6 so it will start to decode the first repetition of TB2 from S6.

[72]   If a scheduled PUSCH cannot be transmitted at the first scheduled symbol due to LBT Failure, the UE may transmit that PUSCH at any subsequent symbols in the scheduled resources after a LBT success instead of dropping the whole PUSCH. The gNB detects the start of the transmission by blindly decoding DMRS at every symbol in the scheduled resources. This scheme guarantees the PUSCH transmission as long as LBT succeeds before the last symbol of the scheduled resource. However, this has two drawbacks. Firstly, the gNB must detect blindly DMRS in every scheduled symbol to find the start of the transmission. Second, the length of PUSCH resource indicated by SLIV is fixed whether or not the LBT succeeds at the first symbol

of the resource. If the UE transmits PUSCH after the first symbol of the scheduled resource, it has to transmit a shorter PUSCH than configured whichreduces the reliability of the PUSCH transmission.

[73]   To deal with the uncertainty of LBT result, a DCI uses the TDRA table with multiple SLIVs to schedule only one PUSCH instead of multiple PUSCHs. When the gNB schedules a high priority UL TB (URLLC TB, for example), it uses a row in the TDRA table with multiple SLIVs to schedule this TB. Each SLIV corresponds to a potential starting point and length of the transmission. The UE selects to follow one SLIV based on the LBT result. To satisfy URLLC latency requirement, the UE selects the closest starting point after LBT success. The length of the transmission indicated in each SLIV also guarantees the required reliability of the transmission.

[74]   The number of symbols that the gNB must look for DMRS to determine the beginning of a transmission is thereby reduced. This number is equal to the number of SLIVs used by the gNB. Moreover, the TDRA of Table1, Table 2, Table 3 or Table 5 in unlicensed spectrum may beused to schedule a transmission with multiple starting points instead of using new field in DCI or new RRC to indicate the flexible starting points. SLIVs in the TDRA table are exploited to indicate multiple starting points for a single TB.

[75]   As illustrated in figure6, the gNB schedules a PUSCH transmission with 3 SLIVs: SLIV1 with the starting symbol S1 and length L, SLIV2 with the starting symbol S3 and length L, SLIV3 with the starting symbol S5 and length L. If LBT succeeds before S1, the UE uses SLIV1 to transmit PUSCH. If LBT succeeds between S1 and S3, the UE uses SLIV2 to transmit PUSCH. If LBT succeeds between S3 and S5, the UE uses SLIV3 to transmit PUSCH. The length indicated in all 3 SLIVs is L so reliability of PUSCH transmission is ensured, although more resources need to be allocated to this transmission type.

[76]   The UE sends scheduling request (SR) to the gNB to demand resource for one PUSCH TB transmission. If the UE receives a DCI UL grant indicating multiple SLIVs, it can determine that these SLIVs are for one PUSCH TB with multiple starting points instead of multiple PUSCH TB transmission. The UE will only use one of these SLIVs to transmit the PUSCH TB based on LBT result.

[77]   Thus resources may be sacrificed for latency and reliability fora high priority transmission in URLLC.

[78]   When the UE has multiple TBs to transmit, the gNB can schedule multiple TB transmission with repetitions for each TB by a single DCI. The gNB indicates multiple SLIVs and the number of repetitions for multiple TBs based on their requirements. In addition, the gNB might need to take into account LBT uncertainty in any scheduling scheme of the TBs that are time sensitive. This leads to an increase of DCI payload to schedule multiple TBs with repetitions because the TDRA table has more entries and more RV bits are required. This affects the performance of DCI transmission and the channel uncertainty may still limit the performance of such multi-TB repetition schemes.

[79]   A generalized resource allocation scheme for multiple uplink transmissions allows the gNB to schedule multiple resources to a UE through an optimized single UL grant DCI. These resources can then be used by a UE to transmit multiple repetitions for multiple transport blocks. This scheme thus simplifies significantly the signalling overhead and combats channel uncertainty issues resulting in delayed start of batched uplink transmissions. Each resource where UE transmits, it includes the necessary information such as hybrid automatic repeat request (HARQ) identity (ID), redundancy version (RV) and new data indicator (NDI), etc to allow correct decoding and buffer management for soft combining at the gNB.

