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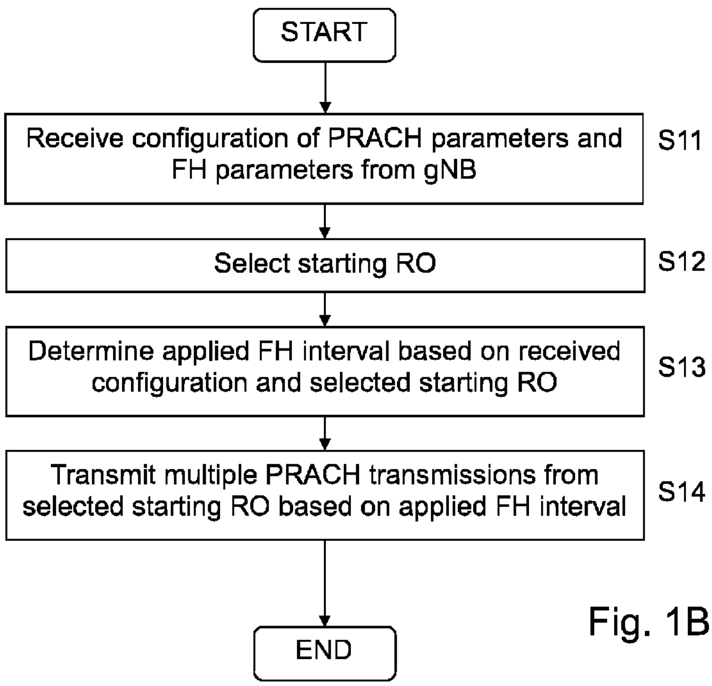


Fig. 1B

**(57) Abstract:** A method is provided, which comprises: receiving, at the user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element; selecting a starting random access occasion for multiple physical random access channel transmissions based on the configuration; determining an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and transmitting the multiple physical random access channel transmissions from the selected starting random access occasion with frequency hopping based on the determined applied frequency hopping interval.

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# METHODS FOR FREQUENCY HOPPING IN PRACH REPETITIONS

## Field of the Invention

The present invention relates to an apparatus, a method and a computer program product for providing security in a roaming scenario in edge computing.

## Related background Art

The following meanings for the abbreviations used in this specification apply:

| | |
|---|---|
| CBRA: | Contention based random access |
| DDDSU: | Slot pattern (D: Downlink, S: Special, U: Upllink) |
| DL: | Downlink |
| FDM: | Frequency Domain Multiplexing |
| FH: | Frequency Hopping |
| FR1: | Frequency Range 1 |
| FR2: | Frequency Range 2 |
| gNB: | NR Node B |
| ID: | Identifier |
| Msg1: | Message 1 |
| NR: | New Radio |
| PBCH: | Physical Broadcast Channel |
| PRACH: | Physical Random Access Channel |
| PRB: | Physical Resource Block |
| PUCCH: | Physical Uplink Control Channel |
| PUSCH: | Physical Uplink Shared Channel |
| RACH: | Random Access Channel |
| RAN: | Radio Access Network |
| RAR: | Random-access response |
| RO: | Rach Occasion |
| RNTI: | Radio Network Temporary Identifier |
| RRC: | Radio Resource Control |

| | |
|---|---|
| SC: | Subcarriers |
| SIB1: | System Information Block 1 |
| SS/PBCH: | Synchronization Signal/Physical Broadcast Channel |
| SSB: | Synchronization Signal Block |
| TC-RNTI: | Temporary Cell RNTI |
| UE: | User Equipment |
| UL: | Uplink |

Example embodiments relate to random access procedures. For example, in 5G NR, two contention based random access (CBRA) procedures are supported, namely 4-step RACH (Rel-15) and 2-step RACH (Rel-16).

Moreover, example embodiments are related to the possibility of enabling Frequency Hopping (FH) while transmitting the PRACH repetitions in different time instances. Frequency hopping can provide additional gains of PRACH repetitions due to frequency diversity.

For this, it is necessary to provide a framework for FH across PRACH repetitions.

## Summary of the Invention

Example embodiments address this situation aim to provide methods, apparatuses and computer programs by which frequency hopping in PRACH repetitions can be provided in a fair manner.

According to a first aspect, a method is provided which comprises

receiving, at the user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element;

selecting a starting random access occasion for multiple physical random access channel transmissions based on the configuration;

determining an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and transmitting the multiple physical random access channel transmissions from the selected starting random access occasion with frequency hopping based on the determined applied frequency hopping interval.

According to a second aspect, an apparatus is provided, which comprises at least one processor and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to: receive, at a user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element; select a starting random access occasion for multiple physical random access channel transmissions based on the configuration; determine an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and transmit the multiple physical random access channel transmissions from the selected starting random access occasion with frequency hopping based on the determined applied frequency hopping interval.

According to a third aspect, a method is provided, the method comprising:

configuring physical random access channel parameters for a user equipment, and

configuring frequency hopping parameters for the user equipment,

wherein the frequency hopping parameters comprise at least one configured frequency hopping interval to be used by the user equipment for determining an applied frequency hopping interval.

According to a fourth aspect, an apparatus is provided, which comprises at least one processor and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to: configure physical random access channel parameters for a user equipment, and configure frequency hopping parameters for the user equipment, wherein the frequency hopping parameters comprise at least one configured frequency hopping interval to be used by the user equipment for determining an applied frequency hopping interval.

Brief Description of the Drawings

These and other objects, features, details and advantages will become more fully apparent from the following detailed description of example embodiments, which is to be taken in conjunction with the appended drawings, in which:

Fig. 1A shows a UE 1 according to an example embodiment,

Fig. 1B shows a procedure carried out by the UE 1 according to the example embodiment,

Fig. 2A shows an gNB 2 according to an example embodiment,

Fig. 2B shows a procedure carried out by the gNB 2 according to the example embodiment,

Fig. 3 illustrates a 4-step RACH procedure,

Fig. 4 illustrates an example of time-domain resource determination for RACH occasions,

Fig. 5 illustrates an example of SSB to RO mapping with *prach-ConfigurationIndex* 251 and UL/DL configuration DDSUU,

Fig: 6 illustrates a FH pattern for PUSCH repetitions,

Fig. 7 illustrates a grid of valid ROs associated to a same SSB index,

Fig. 8 shows a flowchart according to an example embodiment, when a UE derives the FH interval based on specified formula, and

Fig. 9 illustrates PRACH repetitions with FH of two UEs starting from ROs with $n_{RA} = 2$ and $n_{RA} = 5$ according to an example embodiment.

Detailed Description of example embodiments

In the following, description will be made to example embodiments. It is to be understood, however, that the description is given by way of example only, and that the described example embodiments are by no means to be understood as limiting the present invention thereto.

Before describing example embodiment, in the following, problems of the prior art are discussed in some more detail.

First, the random access procedure is described.

In particular, in 5G NR, two contention based random access (CBRA) procedures are supported, namely 4-step RACH (Rel-15) and 2-step RACH (Rel-16). Some example embodiments focus on the former for illustration purpose and simplicity, but the proposed concept is equally applicable to the latter.

As shown in Fig. 3, the 4-step RACH procedure can be summarized as follows:

1. Msg1 (a.k.a. PRACH): The UE sends a specific preamble to the gNB via physical random-access channel (PRACH) using a specific resource called RACH occasion (RO).
2. Msg2 (a.k.a. RAR): The gNB replies with a random-access response (RAR) message, which includes the detected preamble ID, the time-advance command, a TC-RNTI, and UL grant for the transmission of Msg3 on PUSCH.
3. Msg3 (a.k.a. RRC request): The UE responds to Msg2 over the scheduled PUSCH with an ID for contention resolution.
4. Msg4 (a.k.a. RRC setup): The gNB transmits the contention resolution message with the contention-resolution ID.

Upon reception of Msg4, the UE sends an ACK on a PUCCH if its contention-resolution ID is carried by Msg4. This completes the 4-step RACH. It is worth noting that prior to Msg1, there is also a preliminary step of sending and receiving the synchronization signal block (SSB), i.e., DL beam sweeping, which is not formally part of the RACH procedure. As a result of this preliminary step, the UE selects the index of the preferred SSB beam and decodes the associated PBCH for MIB, SIB and so on. This index is also used by UE to identify a suitable RO for the preamble transmission (Msg1), according to the SSB-to-RO mapping implicitly conveyed by SIB1.

It is noted that the 2 step RACH is similar to 4 step RACH described above, , but Msg1 and Msg3 are combined in a MsgA and sent out without waiting for feedback from the UE in between (traditionally Msg2). Similarly, the gNB combines Msg2 and Msg4 into MsgB. The solutions according to some example embodiments for Msg1 can easily be applied , to the preamble/Msg1 part of MsgA.

In the following, configuration of RACH occasions (ROs) is described, wherein at first, the configuration in the time domain is described.

The time-domain resource for RACH occasions (ROs) is RRC configured by *prach-ConfigurationIndex* (in *rach-ConfigGeneric*), which acts as an indicator to a row of a table specified in TS 38.211 (clause 6.3.3.2). With the parameters indicated by *prach-ConfigurationIndex*, the UE determines the preamble format for PRACH and applies the procedure specified in TS 38.211 (clause 5.3.2) to find the ROs in time-domain.

Fig. 4 illustrates an example of time-domain resource determination for RACH occasions, wherein the *prach-ConfigurationIndex* is 251. With this index indicated, the UE determines the following:

- Preamble format C2 should be used.
- ROs are allocated at the system frame numbers (n_SFN) that satisfy n_SFN mod 1=0 (i.e. all SFN numbers are valid).
- Within each of the determined SFNs, ROs are allocated at subframe number 2 and 7.
- Within each of the determined subframes, the remaining parameters in the considered row indicate that ROs will start at symbol number 0, 6, 14, 20. The

symbol number is continuously counted regardless of the number of slots within the subframe, which depends on the sub-carrier spacing configured for PRACH.

ROs duration is 6 symbols (although the actual duration of the preamble format can be less than that).

Finally, the validity of the determined ROs is checked. According to TS 38.213 (clause 8.1) an RO is determined as valid, if it is within UL symbols or if it has a sufficient gap after the last SSB/DL symbol in case it is within flexible symbols.

In the following, the configuration in the frequency domain is described.

