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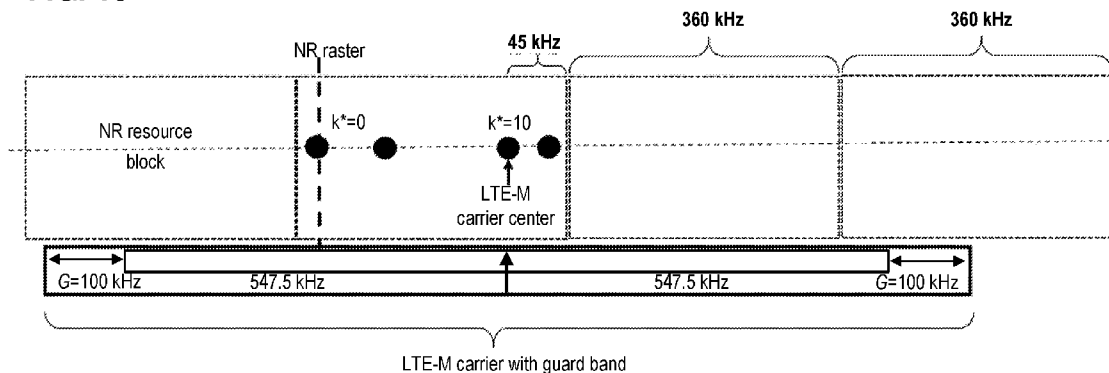
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FIG. 10



(57) Abstract: A network device transmits or receives using an LTE-M carrier with guard bands within the bandwidth of an NR carrier, wherein the subcarriers in the LTE-M carrier maximally align with subcarriers in NR. The center of the LTE-M carrier is located within the NR bandwidth such that: 1) a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and/or 2) given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any part of the LTE-M carrier and the guard bands is maximized.



LTE-M CARRIER PLACEMENT WITH GUARD BAND IN NR BAND

RELATED APPLICATIONS

5 [0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/800,983, filed February 4, 2019, the disclosure of which is hereby incorporated herein by reference in its entirety.

10 TECHNICAL FIELD

[0002] The present disclosure generally relates to the field of wireless network communications, and more particularly, to deploying LTE-M in coexistence with New Radio (NR).

BACKGROUND

15 [0003] Machine-type communications (MTC) are widely used in many applications such as vehicle tracking, user and home security, banking, remote monitoring and smart grids. According to some reports, by 2023 there will be 3.5 billion wide-area devices connected to cellular networks. In this regard, Long Term Evolution - Machine Type Communication (LTE-M, LTE-MTC or eMTC) networks are being rolled out at a fast pace, and it is foreseen that in
20 the next few years, a massive number of devices will be connected to the networks, addressing a wide spectrum of LTE-M use cases. Thanks to a design that enables 10-year battery lifetime of LTE-M devices, many of these devices will remain in service years after deployment. During the lifetime of these deployed LTE-M devices, many networks will undergo LTE to 5G New Radio (NR) migration. A smooth migration without causing service interruption to the
25 deployed Internet-of-Things (IoT) devices is extremely important to mobile network operators (MNO). Furthermore, a migration solution that ensures superior radio resource utilization efficiency and superior coexistence performance between LTE-M and NR is highly desirable.

SUMMARY

[0004] Embodiments of the present invention provide for better coexistence of an LTE-M carrier inside an NR carrier. In general, if the LTE-M carrier can be placed in arbitrary
30 places, this would satisfy its channel raster requirement. But this type of flexibility would require a guard band to be reserved within an NR carrier, around the LTE-M carrier, to prevent

interference between the two systems. As a result, a significant number of NR resource blocks (RBs) might need to be reserved to accommodate the LTE-M carrier.

[0005] According to some embodiments, certain methodologies are used to determine the position where an LTE-M carrier will be placed within an NR carrier, to minimize interference between NR and LTE-M. To this end, the locations of LTE-M carrier center are identified that lead to subcarrier grid alignment between NR and LTE-M – ideally, a maximum amount of grid alignment. In addition, the possible locations of the LTE-M carrier center are identified such that a minimum number of NR resource blocks is used for accommodating the LTE-M carrier in the NR carrier. Further, the possible locations of the LTE-M carrier center are identified for which the maximum guard band can be used for LTE-M within a given number of NR RBs. Guard bands are dedicated spaces to prevent interference and are immediately adjacent to each end of the LTE-M carrier. In this case, the LTE-M guard bands fit entirely within the NR bandwidth. The maximum guard band may be the guard band amount at an LTE-M carrier center position (or positions) that is greater than the guard band amount that is available at other possible LTE-M carrier center grid-aligned positions. Transmission and reception are then carried out by network devices, while centering the LTE-M carrier in the NR bandwidth according to one of the identified possible locations for the LTE-M carrier center.