[80]   To reduce the burden of scheduling at the gNB and DCI payload in multiple TB transmission with repetitions, and to combat the channel uncertainty in a more flexible manner, a generalized resource allocation scheme for uplink transmissions may be utilised. Having received the scheduling request and/or buffer status report from a UE, the gNB can determine the traffic requirements for this UE and, based upon the available resource and traffic situations from other devices, the scheduler at gNB can accommodate a given number of a TBs with a given number of repetitions for each. The gNB indicates the resources to the UE without specifying explicitly the number of TBs, and the number of repetitions per TB. Thus, the UL grant DCI will indicate the generic resources to the UE. Having received such an allocation of resources for uplink transmission, a UE will start transmitting its TBs with suitable number of repetitions in those resources to satisfy the TBs' requirements. The UE has multiple TBs with different requirements in the buffer so it sends SR to the gNB to ask for the resources to transmit these TBs. To reduce DCI and LBT latency, the gNB uses a single DCI to schedule multiple TBs.

[81]   A number of different signaling options may be used by the gNB to indicate multiple resources allocated to the UE. If the gNB has the same time frequency resource available in multiple slots and it allocates this resource to a single UE, the gNB uses a TDRA table with only one SLIV in a row to schedule single TB. The SLIV indicates the starting symbol and length of UL resources in a slot that the UE can use to transmit the TBs. A new RRC parameter *PUSCH-resourceRepetition* may be configured to indicate the number of the slots allocated.

[82]   As Illustrated in figure7, the gNB indicates UL resource in Slot1 by a SLIV with S=1 and L=6. It configures *PUSCH-resourceRepetition* to be 2 so the resource in Slot1 is repeated in Slot2 at the same time domain.

[83]   The UE may use the resources indicated by the SLIV and *PUSCH-resourceRepetition* to transmit the TBs in the buffer. The UE determines the transmission order of the TBs and the number of repetitions of each TB by itself to satisfy the TBs' requirements. The UE also selects the RV sequence for the repetitions of a TB.

[84]   The UCI may be multiplexed in PUSCH containing a HARQ ID and an RV. By decoding the UCI, the gNB has the information of the corresponding PUSCH and can determine the first repetition of a TB when it receives new HARQ ID and RVs of the repetitions so that the gNB can do soft-combining.

[85]   To further reduce latency if there is an error in decoding at the gNB and the gNB must schedule a retransmission, the UCI carries an indication to tell the UE whether a repetition is a last one of a TB or not. If the gNB uses HARQ ID to determine a new transmission and there is a gap between two resources as in figure7, the gNB must wait from the middle of Slot 1 to the beginning of Slot 2 to know whether it has receive the last repetition of a TB in Slot 1 before rescheduling TB if necessary. If the last repetition of a TB is in Slot 1, the gNBcan quickly reschedule the TB in the case of decoding error.

[86]   In an alternative signaling scheme for allocating multiple resources, when the gNB does not have the same time frequency resource in multiple slots, it can indicate different resources in different slots to the UE. The indication of such multiple resources to the UE can be obtained by TDRA table with multiple SLIV values with potentially a single repetition value per TB or a table with multiple SLIV values with one repetition value per SLIV. The UE will select the number of TBs, and the number of repetitions per TB. HARQ ID, RV, last repetition's indication and new data indicator (NDI) are transmitted as part of UCI multiplexed with PUSCH over each single resource that UE transmits. This ensures that there is no confusion at the gNB as to what was transmitted by UE.

[87]   When the gNB schedules the UL transmission of a single TB, it can use a SLIV to indicate the starting symbol and length of resource for that TB. When the UE sends SR to the gNB to ask the resource for one TB, the gNB sends UL grant DCI to allocate resource to the UE for the transmission of that TB. The DCI does not specify the number of repetitions for that TB but the UE will determine it based on the length of TB, resources and QoS. The SLIV used in DCI indicates the starting symbol and length of resource for that TB. RV for each repetition is also determined by the UE and is communicated to the gNB by a UCI multiplexed with PUSCH. The gNB also can use new RRC parameter *PUSCH-resourceRepetition* to indicate the repetitions of resource in the consecutive slots.

[88]   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.

[89]   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 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.

[90]   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 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.

[91]   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) (RTM) read or write drive (R or 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.

[92]   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.

[93]   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.

[94]   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 45 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.