The parameters *Msg1-FrequencyStart* and *Msg1-FDM* configured in *RACH-ConfigGeneric* indicate the offset of the lowest RO in frequency domain from the start of the UE uplink bandwidth part and the number of ROs multiplexed in frequency domain for each time instance, respectively. Such ROs are indexed as $n_{RA}$={0,1,… ,M - 1}, where M equals the higher-layer parameter *Msg1-FDM*, and are numbered in increasing order within the UE uplink bandwidth part, starting from the lowest frequency. An example of such mapping is also shown in Fig. 5, which illustrates an example of SSB to RO mapping with *prach-ConfigurationIndex* 251 and UL/DL configuration DDDSU, in the case of *Msg1-FDM* = 2.

The number of occupied resource blocks per RO, expressed in number of RBs for PUSCH, is specified in Section 6.3.3.2 of TS 38.211, depending on the configured preamble length and sub-carrier spacings for PRACH and PUSCH.

In the following, SSB to RO mapping is described.

The mapping of SSB indexes to the determined ROs is fundamental for a UE to understand which ROs are associated to the SSB index selected during the preliminary step before the start of the RACH procedure. The different SSB indexes are beamformed in different directions in the cell, hence selection of a wrong SSB index may entail failure of the RACH procedure.

To this purpose, one fundamental parameter *ssb-perRACH-OccasionAndCB-PreamblesPerSSB* is configured in *RACH-ConfigCommon* and indicates two information: (i) the number of SSB indexes per RO and (ii) the number of contention-based preambles per SSB index. Once this information is available to a UE, the UE maps the SSB indexes to the time-frequency grid of ROs (determined as described above) in increasing order of frequency resource indices, time resource indices of the ROs within a PRACH slot, and the PRACH slots, sequentially.

Fig. 5 illustrates an example of valid ROs in one subframe determined as illustrated in Fig. 4, and further assumes the following additional configuration: DDDSU slot structure, *Msg1-FDM* = two, and *ssb-perRACH-OccasionAndCB-PreamblesPerSSB* is one-half. Based on the configuration, two ROs are multiplexed in the frequency domain (*Msg1-FDM* = two) and any two FDM'd ROs (i.e., two ROs multiplexed in the frequency domain) are mapped to the same SSB index (*ssb-perRACH-OccasionAndCB-PreamblesPerSSB* = 1/2). The original ROs #4, #5, #6, and #7 are barred as considered as valid since they are within DL symbols.

Frequency hopping is defined in 3GPP specifications (TS 38.214) for PUSCH repetitions as described in the following:

"In case of inter-slot frequency hopping and when *PUSCH-DMRS-Bundling* is not enabled, or for inter-slot frequency hopping for a PUSCH scheduled by RAR UL grant or DCI format 0_0 with CRC scrambled by TC-RNTI, the starting RB during slot $n_s^\mu$ is given by:

$$\mathrm{RB}_{\mathrm{start}}\left(n_s^\mu\right)=\begin{cases}\mathrm{RB}_{\mathrm{start}} & n_s^\mu \bmod 2=0\\ \left(\mathrm{RB}_{\mathrm{start}}+\mathrm{RB}_{\mathrm{offset}}\right) \bmod N_{BWP}^{size} & n_s^\mu \bmod 2=1\end{cases},$$

where $n_s^\mu$ is the current slot number within a system radio frame, where a multi-slot PUSCH transmission can take place, $\mathrm{RB}_{\mathrm{start}}$ is the starting RB within the UL BWP, as calculated from the resource block assignment information of resource allocation type 1 (described in Clause 6.1.2.2.2) and $\mathrm{RB}_{\mathrm{offset}}$ is the frequency offset in RBs between the two frequency hops."

In other words, while doing repetitions UE hops between two frequency hops in an alternating fashion (so called frequency hopping (FH) pattern), the two frequency hops being separated in frequency by a frequency offset (that will be also referred to as frequency hopping interval or FH interval in this application).

A simple example of FH pattern is shown in Fig. 6, where each box represents one Resource Block (RB), and each greyed box represents one PUSCH repetition (assumed to be allocated to only one RB) in one RB. In this case UE is following an FH pattern with an RB offset of 3 RBs and 4 PUSCH repetitions.

To explain the problem addressed according to some example embodiments, it is referred to Fig. 7, which represents a grid of valid ROs (each box is one RO), all associated to the same SSB index and where the horizontal domain represents time and the vertical domain represents frequency. Even if the ROs are represented contiguous in time and frequency for the sake of representation, it is not a necessary condition for example embodiments. In each box, a specific UE can be present, each UE being assumed to start from a different RO in the first time instance (first column) and performing 4 repetitions in different time instances, each repetition in an RO at a different frequency (and therefore different $n_{RA}$ index) than the previous repetition (i.e. frequency hopping). In the example, it is shown how four different UEs, namely UE-A, UE_B, UE_C and UE_D, perform repetitions in different time instances at a different frequency.

In this example it is assumed a certain way of operation for the frequency hopping. More specifically, it is assumed that a hopping interval of 1 RO (or 1 $n_{RA}$ index) is configured, and each UE determines the two hops for the PRACH repetitions: a first hop on the $n_{RA}$ of the starting RO and a second hop as the RO at a distance 1 $n_{RA}$ (higher in frequency) from the first hop in modulo operation. For example, for UE_A, the first hop is at $n_{RA}$ =0 and the second hop at $n_{RA}$ =1. This latter constraint (modulo operation) is specifically relevant for UE_D, which is not able to hop to a higher RO so that it will hop to the lowest RO of the grid (i.e. the second hop for the UE_D should be at $n_{RA}$ = 4 since the first hop is at $n_{RA}$ =3, but since $n_{RA}$ =4 is not present, UE_D transmits at $n_{RA}$ =0 as the second hop, $n_{RA}$ =0 being the result of the modulo operation). Because of this, the UE_D will be able to enjoy more frequency diversity (first and second hop more spaced in frequency) compared to the other three UEs, creating a performance advantage if the RO at $n_{RA}$ = 3 is selected as the starting RO for PRACH repetitions, risking of inducing UE implementations selecting always such RO as starting RO for transmission of the PRACH repetitions, in turn increasing the collision probability for PRACH repetitions. In addition, to avoid increasing the false alarm probability of the PRACH repetitions, the FH patterns need to be designed so that the ROs of different FH patterns do not overlap, leading to the UE_D not being able to select $n_{RA}$=2 as the second hop.

Based on the above, methods for enabling fair and exclusive hopping patterns (i.e. fair as all having the same degree of frequency diversity and exclusive as not overlapping with each other), which results in an FH pattern which is fair and exclusive regardless of the chosen RO as starting RO are necessary and will be the focus of some example embodiments described in the following.

According to some example embodiments, procedures are proposed, by which frequency hopping across PRACH repetitions is enabled, which results in an FH pattern which is fair and exclusive regardless of the starting RO chosen for the PRACH repetitions.

In the following, a general overview of some example embodiments is described by referring to Figs. 1A, 1B, 2A and 2B.

Fig. 1A shows a UE 1 according to the present example embodiment. The UE 1 is an example for an apparatus, which could be or be a part of a user equipment, for example. A procedure carried out by the UE 1 is illustrated in Fig. 1B. The UE 1 shown in Fig. 1A comprises at least one processor 11 and at least one memory 12 including computer program code. The at least one processor 11, with the at least one memory 12 and the computer program code, is configured to cause the apparatus to perform: receiving, at the user equipment, configuration of physical random access channel (PRACH)] parameters and frequency hopping parameters from a network control element (e.g., gNB 2 shown in Fig. 2A) (S11 in Fig. 1B); selecting a starting random access occasion (RO) for multiple physical random access channel (PRACH) transmissions based on the configuration (S12 in Fig. 1B); determining an applied frequency hopping interval ($FH_{interval}$) based on the configuration and the selected starting random access occasion (S13 in Fig. 1B); and transmitting the multiple physical random access channel (PRACH) transmissions from the selected starting random access occasion (with frequency hopping) based on the determined applied frequency hopping interval (S14 in Fig. 1B).

Fig. 2A shows a gNB 2 according to the present example embodiment. The gNB 2 is an example for an apparatus, which could be or be a part of a network element, for example. A procedure carried out by the gNB 2 is illustrated in Fig. 2B. The gNB 2 shown in Fig. 2A comprises at least one processor 21 and at least one memory 22 including computer program code. The at least one processor 21, with the at least one memory 22 and the computer program code, is configured to cause the apparatus to perform: configuring physical random access channel (PRACH) parameters for a user equipment (S21 in Fig. 2B); and configuring frequency hopping parameters for the user equipment (S22 in Fig. 2B), wherein the frequency hopping parameters comprise at least one configured frequency hopping interval ($FH_{config}$) to be used by the user equipment for determining an applied frequency hopping interval ($FH_{interval}$).

Thus, according to example embodiments, the UE is configured with PRACH and FH parameters, based on which a starting RO and an applied (actual) frequency hopping (FH) interval are determined. In this way, frequency hopping across PRACH repetitions with fair and exclusive hopping patterns can be provided, regardless of the starting RO chosen for the PRACH repetitions.

It is noted that according to some example embodiments, a frequency hopping (FH) interval defines a distance in frequency (i.e. hop) between one repetition and the next repetition.

It is noted that the term frequency hopping interval may also be referred to as a frequency offset. The frequency hopping (FH) interval or the frequency offset indicate the difference in frequency between two frequency hops.

It is noted that applied (actual) frequency hopping interval may be set to different values depending on the configured frequency hopping parameters. This may include zero, effectively resulting in a UE not performing frequency hopping across the PRACH repetitions.

For example, the frequency hopping interval may also be set to zero, so that for this instant no frequency hopping is carried out. For example, a further configuration information of the frequency hopping configuration parameters may comprise values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to zero, based on the selected starting RO. This could be made in form of a bitmap (such as [1 0 1 0] or the like), each bit of the bitmap referring to a different starting RO of the PRACH repetitions, in which e.g., 1 indicates the user equipment to set the applied frequency hopping interval to the configured frequency hopping interval, and 0 indicates the user equipment (UE) to set the applied frequency hopping interval to zero.

Alternatively, such a bitmap could be used to either indicate setting the applied frequency hopping interval to the configured frequency hopping interval or to the opposite thereof.