[0006] The embodiments described herein, using identified possible LTE-M carrier center locations, can be used to effectively deploy LTE-M in coexistence with NR in the case of, for example, 30 kHz NR subcarrier spacing. The approach addresses the problems of subcarrier grids alignment, interference (between NR and LTE-M) reduction, and resource utilization, which are the key issues in the coexistence of NR and LTE-M. When deploying LTE-M inside an NR carrier, this solution determines the best locations of LTE-M carrier center that leads to: 1) the maximum subcarrier grid alignment between NR and LTE-M thus minimizing the interference between these two systems, 2) the minimum reserved resources of NR RBs thus enhancing resource efficiency, and 3) the maximum potential guard band that can be considered for LTE-M within a given number of NR RBs. This, in turn, facilitates the coexistence of LTE-M with NR that in case of 30 kHz NR subcarrier spacing.

[0007] According to some embodiments, a method for communicating in a wireless communication network includes transmitting or receiving using an LTE-M carrier within the bandwidth of a NR carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth. The center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and wherein a maximum number

of subcarriers in the LTE-M carrier align with subcarriers in NR. The center of the LTE-M carrier is located within the NR bandwidth such that: 1) a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and/or 2) given a predetermined number
5 of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is maximized.

[0008] According to some embodiments, a network device, such as a wireless device
10 or a radio network node, includes communication circuitry and processing circuitry. The processing circuitry is configured to transmit or receive using an LTE-M carrier within the bandwidth of a NR carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth. The center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and where a maximum number
15 of subcarriers in the LTE-M carrier align with subcarriers in NR. The center of the LTE-M carrier is located within the NR bandwidth such that: 1) a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and/or 2) given a predetermined number
20 of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is maximized.

[0009] The techniques may also apply to LTE carriers more generally. According to
25 some embodiments, a network device, such as a wireless device or a radio network node, includes communication circuitry and processing circuitry. The processing circuitry is configured to transmit or receive using an LTE carrier within the bandwidth of a NR carrier with guard bands that are immediately adjacent to each end of the LTE carrier and that fit entirely within the NR bandwidth. The center of the LTE carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and where a maximum number of subcarriers in the
30 LTE carrier align with subcarriers in NR. The center of the LTE carrier is located within the NR bandwidth such that: 1) a minimum number of NR resource blocks are occupied by any part of the LTE carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and/or 2) given a predetermined number of NR resource blocks that can be occupied by any part of the LTE carrier and the guard bands at each end, a minimum

guard band bandwidth from each end of the LTE carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE carrier and the guard bands is maximized.

[0010] Further aspects of the present invention are directed to an apparatus, network
5 node, base station, wireless device, user equipment (UE), network devices, MTC devices, computer program products or computer readable storage medium corresponding to the methods summarized above and functional implementations of the above-summarized apparatus and UE.

[0011] Of course, the present invention is not limited to the above features and
10 advantages. Those of ordinary skill in the art will recognize additional features and advantages upon reading the following detailed description, and upon viewing the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

- [0012] FIG. 1 illustrates a frame structure in NR for 30 kHz subcarrier spacing.
- 15 [0013] FIG. 2 illustrates an example of NR raster location for 10 MHz channel bandwidth with 24 resource blocks (RBs) and 30 kHz subcarrier spacing, according to some embodiments.
- [0014] FIG. 3 illustrates subcarrier grids for NR and LTE-M, according to some embodiments.
- 20 [0015] FIG. 4 illustrates subcarrier alignment in NR and LTE-M coexistence, according to some embodiments.
- [0016] FIG. 5 illustrates a maximum subcarrier grid alignment between NR and LTE-M, according to some embodiments.
- [0017] FIG. 6 illustrates maximum and minimum frequencies that need to be reserved
25 for embedding LTE-M with guard band, according to some embodiments.
- [0018] FIG. 7 illustrates the placing of LTE-M with guard band inside NR, according to some embodiments.
- [0019] FIG. 8 illustrates resource block edges for an even number of NR resource blocks, according to some embodiments.
- 30 [0020] FIG. 9 illustrates resource block edges for an odd number of NR resource blocks, according to some embodiments.
- [0021] FIG. 10 illustrates an LTE-M carrier with guard bands that overlaps four NR resource blocks, according to some embodiments.