[95]   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.

[96]   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.

[97]   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.

[98]   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.

[99]   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 recognise 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.

[100]   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.

[101]   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 a plurality.

[102]   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 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 of transmitting downlink control information in a cellular communications network utilising an OFDM transmission format, the method comprising:
        transmitting, from abase station to a UE operating in the network, a DCI message containing at least one additional field that dynamically allocates a number n of repetitions to be applied to a transport block to be transmitted by the UE.

2.   A method according to claim 1 wherein the UE operating in the network transmitsin response to the DCI message n repetitions of the transport block.

3.   A method according to claim 1 wherein a TDRA table contained within theDCI message contains at least one additional field that allocates the number n of repetitions to be applied to a transport block.

4.   A method according to claim 3 wherein the at least one additional field includes a repetitions indicator associated with at least one SLIV entry in the TDRA table.

5.   A method according to claim 3 wherein the at least one additional field includes a repetitions indicator associated with a plurality of SLIV entries in the TDRA table.

6.   A method according to claim 4 or 5 wherein a plurality of SLIV entries are allocated to a single repetition of a TB.

7.   A method according to claim 1 wherein the at least one additional fieldcomprises a parameter in the DCI message, which parameter indicates the number n of repetitions to be applied to a transport block.

8.   A method according to claim 7, wherein the parameter is an RRC parameter.

9.   A method according to claim 8 wherein the parameter is an existing RRC parameter extended to indicate the number n of repetitions.

10.   A method according to claim 2wherein each repetition of the transport block includes a dynamically configured redundancy version transmitted by the UE to the base station.

11.   A method according to claim 2 wherein the base station and/or the UE is required to do a listen before transmit check.

12.   A method according to claim 11 wherein the UE can pre-empt transmission in a slot allocated to a lower priority transmission block with additional repetitions of a higher priority transmission block.

13.   The method of any preceding claim wherein the cellular communications network is operating in both licensed and unlicensed spectra.

14.   The method of any preceding claim wherein the n repetitions are scheduled as n repetitions of a transport block with n PUSCH repetitions.