Alternatively, such a bitmap could be used to either indicate setting the applied frequency hopping interval to the opposite of the configured frequency hopping interval or to zero.

Alternatively, such a bitmap could be used to either indicate setting the applied frequency hopping interval to a value related to the configured frequency hopping interval or to zero.

Such a bitmap could be present in form of a vector.

The apparatuses 1 and 2 shown in Figs. 1A and 2A may comprise more components than described above, and may further comprise I/O units 13, 23, which are capable of transmitting to and receiving from other network elements.

In the following, the procedures described above are described in some more detail following by referring to some further detailed embodiments.

As mentioned above, some example embodiments propose methods for enabling frequency hopping across PRACH repetitions (as described above in connection with Fig. 7, for example), which results in an FH pattern which is fair and exclusive regardless of the starting RO chosen for the PRACH repetitions. In particular, conditions are proposed to satisfy in the frequency hopping configuration and frequency hopping intervals to guarantee that UEs benefit of a same degree of frequency diversity while transmitting on exclusive patterns, resulting in FH patterns which are fair and exclusive regardless of the starting RO chosen for the PRACH repetitions.

In the following, a configuration of frequency hopping parameters for PRACH repetitions according to some example embodiments is described.

In particular, according to an example embodiment, which is referred to as embodiment 1a in the following, the UE is configured with multiple frequency hopping intervals ($FH_{config}$), the multiple frequency hopping intervals defining the distance in frequency (i.e. hop) between one repetition and the next repetition, and the applied (actual) frequency hopping intervals ($FH_{interval}$) are determined by the UE based on the configuration. It is noted that the frequency hopping intervals ($FH_{config}$), which are configured by the network (e.g., by a gNB) are also referred to as "configured FH intervals" or "configured frequency hopping intervals", and that the actual frequency hopping intervals are also referred to as "applied frequency hopping interval".

If the number of repetitions is indicated as N, the number of frequency hopping intervals is equal or lower than N-1. If equal to N-1, one frequency hopping interval is mapped to a bundle of repetitions characterized by two consecutive repetitions (in all generality, this does not mean that the repetitions are actually consecutive in time). By contrast, if lower than N-1, one frequency hopping interval is mapped to a bundle of repetitions characterized by more than two repetitions. For example, if N=8 but only 2 frequency hopping intervals are configured, each interval is then mapped to a bundle of 4 repetitions, meaning that the same hop is performed between the 1st and 2nd repetition, between the 2nd and 3rd repetition, and between the 3rd and 4th repetition and the same, but possibly different, hop is performed between the $4^{th}$ and $5^{th}$ repetition, between the $5^{th}$ and $6^{th}$ repetition, and between the $6^{th}$ and $7^{th}$ repetition, and between the $7^{th}$ and $8^{th}$ repetition.

The configured multiple frequency hopping intervals may be the same, if resulting in an FH pattern which is fair and exclusive regardless of the starting RO (in time) for the PRACH repetitions, or may be specific to the starting RO (in time) for the PRACH repetitions.

According to another embodiment, which is referred to as embodiment 1b in the following, the UE is configured with only one frequency hopping interval for all of the repetitions N ($FH_{config}$), and the applied (actual) frequency hopping interval ($FH_{interval}$) is determined by the UE, for example based on embodiment 2 and its variants described later. In this case, the first hop (in units of $n_{RA}$) of the FH pattern is provided by the $n_{RA}$ index of the starting RO (also referred to as $n_{RA\_start}$ in the following), whereas the second hop of the FH pattern is calculated as $n_{RA\_start}$ + $FH_{interval}$.

According to another embodiment, which is referred to as embodiment 1c in the following, the UE is configured with one or more starting ROs for the PRACH repetitions with frequency hopping. In other words, and for example with reference to Figure 7, not all the ROs in the first time instance (first column) would allow frequency hopping across the PRACH repetitions, but UE could perform frequency hopping only if starting from a subset of such ROs.

The configuration according to this embodiment could be in the form of a bitmap of length equal to the number of ROs multiplexed in frequency domain and mapped to the same SSB index, where the ones represent the starting ROs for the PRACH repetitions with frequency hopping and the zeros represent the starting ROs for the PRACH repetitions without frequency hopping.

Alternatively, the configuration according to this embodiment could be in the form of a vector of $n_{RA}$ indexes of length less or equal than the number of ROs multiplexed in frequency domain and mapped to the same SSB index, where the $n_{RA}$ indexes represent the $n_{RA}$ indexes associated to the starting ROs for the PRACH repetitions with frequency hopping.

Further alternatively, the configuration could be in the form of one $n_{RA}$ index and a length value $L_{RA}$, and UE derives the $n_{RA}$ indexes of the starting ROs for the PRACH repetitions with frequency hopping as all the $n_{RA}$ indexes between $n_{RA}$ and $n_{RA} + L_{RA}$-1.

According to another embodiment, which is referred to as embodiment 1d in the following, the UE determines whether the configured frequency hopping interval(s) ($FH_{config}$) are valid. For example, the UE considers the configured frequency hopping interval(s) as valid when they satisfy certain conditions.

If the CHOICE part of the field *ssb-perRACH-OccasionAndCB-PreamblesPerSSB* in *RACH-ConfigCommon* is less than one, let us call $M$ the inverse of it. In one embodiment, which is referred to as embodiment 1d1 in the following, the configured frequency hopping interval(s) is (are) valid only if the ratio between $\min(M,K)$ and the configured frequency hopping interval(s) is (are) an even integer. Here $K$ is the number of configured one or more starting ROs for the PRACH repetitions with FH, as by embodiment 1c described above.

If the CHOICE part of the field *ssb-perRACH-OccasionAndCB-PreamblesPerSSB* in *RACH-ConfigCommon* is larger than one, let us call $M$ the inverse of it. In one embodiment, which is referred to as embodiment 1d2 in the following, the configured frequency hopping interval(s) is (are) valid only if the ratio between $f(M)$ and the configured frequency hopping interval(s) is (are) an even integer, where

$$f(M) = \frac{\min(Msg1-FDM, K)}{\#SSB_{indexes} * M}.$$

Moreover, *Msg1-FDM* is a parameter configured in *RACH-ConfigCommon* and *#SSBindexes* is the total number of configured SSB indexes. Here, $K$ is the number of configured one or more starting ROs for the PRACH repetitions with FH, as by embodiment 1c described above.

An invalid frequency hopping configuration as per embodiment 1d1 and 1d2 described above disables UE frequency hopping across PRACH repetitions.

According to another embodiment, which is referred to as embodiment 1e in the following, a valid configured frequency hopping interval as per embodiment 1d enables the PRACH repetitions in the cell. Conversely, an invalid frequency hopping configuration disables the PRACH repetitions in the cell.

According to another embodiment, which is referred to as embodiment 1f in the following, the units of the configured frequency hopping interval(s) is in subcarriers (SCs) or Physical Resource Blocks (PRBs) or the index $n_{RA}$.

According to another embodiment, which is referred to as embodiment 2 in the following, an UE determination of actual frequency hopping interval(s) based on at least one of the configuration and the starting RO for the PRACH repetitions is described.

In particular, according to another embodiment referred to as embodiment 2a in the following, the applied (actual) frequency hopping interval(s) ($FH_{interval}$) is (are) the one(s) used by the UE for hopping across the PRACH repetitions.

According to another embodiment referred to as embodiment 2b in the following, in the case multiple frequency hopping intervals are configured, the UE determines the actual FH intervals based on the configuration by setting $FH_{interval} = FH_{config}$, where $FH_{config}$ are the configured multiple frequency hopping intervals according to the embodiments 1a to 1f described above.

According to another embodiment referred to as embodiment 2c in the following, in the case only one FH interval is configured, the UE determines the actual FH intervals based on the configuration and on the starting RO for PRACH repetitions. In this case, the first hop (in units of $n_{RA}$) of the FH pattern is provided by the $n_{RA}$ index of the starting RO ($n_{RA\_Start}$), whereas the second hop of the FH pattern is calculated as $n_{RA\_Start} + FH_{interval}$. If we enumerate the repetitions from 1 to N, the UE transmits in the first hop in odd repetitions and in the second hop in even repetitions.

According to one embodiment, which is referred to as embodiment 2d in the following, for the case of only one configured FH interval, the determination of the actual frequency hopping interval is based on a specific formula:

$$FH_{interval} = \left(-2 * mod\left(floor\left(\frac{n_{RA\_Start}}{FH_{config}}\right), 2\right) + 1\right) * FH_{config},$$

wherein $n_{RA\_Start}$ is the $n_{RA}$ index of the starting RO, $FH_{config}$ is the configured frequency hopping interval and mod is the modulo operation.

According to another embodiment, which is referred to as embodiment 2e in the following, for the case of only one configured FH interval, the determination of the actual frequency hopping interval is based on further configuration from gNB of a vector of values, the vector having a length equal to the number of frequency multiplexed ROs and mapped to the same SSB index.

In particular, according to one implementation, the vector is a bitmap, where the value 1 indicates to UE to set $FH_{interval}$ to the configured value $FH_{config}$ and the value 0 indicates to UE to set $FH_{interval}$ to the opposite of configured value (i.e. $-FH_{config}$).

According to another implementation, the vector is a bitmap, where the value 0 indicates to UE to set $FH_{interval}$ to the configured value $FH_{config}$ and the value 1 indicates to UE to set $FH_{interval}$ to the opposite of configured value (i.e. $-FH_{config}$).

According to another implementation, the vector includes values indicating to UE to either set $FH_{interval}$ to the configured value $FH_{config}$ or to the opposite of the configured value (i.e. $-FH_{config}$).

In the following, an example implementation of the proposed procedures, is described as a further example embodiment by referring to Fig. 8.

In processes P1A and P1B, UE configuration from gNB of the PRACH parameters and frequency hopping parameters is carried out. That is, according to the example shown in Fig. 8, in process P1A configuration of PRACH parameters is carried out, and in process P1B, configuration of frequency hopping parameters for PRACH repetitions (e.g., including a bitmap for starting RO and $FH_{config}$) is carried out. It is noted that, even if they are shown as two different processes in the flowchart, they may be configured at the same time (as a process P1) or not in the order shown in the flowchart.