15.   A base station configured to perform the method of any of claims 1 to 14.

16.   A UE configured to decode a DCI message transmitted in accordance the method of any of claims 1 to 14, wherein the UE transmits in response to the DCI message the n repetitions of the transport block.
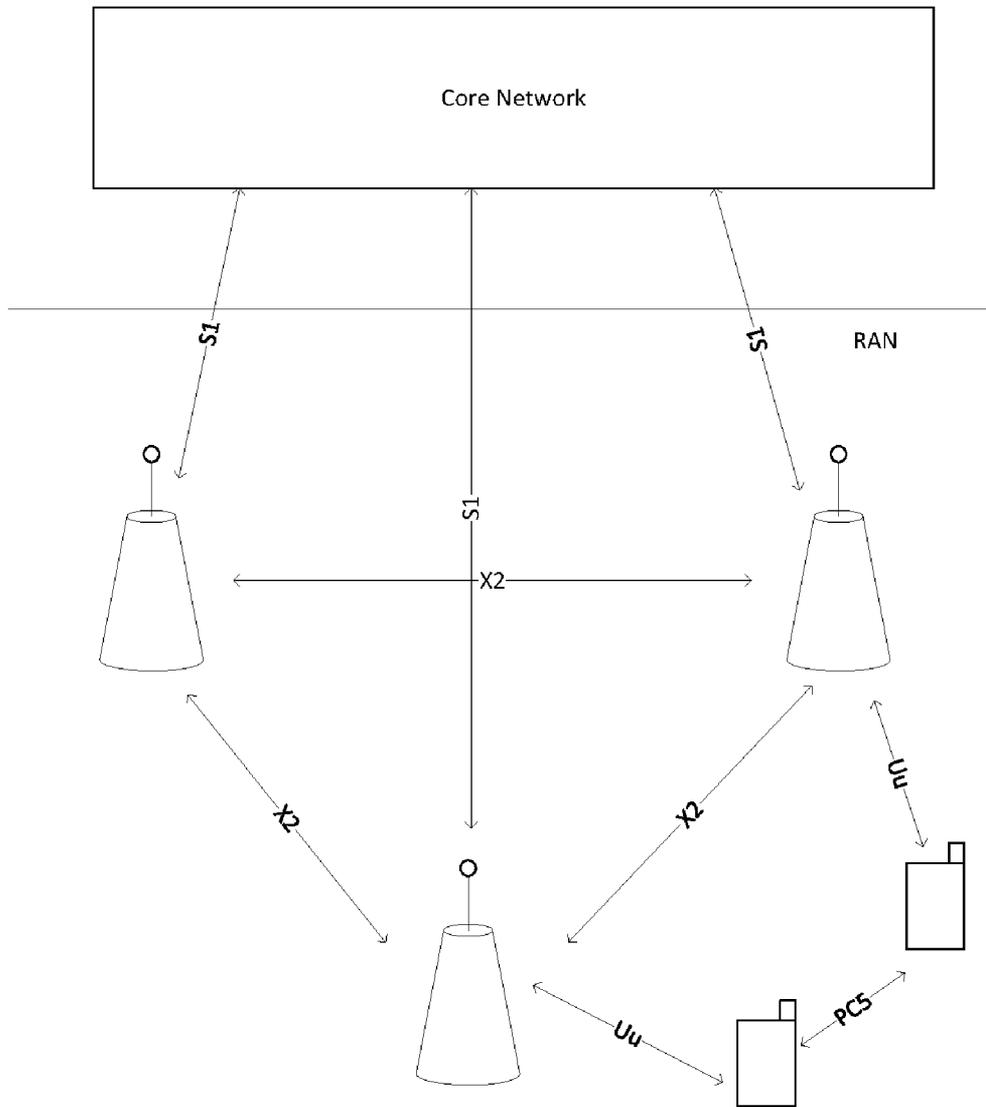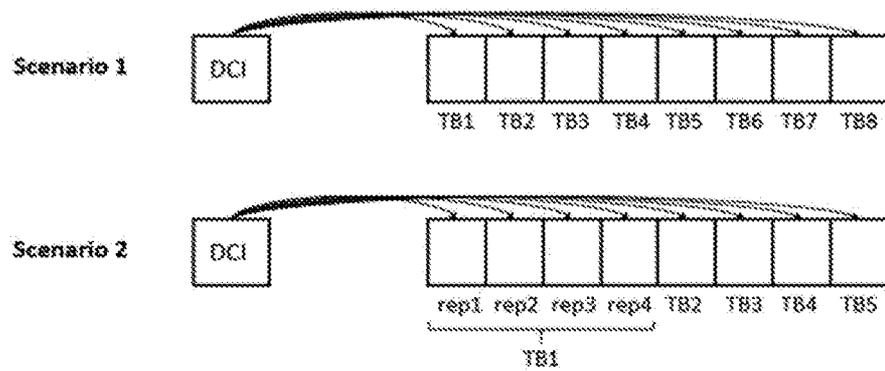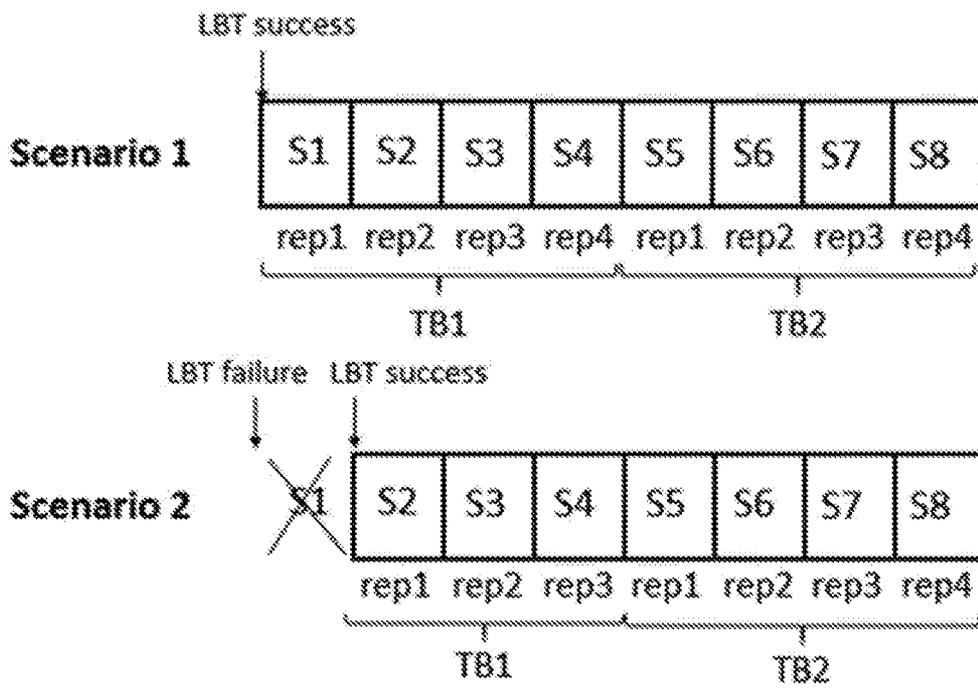
Figure 1

Figure 2

DCI		TDRA field	Repetition indication field
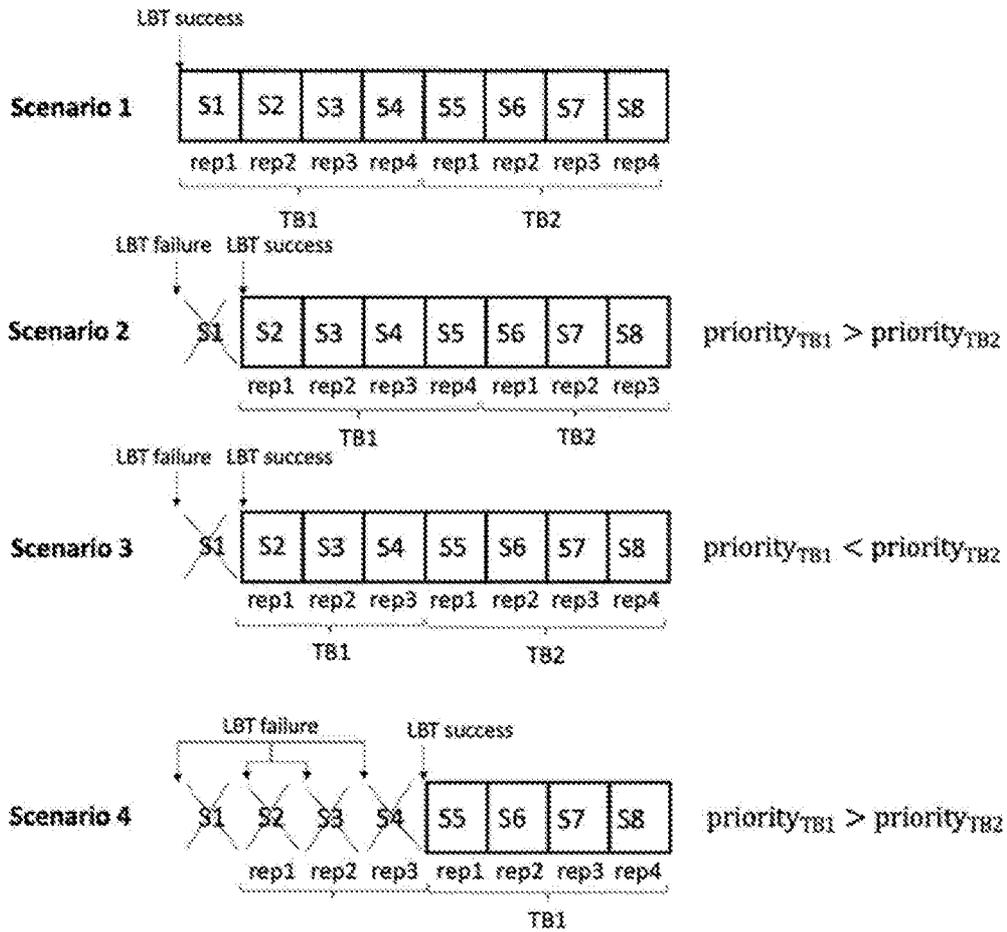
Figure 3