The PRACH parameters include the parameters for determining the PRACH resources in terms of RACH Occasions (ROs) and of preamble format for PRACH transmission. The FH parameters for PRACH repetitions include at least one or multiple FH intervals and one or more starting ROs for PRACH repetitions with FH.

In this example, without loss of generality, only one FH interval and a bitmap for starting RO are configured.

For example, if 4 ROs are multiplexed in the frequency domain and associated to the same SSB index, the bitmap has a size of 4 bits, each bit representing one RO. For example, entries with a value 1 represent starting ROs for PRACH repetitions with FH whereas entries with a value 0 represent starting ROs for PRACH repetitions without FH.

In process P2, the UE selects the starting RO among the configured starting ROs for PRACH repetitions with FH in a random fashion. For example, the configured starting ROs are conveyed by the bitmap [1 1 0 0 1 1 1 1], associated to $n_{RA}$ indexes from 0 to 7 (8 ROs multiplexed in frequency domain and associated to the same SSB index).

For example, UE randomly selects $n_{RA}$ = 5 as the starting RO.

Moreover, it is assumed that the time instance of the starting ROs is known by the UE.

In process P3, the UE derives the actual FH interval ($FH_{interval}$) based on the configured FH interval ($FH_{config}$) and the selected starting RO based on the formula

$$FH_{interval} = \left(-2 * mod\left(floor\left(\frac{n_{RA\_start}}{FH_{config}}\right), 2\right) + 1\right) * FH_{config}$$

For example, in a first example, if the selected starting RO is the RO with $n_{RA\_Start}$ = 5 (as by previous step) and $FH_{config} = 4$, $FH_{interval} = -FH_{config}$.

In a second example, if the selected starting RO is the RO with $n_{RA\_Start}$ = 0(as by previous step) and $FH_{config} = 4$, $FH_{interval} = FH_{config}$.

In a third example, if the selected starting RO is the RO with $n_{RA\_Start}$ = 2(as by previous step), UE does not perform FH according to the configured bitmap and transmits all four PRACH repetitions on $n_{RA} = 2$.

Alternatively, in process P3, the UE derives the actual FH interval ($FH_{interval}$) based on the configured FH interval ($FH_{config}$) and the selected starting RO based on the configured bitmap of starting ROs. In particular, if the value of the bitmap is 1 the UE sets the actual FH interval to the configured FH interval, whereas if the value of the bitmap is 0, the UE sets the actual FH interval to 0 and does not perform FH.

For example, in a first example, if the selected starting RO is the RO with $n_{RA\_Start}$ = 5 (as by previous step), $FH_{interval} = FH_{config}$.

In a second example, if the selected starting RO is the RO with $n_{RA\_Start}$ = 2(as by previous step), $FH_{interval} = 0$ and UE does not perform FH and transmits all four

PRACH repetitions on $n_{RA} = 2$.

In process P4, the UE transmits PRACH repetitions from the selected starting RO and utilizing an FH pattern based on the derived actual (applied) FH interval, if the starting RO allows for frequency hopping based on the configured bitmap.

For example, if the selected starting RO is the RO with $n_{RA}$ =5 and $FH_{config}$ = 4, giving $FH_{interval}$ =-4 (the first example described above), UE follows the $n_{RA}$ pattern {5, 1, 5, 1}.

For example, if the selected starting RO is the RO with $n_{RA}$ =0 and $FH_{config}$ = 4, giving $FH_{interval}$ =4 (the second example described above), UE follows the $n_{RA}$ pattern {0, 4, 0, 4}

These examples are further shown in Fig. 9, wherein the UE_A is the UE of the first example, UE_B is the one of the second example, whereas the UE_C is the one of the third example.

Thus, according to some example embodiments, methods for enabling frequency hopping across PRACH repetitions with fair and exclusive hopping patterns are provided, regardless of the starting RO chosen for the PRACH repetitions. In particular, according to some example embodiments, conditions are provided in order to satisfy in the frequency hopping configuration and frequency hopping intervals to guarantee that UEs benefit of a same degree of frequency diversity while transmitting on exclusive patterns, regardless of the starting RO chosen for the PRACH repetitions.

The above-described example embodiments are only examples and may be modified.

According to a first aspect of example embodiments, a method, in a user equipment, is provided, the method comprising:

receiving, at the user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element;

selecting a starting random access occasion for multiple physical random access channel transmissions based on the configuration;

determining an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and

transmitting the multiple physical random access channel transmissions from the selected starting random access occasion (with frequency hopping) based on the determined applied frequency hopping interval.

According to a second aspect, an apparatus is provided, which comprises at least one processor and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to:

receive, at a user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element;

select a starting random access occasion for multiple physical random access channel transmissions based on the configuration;

determine an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and

transmit the multiple physical random access channel transmissions from the selected starting random access occasion (with frequency hopping) based on the determined applied frequency hopping interval.

The first and second aspects may be modified as follows:

The frequency hopping parameters may comprise a configured frequency hopping interval, and the method may further comprise

determining the applied frequency hopping interval based on the configured frequency hopping interval and the selected starting random access occasion.

The frequency hopping parameters may comprise a configured frequency hopping interval, and the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to determine the applied frequency hopping interval based on the configured frequency hopping interval and the selected starting random access occasion.

The applied frequency hopping interval may be determined based on the formula:

$$FH_{interval} = \left(-2 * mod\left(floor\left(\frac{n_{RA\_Start}}{FH_{config}}\right), 2\right) + 1\right) * FH_{config},$$

wherein $n_{RA\_Start}$ is the $n_{RA}$ index of the selected starting random access occasion, $FH_{config}$ is the configured frequency hopping interval and mod is the modulo operation.

The method may further comprise

determining whether the configured frequency hopping interval is valid or not, and

disabling frequency hopping when it is determined that the configured frequency hopping interval is not valid, or

enabling frequency hopping when it is determined that the configured frequency hopping interval is valid.

The at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to determine whether the configured frequency hopping interval is valid or not, and to disable frequency hopping when it is determined that the configured frequency hopping interval is not valid, or to enable frequency hopping when it is determined that the configured frequency hopping interval is valid.

The physical random access channel parameters may comprise at least one starting random access occasion.

The physical random access channel parameters may comprise a plurality of starting random access occasions, and the method may further comprise

selecting the selected starting random access occasion randomly from the plurality of starting random access occasions.

The physical random access channel parameters may comprise a number of physical random access channel repetitions.

The frequency hopping parameters may comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to the opposite of the configured frequency hopping interval based on the selected starting random access occasion.

The further configuration information may comprises a vector in which the values are included, wherein the vector may comprise a length equal to a number of frequency multiplexed random access occasion.

The vector may be a bitmap, each bit of the bitmap referring to a different starting random access occasion (starting RO of the PRACH repetitions), and a first value (e.g., 1 or 0) of each bit indicates the user equipment to set the applied frequency hopping interval to the configured frequency hopping interval, and a second value (e.g., 0 or 1) of each bit indicates the user equipment to set the applied frequency hopping interval to the opposite of the configured frequency hopping interval.

The frequency hopping parameters may comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to zero, based on the selected starting random access occasion. It is noted that, therefore, the further configuration information indicates to the UE whether to perform frequency hopping based on the configured frequency hopping interval or to not perform frequency hopping (equivalent to setting the applied frequency hopping interval to zero) based on the selected starting random access occasion.

The further configuration parameters may be in the form of a bitmap, each bit of the bitmap referring to a different starting RO of the PRACH repetitions, wherein a first value (e.g., 1 or 0) of each bit indicates the user equipment to set the applied frequency hopping interval to the configured frequency hopping interval, and a second value (e.g. 0 or 1) of each bit indicates the user equipment to set the applied frequency hopping interval to zero.

According to a third aspect of some example embodiments, a method, in a network control element, is provided, the method comprising:

configuring physical random access channel parameters for a user equipment, and

configuring frequency hopping parameters for the user equipment,

wherein the frequency hopping parameters comprise at least one configured frequency hopping interval to be used by the user equipment for determining an applied frequency hopping interval.

According to a fourth aspect of some example embodiments, an apparatus is provided, which comprises at least one processor and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to:

configure physical random access channel parameters for a user equipment, and

configure frequency hopping parameters for the user equipment,

wherein the frequency hopping parameters comprise at least one configured frequency hopping interval to be used by the user equipment for determining an applied frequency hopping interval.

The third and fourth aspects may be modified as follows:

The physical random access channel parameters may comprise information concerning at least one starting random access occasion.

The frequency hopping parameters may comprise a number of physical random access channel repetitions.

The frequency hopping parameters may comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to the opposite of the configured frequency hopping interval.

The further configuration information may comprise a vector in which the values are included, wherein the vector may comprise a length equal to a number of frequency multiplexed random access occasion.

The vector may be a bitmap, and a first value (e.g., 1 or 0) of each bit may indicate the user equipment to set the applied frequency hopping interval to the configured frequency hopping interval, and a second value (e.g., 0 or 1) of each bit may indicate the user equipment to set the applied frequency hopping interval to the opposite of the configured frequency hopping interval.

The frequency hopping parameters may comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to zero.

The values of the further configuration information may be in the form of a bitmap, wherein a first value (e.g., 1 or 0) of each bit indicates the user equipment to set the applied frequency hopping interval to the configured frequency hopping interval, and a second value (e.g. 0 or 1) of each bit indicates the user equipment to set the applied frequency hopping interval to zero.

According to a fifth aspect of some example embodiments, a computer program product is provided which comprises code means for performing a method according to any one of the first and third aspects and/or their modifications when run on a processing means or module. The computer program product may be embodied on a computer-readable medium, and/or the computer program product may be directly loadable into the internal memory of the computer and/or transmittable via a network by means of at least one of upload, download and push procedures.

According to a sixth aspect of some example embodiments, an apparatus is provided which comprises

means for receiving, at a user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element;

means for selecting a starting random access occasion for multiple physical random access channel transmissions based on the configuration;

means for determining an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and

means for transmitting the multiple physical random access channel transmissions from the selected starting random access occasion with frequency hopping based on the determined applied frequency hopping interval.

According to a seventh aspect, an apparatus is provided, which comprises

means for configuring physical random access channel parameters for a user equipment, and

means for configuring frequency hopping parameters for the user equipment,

wherein the frequency hopping parameters comprise at least one configured frequency hopping interval to be used by the user equipment for determining an applied frequency hopping interval.