Figure 4

Figure 5
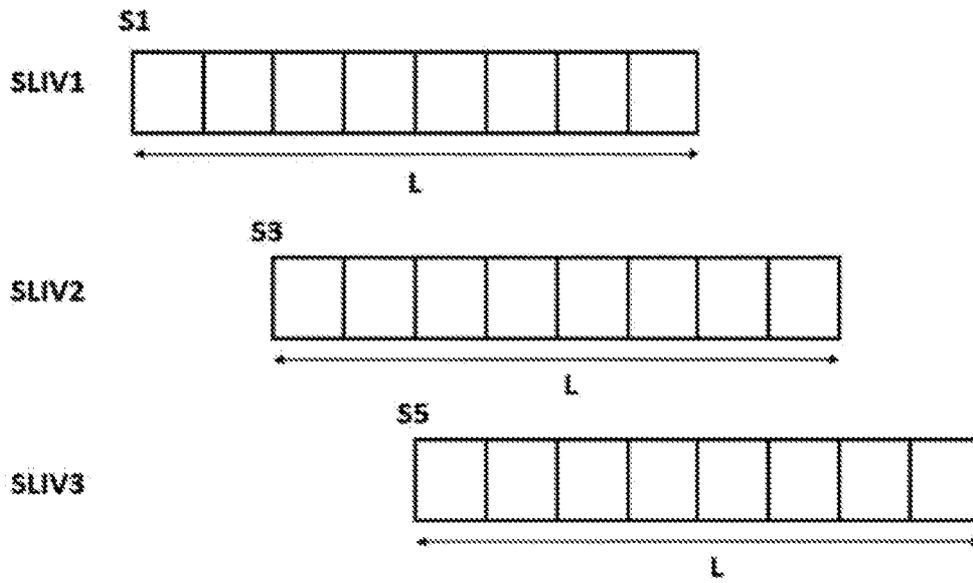
Figure 6
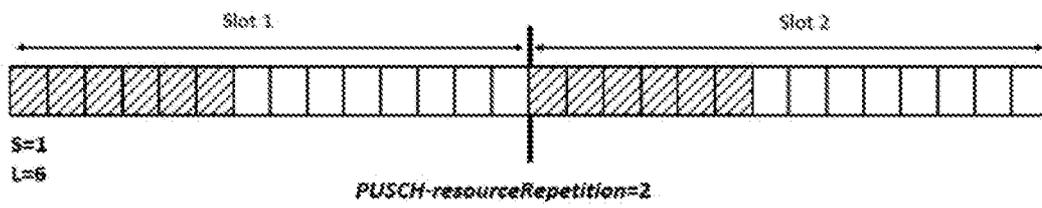
Figure 7

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

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)

CNKI;CNPAT;WPI;EPODOC;3GPP: DCI, downlink control, number, repetition+, repeat+, addition+, field, indicat+, retransm +, block?, PUSCH, TDRA

C.   DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2020033785 A1 (INTEL CORPORATION) 13 February 2020 (2020-02-13) claims 1-20, description, paragraphs 0026-0058	1-16
X	WO 2019215340 A1 (TELEFONAKTIEBOLAGET LM ERICSSON PUBL) 14 November 2019 (2019-11-14) claims 1-33, description, page 1 line 29 to page 6 line 16	1-16
A	WO 2015072774 A1 (SAMSUNG ELECTRONICS CO., LTD.) 21 May 2015 (2015-05-21) the whole document	1-16
A	CN 110999491 A (LG ELECTRONICS INC.) 10 April 2020 (2020-04-10) the whole document	1-16
A	WO 2019214650 A1 (SHARP KK et al.) 14 November 2019 (2019-11-14) the whole document	1-16

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

* Special categories of cited documents:	"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
"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	"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
"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)	"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
"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	"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 September 2021	**29 October 2021**

Name and mailing address of the ISA/CN	Authorized officer
National Intellectual Property Administration, PRC 6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088 China	**WANG,Dechuang**
Facsimile No. **(86-10)62019451**	Telephone No. **86-(10)-53961791**

Form PCT/ISA/210 (second sheet) (January 2015)

International application No.

PCT/CN2021/110366

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				EP	3811701	A1	28 April 2021
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				CN	105917598	A	31 August 2016
				US	2020059328	A1	20 February 2020
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				US	2020177314	A1	04 June 2020
				EP	3069455	A1	21 September 2016
CN	110999491	A	10 April 2020	EP	3664559	A1	10 June 2020
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				WO	2019203547	A1	24 October 2019
WO	2019214650	A1	14 November 2019	CN	110475371	A	19 November 2019
				KR	20210008004	A	20 January 2021
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