Names of network elements, protocols, and methods are based on current standards. In other versions or other technologies, the names of these network elements and/or protocols and/or methods may be different, as long as they provide a corresponding functionality.

In general, the example embodiments may be implemented by computer software stored in the memory (memory resources, memory circuitry) 12, 22 and executable by the processor (processing resources, processing circuitry) 11, 21 or by hardware, or by a combination of software and/or firmware and hardware.

As used in this application, the term "circuitry" refers to all of the following:
(a) hardware-only circuit implementations (such as implementations in only analog and/or digital circuitry) and
(b) to combinations of circuits and software (and/or firmware), such as (as applicable): (i) to a combination of processor(s) or (ii) to portions of processor(s)/software (including digital signal processor(s)), software, and memory(ies) that work together to cause an apparatus, such as a mobile phone or server, to perform various functions) and
(c) to circuits, such as a microprocessor(s) or a portion of a microprocessor(s), that require software or firmware for operation, even if the software or firmware is not physically present.

This definition of "circuitry" applies to all uses of this term in this application, including in any claims. As a further example, as used in this application, the term "circuitry" would also cover an implementation of merely a processor (or multiple processors) or portion of a processor and its (or their) accompanying software and/or firmware. The term "circuitry" would also cover, for example and if applicable to the particular claim element, a baseband integrated circuit or applications processor integrated circuit for a mobile phone or a similar integrated circuit in server, a cellular network device, or other network device.

The terms "connected," "coupled," or any variant thereof, mean any connection or coupling, either direct or indirect, between two or more elements, and may encompass the presence of one or more intermediate elements between two elements that are "connected" or "coupled" together. The coupling or connection between the elements can be physical, logical, or a combination thereof. As employed herein two elements may be considered to be "connected" or "coupled" together by the use of one or more wires, cables and printed electrical connections, as well as by the use of electromagnetic energy, such as electromagnetic energy having wavelengths in the radio frequency region, the microwave region and the optical (both visible and invisible) region, as non-limiting examples.

The memory (memory resources, memory circuitry) 12, 22 may be of any type suitable to the local technical environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory, and non-transitory computer-readable media. The processor (processing resources, processing circuitry) 11, 21 may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on a multi core processor architecture, as non-limiting examples.

It is to be understood that the above description is illustrative of the invention and is not to be construed as limiting the invention. Various modifications and applications may occur to those skilled in the art without departing from the true spirit and scope of the invention as defined by the appended claims.

CLAIMS

1. A method, in a user equipment, the method comprising:

receiving, at the user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element;

selecting a starting random access occasion for multiple physical random access channel transmissions based on the configuration;

determining an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and

transmitting the multiple physical random access channel transmissions from the selected starting random access occasion based on the determined applied frequency hopping interval.

2. The method according to claim 1, wherein the frequency hopping parameters comprise a configured frequency hopping interval, the method further comprising

determining the applied frequency hopping interval based on the configured frequency hopping interval and the selected starting random access occasion.

3. The method according to claim 2, wherein the applied frequency hopping interval is determined based on the formula:

$$FH_{interval} = \left(-2 * mod\left(floor\left(\frac{n_{RA\_Start}}{FH_{config}}\right), 2\right) + 1\right) * FH_{config},$$

wherein $n_{RA\_Start}$ is the $n_{RA}$ index of the selected starting random access occasion, $FH_{config}$ is the configured frequency hopping interval and mod is the modulo operation.

4. The method according to claim 2 or 3, further comprising

determining whether the configured frequency hopping interval is valid or not, and disabling frequency hopping when it is determined that the configured frequency hopping interval is not valid, or

enabling frequency hopping when it is determined that the configured frequency hopping interval is valid.

5. The method according to any one of the claims 1 to 4, wherein the the configuration comprises at least one starting random access occasion.

6. The method according to any one of the claims 1 to 5, wherein the configuration comprises a plurality of starting random access occasions, and the method further comprises

selecting the selected starting random access occasion randomly from the plurality of starting random access occasions.

7. The method according to any one of the claims 1 to 6, wherein the physical random access channel parameters comprise a number of physical random access channel repetitions.

8. The method according to any one of the claims 1 to 7, wherein the frequency hopping parameters comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to the opposite of the configured frequency hopping interval based on the selected starting random access occasion.

9. The method according to claim 8, wherein the further configuration information comprises a vector in which the values are included, wherein the vector comprises a length equal to a number of frequency multiplexed random access occasion.

10. The method according to claim 9, wherein the vector is a bitmap, each bit of the bitmap referring to a different starting random access occasion, and a first value of each bit indicates the user equipment to set the applied frequency

hopping interval to the configured frequency hopping interval, and a second value of each bit indicates the user equipment to set the applied frequency hopping interval to the opposite of the configured frequency hopping interval.

11. The method according to any one of the claims 1 to 7, wherein the frequency hopping parameters comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to zero based on the selected starting random access occasion.

12. The method according to claim 11, wherein the values of the further configuration information are in the form of a bitmap, each bit of the bitmap referring to a different starting random access occasion, wherein a first value of each bit indicates the user equipment to set the applied frequency hopping interval to the configured frequency hopping interval, and a second value of each bit indicates the user equipment to set the applied frequency hopping interval to zero.

13. A method, in a network control element, the method comprising:

configuring physical random access channel parameters for a user equipment, and

configuring frequency hopping parameters for the user equipment,

wherein the frequency hopping parameters comprise at least one configured frequency hopping interval to be used by the user equipment for determining an applied frequency hopping interval.

14. The method according to claim 13, wherein the physical random access channel parameters comprise information concerning at least one starting random access occasion.

15. The method according to claim 13 or 14, wherein the frequency hopping parameters comprise a number of physical random access channel repetitions.

16. The method according to any one of the claims 13 to 15, wherein the frequency hopping parameters comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to the opposite of the configured frequency hopping interval, or

wherein the frequency hopping parameters comprise one configured frequency hopping interval, and further configuration information comprising values indicating the user equipment either to set the applied frequency hopping interval to the configured frequency hopping interval or to zero.

17. An apparatus comprising at least one processor and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to:

receive, at a user equipment, configuration of physical random access channel parameters and frequency hopping parameters from a network control element;

select a starting random access occasion for multiple physical random access channel transmissions based on the configuration;

determine an applied frequency hopping interval based on the configuration and the selected starting random access occasion; and

transmit the multiple physical random access channel transmissions from the selected starting random access occasion based on the determined applied frequency hopping interval.

18. An apparatus comprising at least one processor and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to:

configure physical random access channel parameters for a user equipment, and

configure frequency hopping parameters for the user equipment,

wherein the frequency hopping parameters comprise at least one configured frequency hopping interval to be used by the user equipment for determining an applied frequency hopping interval.

19. A computer program product comprising code means for performing a method according to any one of the claims 1 to 16 when run on a processing means or module.

20. The computer program product according to claim 19, wherein the computer program product is embodied on a computer-readable medium, and/or the computer program product is directly loadable into the internal memory of the computer and/or transmittable via a network by means of at least one of upload, download and push procedures.

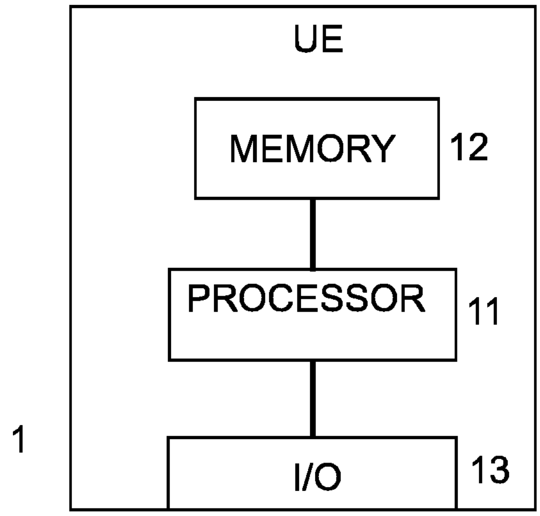
UE
MEMORY
12
PROCESSOR
11
1
I/O
13

Fig. 1A

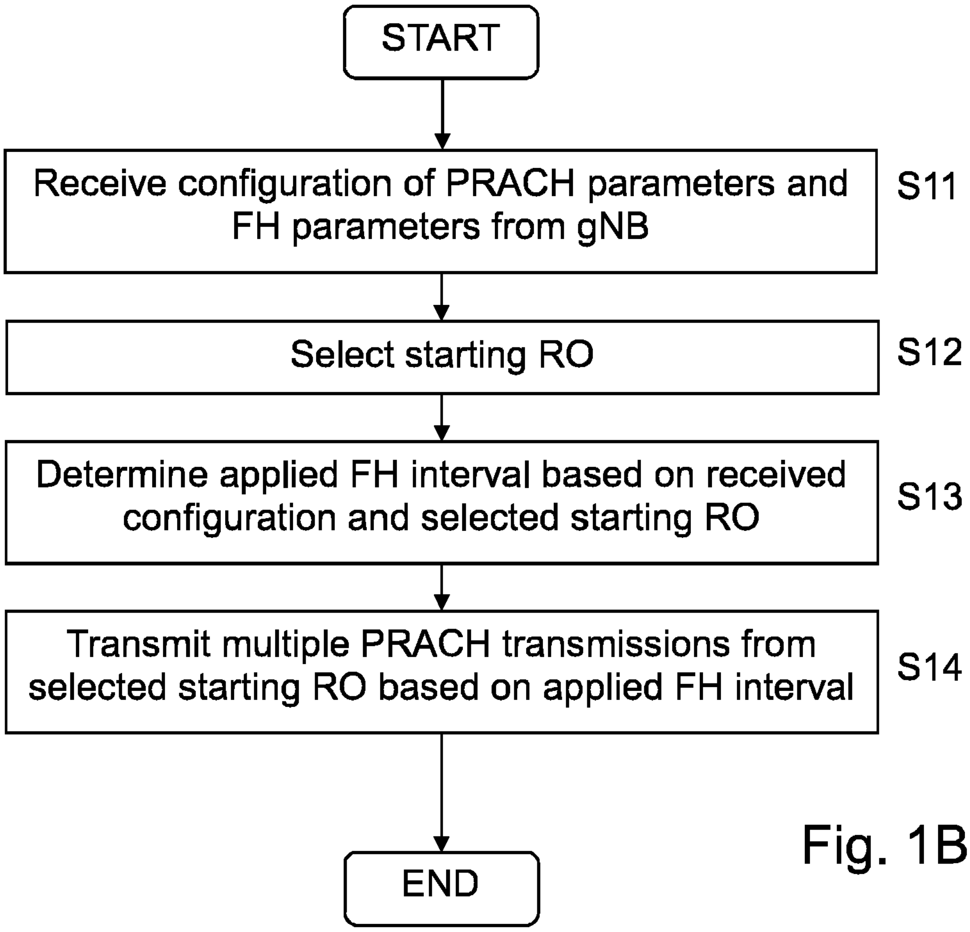
START
Receive configuration of PRACH parameters and FH parameters from gNB
S11
Select starting RO
S12
Determine applied FH interval based on received configuration and selected starting RO
S13
Transmit multiple PRACH transmissions from selected starting RO based on applied FH interval
S14
END

Fig. 1B

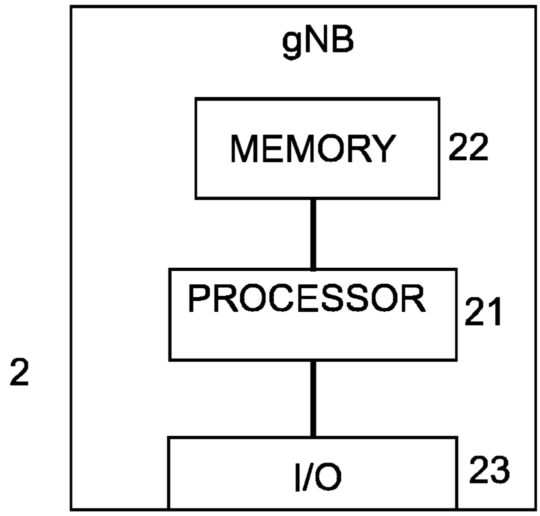
gNB
MEMORY
22
PROCESSOR
21
2
I/O
23

Fig. 2A

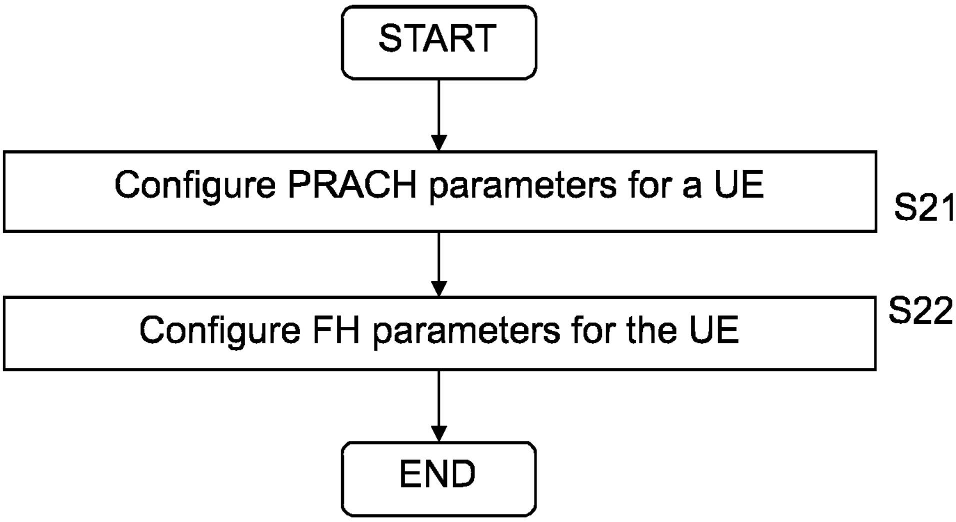
START
Configure PRACH parameters for a UE
S21
Configure FH parameters for the UE
S22
END

Fig. 2B

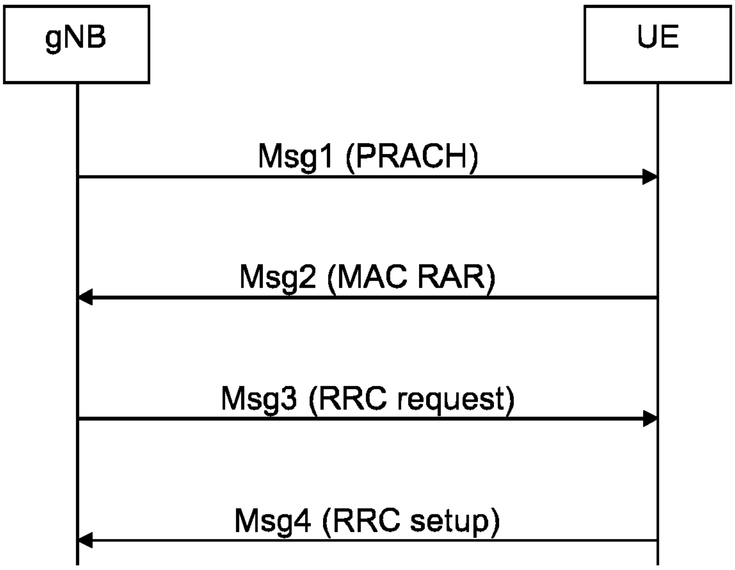
gNB
UE
Msg1 (PRACH)
Msg2 (MAC RAR)
Msg3 (RRC request)
Msg4 (RRC setup)

Fig. 3

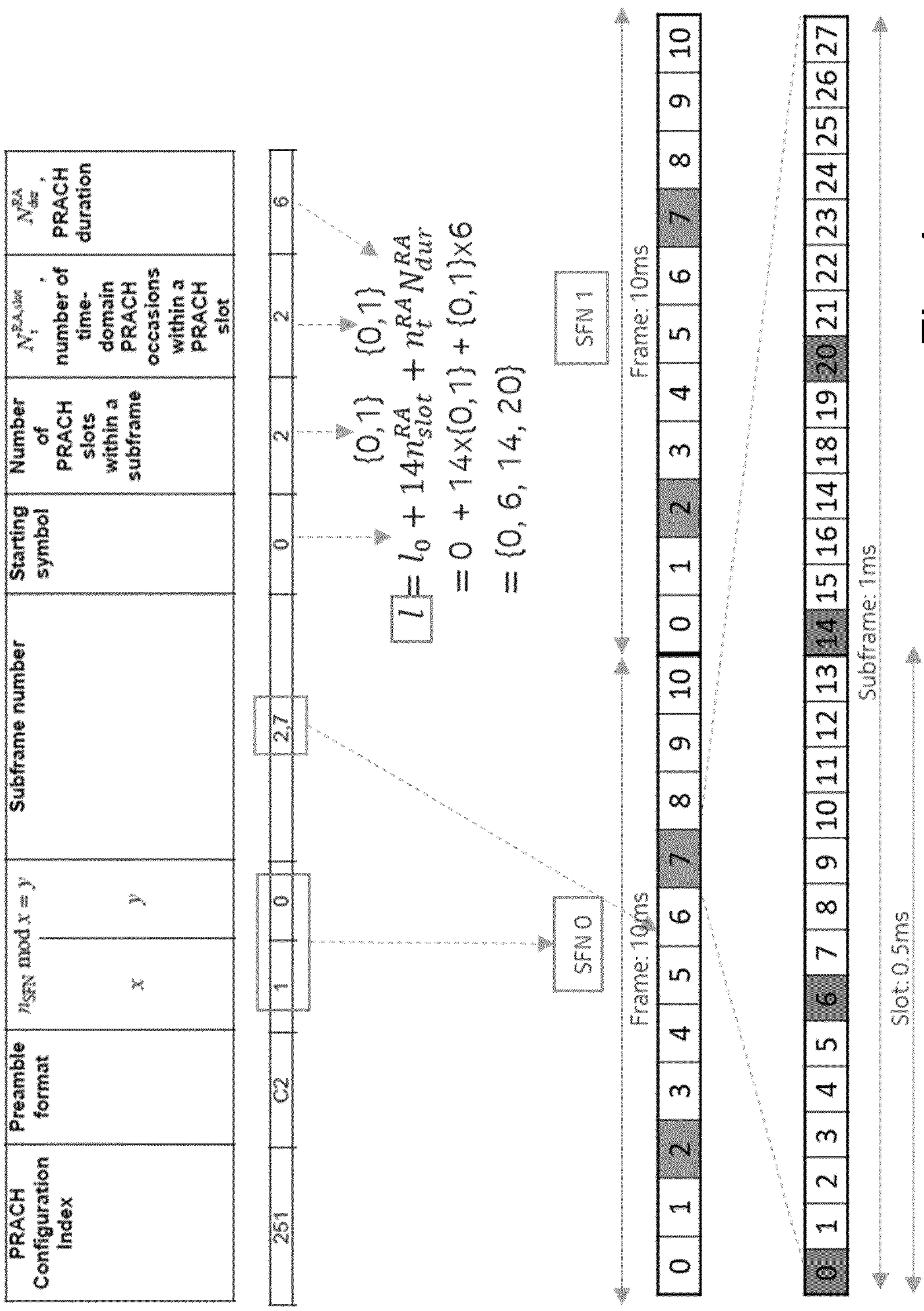
PRACH Configuration Index
Preamble format
$n_{SFN} \bmod x = y$
x
y
Subframe number
Starting symbol
Number of PRACH slots within a subframe
$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot
$N_{dur}^{RA}$, PRACH duration
251
C2
1
0
2,7
0
2
2
6
$l = l_0 + 14n_{slot}^{RA} + n_t^{RA}N_{dur}^{RA}$
{0,1} {0,1}
$= 0 + 14\times\{0,1\} + \{0,1\}\times 6$
$= \{0, 6, 14, 20\}$
SFN 0
SFN 1
Frame: 10ms
Frame: 10ms
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 14 18 19 20 21 22 23 24 25 26 27
Subframe: 1ms
Slot: 0.5ms

Fig. 4

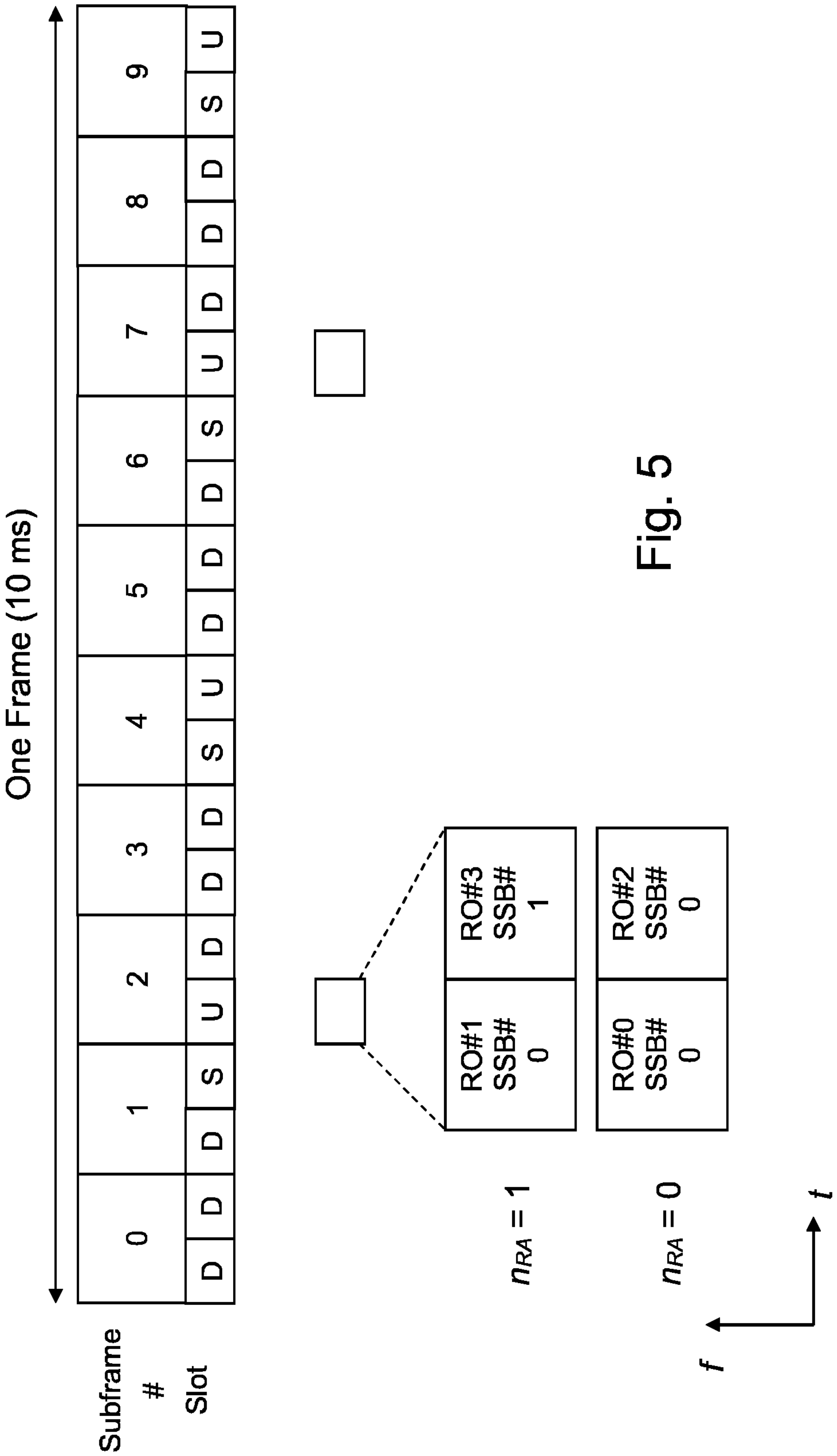
One Frame (10 ms)
Subframe #
Slot
0
1
2
3
4
5
6
7
8
9
D D D S U D D D D S U D D D D S U D D D S U
RO#1 SSB# 0
RO#3 SSB# 1
RO#0 SSB# 0
RO#2 SSB# 0
$n_{RA}$ = 1
$n_{RA}$ = 0
f
t

Fig. 5

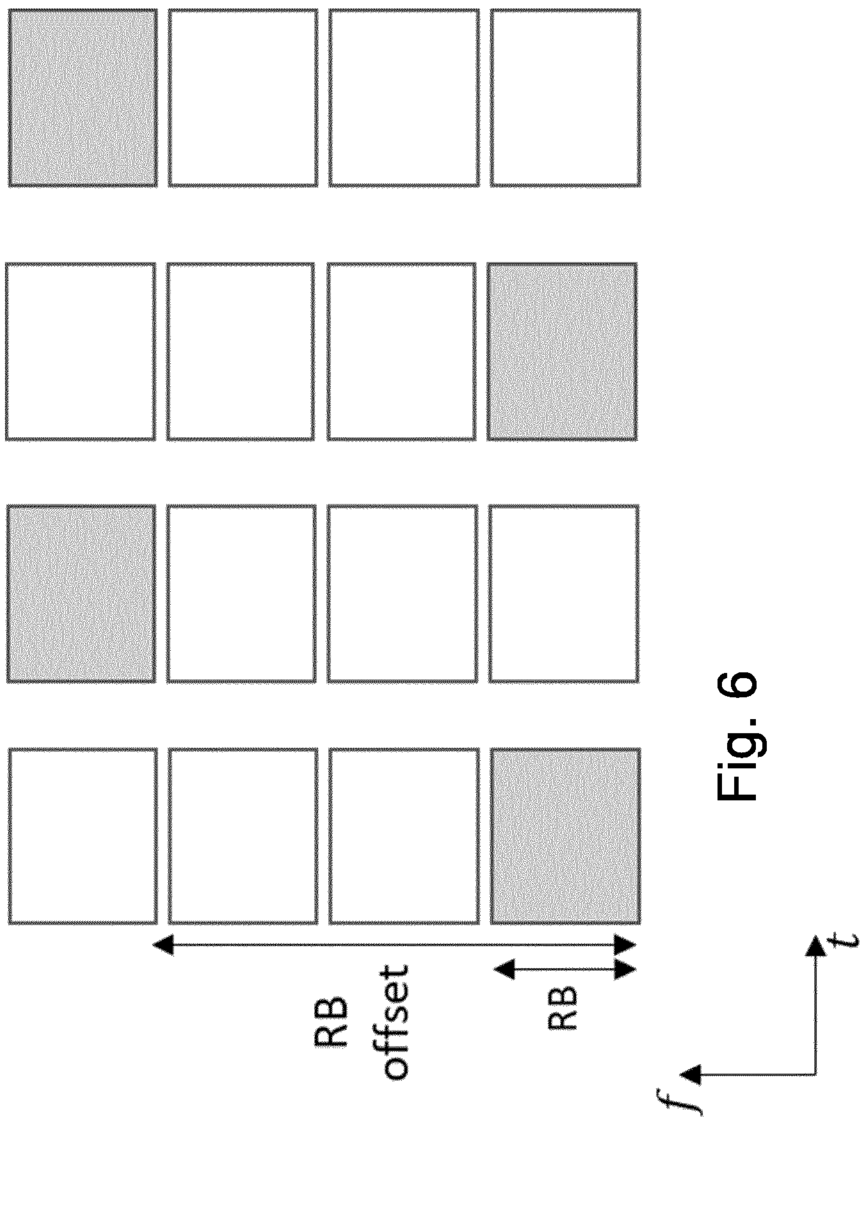


Fig. 6

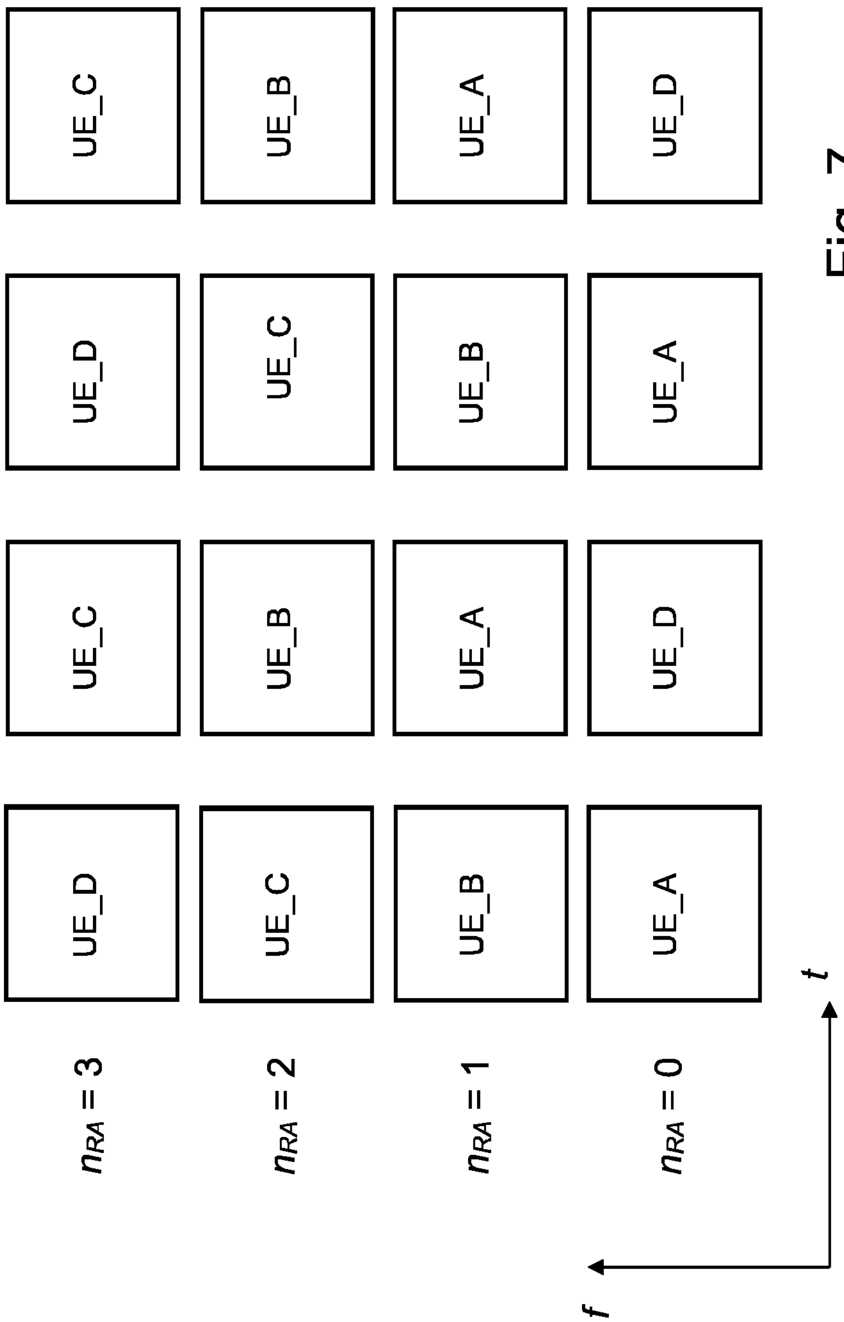
f
t
nRA = 0
nRA = 1
nRA = 2
nRA = 3
UE_A
UE_B
UE_C
UE_D
UE_D
UE_A
UE_B
UE_C
UE_A
UE_B
UE_C
UE_D
UE_D
UE_A
UE_B
UE_C

Fig. 7

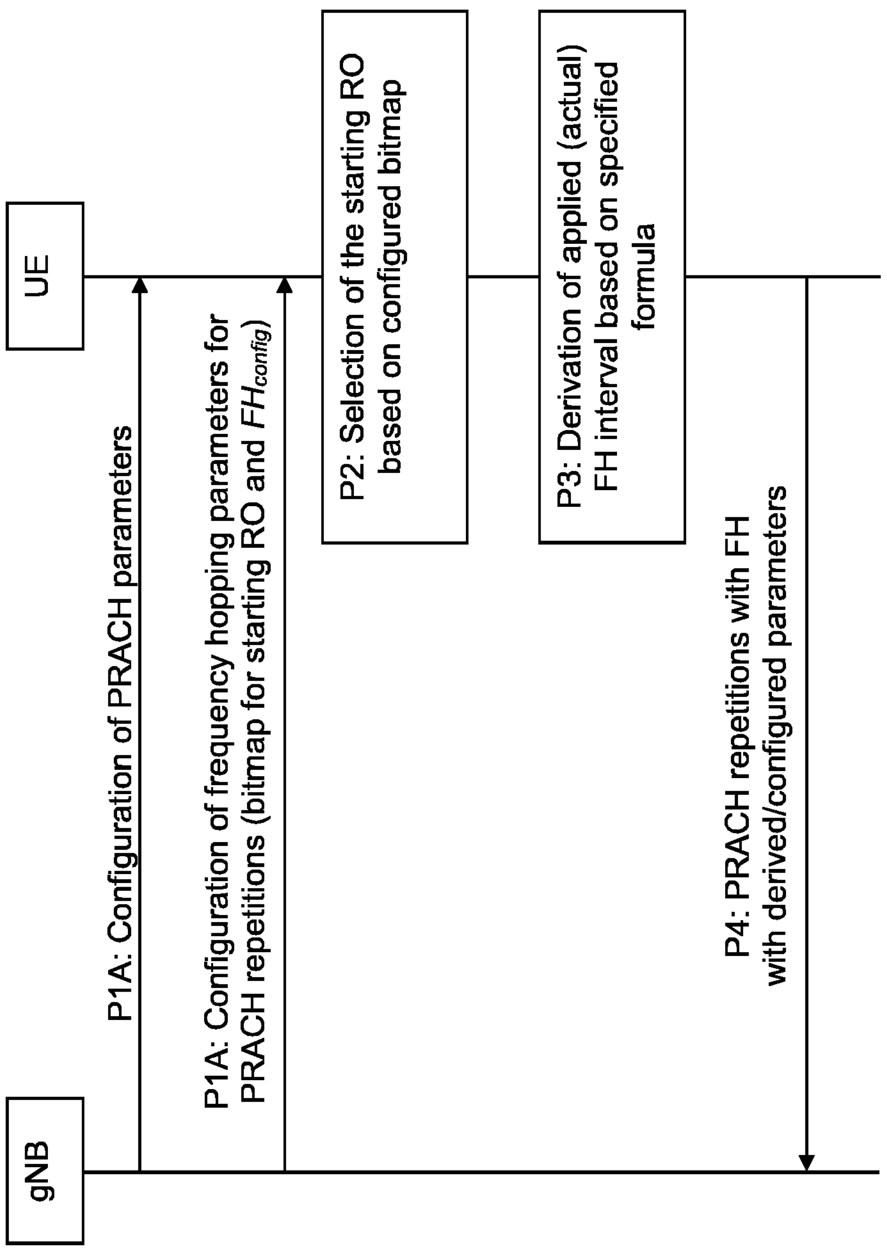
gNB
UE
P1A: Configuration of PRACH parameters
P1A: Configuration of frequency hopping parameters for PRACH repetitions (bitmap for starting RO and $FH_{config}$)
P2: Selection of the starting RO based on configured bitmap
P3: Derivation of applied (actual) FH interval based on specified formula
P4: PRACH repetitions with FH with derived/configured parameters

Fig. 8

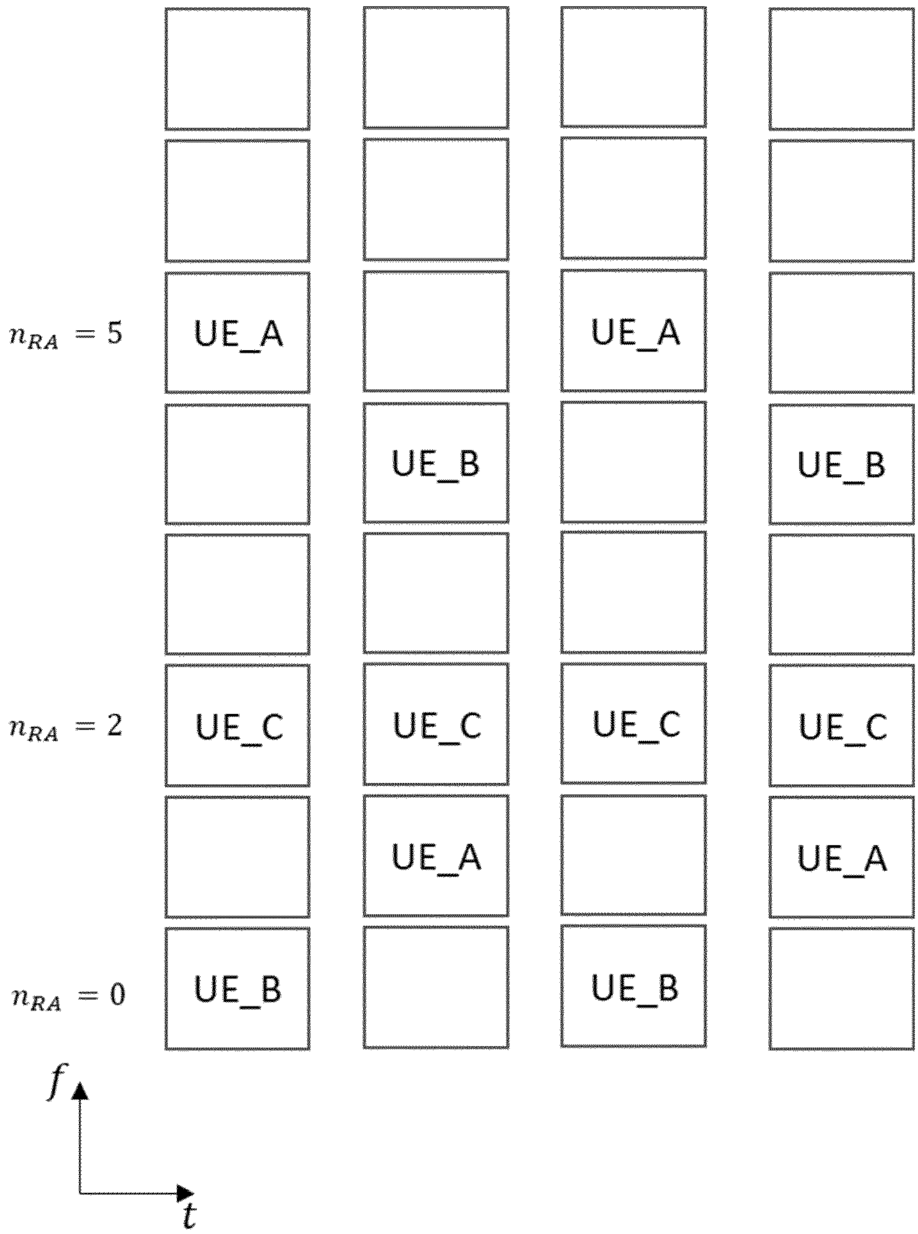
$n_{RA} = 5$
UE_A
UE_A
UE_B
UE_B
$n_{RA} = 2$
UE_C
UE_C
UE_C
UE_C
UE_A
UE_A
$n_{RA} = 0$
UE_B
UE_B
f
t

Fig. 9

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/052611

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. H04B1/7143 H04L5/00 H04W74/0833
ADD.

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)
H04B H04W 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)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br><br><br>A | WO 2021/004172 A1 (ERICSSON TELEFON AB L M [SE]; LIN ZHIPENG [CN]) 14 January 2021 (2021-01-14) paragraphs [0059] - [0079], [0080], [0088]; figures 4,5<br>----- | 1,2,4-7, 11-20<br><br>3,8-10 |
| A | WO 2021/231816 A1 (CONVIDA WIRELESS LLC [US]) 18 November 2021 (2021-11-18) paragraph [0243] - paragraph [0246]; figures 19-20<br>----- | 1-20 |

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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)
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"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
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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 28 April 2024 | 14/05/2024 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Giglietto, Massimo |

1

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

International application No
PCT/EP2024/052611

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| WO 2021004172 A1 | 14-01-2021 | AR 119315 A1 | 09-12-2021 |
| | | CN 113545153 A | 22-10-2021 |
| | | EP 3997938 A1 | 18-05-2022 |
| | | JP 7220797 B2 | 10-02-2023 |
| | | JP 2022539637 A | 13-09-2022 |
| | | US 2023015550 A1 | 19-01-2023 |
| | | WO 2021004172 A1 | 14-01-2021 |
| WO 2021231816 A1 | 18-11-2021 | CN 115553043 A | 30-12-2022 |
| | | EP 4151038 A1 | 22-03-2023 |
| | | US 2023188261 A1 | 15-06-2023 |
| | | WO 2021231816 A1 | 18-11-2021 |