- [0022] FIG. 11 illustrates an LTE-M carrier with guard bands that overlaps five NR resource blocks, according to some embodiments.
- [0023] FIG. 12 illustrates an LTE-M carrier inside q NR resource blocks, according to some embodiments.
- 5 [0024] FIG. 13 illustrates a flow diagram of a method that may be used by network devices, according to some embodiments.
- [0025] FIG. 14 illustrates a block diagram of a network device that is a network node, according to some embodiments.
- [0026] FIG. 15 illustrates is a block diagram of a network device that is a wireless
10 device, according to some embodiments.
- [0027] FIG. 16 schematically illustrates a telecommunication network connected via an intermediate network to a host computer, according to some embodiments.
- [0028] FIG. 17 is a generalized block diagram of a host computer communicating via a base station with a user equipment over a partially wireless connection, according to some
15 embodiments.
- [0029] FIGS. 18, 19, 20, and 21 are flowcharts illustrating example methods implemented in a communication system including a host computer, a base station and a user equipment.
- [0030] FIG. 22 is a block diagram illustrating a functional implementation of a
20 network node, according to some embodiments.
- [0031] FIG. 23 is a block diagram illustrating a functional implementation of a wireless device, according to some embodiments.

DETAILED DESCRIPTION

[0032] Exemplary embodiments of the present disclosure will now be described more
25 fully hereinafter with reference to the accompanying drawings, in which examples of embodiments of inventive concepts are shown. Inventive concepts may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of present inventive concepts to those skilled in the
30 art. It should also be noted that these embodiments are not mutually exclusive. Components from one embodiment can be tacitly assumed to be present/used in another embodiment. Any two or more embodiments described in this document may be combined with each other. The embodiments are described with respect to LTE-M and NR but can be adapted in other radio

access technologies (RATs) where the techniques or selections may be relevant. While the embodiments described herein involve LTE-M, these techniques and selected positions may also apply to LTE carriers more generally.

5 [0033] Embodiments described herein provide a method of network devices operating according to optimal positions of an LTE-M carrier within an 5G NR carrier (with, e.g., 30kHz subcarrier spacing) for which the interference between the two systems is minimized, while using the minimum number of NR RBs. In particular, the optimal positions of the LTE-M carrier center are identified for two key scenarios: 1) efficient placement of LTE-M inside NR given the required guard band for LTE-M (maximizing resource utilization); and 2) efficient
10 placement of LTE-M inside NR given the number of NR RBs that can be reserved (interference mitigation by maximizing guard band).

[0034] Compared to LTE numerology where only one type of subcarrier spacing (15 kHz) is considered, NR supports different types of subcarrier spacing. Consequently, slot (or mini-slot in NR) length can be different between NR and LTE-M, depending on numerology.
15 In various embodiments, the optimal coexistence of NR and LTE-M for 30 kHz NR subcarrier spacing is considered. For the case of 30 kHz NR subcarrier spacing, orthogonal OFDM symbol duration and subframe duration are shown in FIG. 1. In NR, frame, subframe, and slot are, respectively, 10 ms units, 1 ms units, and 14 OFDM symbols. Slot duration and number of slots in each subframe depends on the subcarrier spacing.

20 [0035] In LTE-M, the subcarrier spacing is 15 kHz. Therefore, full orthogonality between NR and LTE-M cannot be easily maintained in the case of 30 kHz NR subcarrier spacing. Nonetheless, it is possible to significantly reduce interference by maximizing the number of aligned subcarriers between NR and LTE-M. One LTE-M resource block includes 12 subcarriers, which is equivalent to a 180 kHz bandwidth. One NR resource block with 12
25 subcarriers and 30 kHz subcarrier spacing occupies a 360 kHz bandwidth. In this case, placing an LTE-M RB within an NR RB can enhance the resource efficiency, thus reducing overhead in the LTE-M and NR coexistence. The NR subcarrier spacing of 30 kHz (or higher) and the embodiments described herein may be beneficial to Ultra-Reliable Low-Latency Communication (URLLC) applications.

30 [0036] Table 1, shown below, lists frequency bands used by both NR and LTE-M and shows, for each band, the possible channel bandwidths for 30 kHz NR subcarrier spacing.

Band	Downlink (DL)	Channel bandwidth for 30 kHz spacing [MHz]	Raster step [kHz]
1	2110 - 2170 MHz	10, 15, 20	100
2	1930 - 1990 MHz	10, 15, 20	100
3	1805 - 1880 MHz	10, 15, 20, 25, 30	100
5	869 - 894 MHz	10, 15, 20	100
7	2620 - 2690 MHz	10, 15, 20	100
8	925 - 960 MHz	10, 15, 20	100
12	729 - 746 MHz	10, 15	100
20	791 - 821 MHz	10, 15, 20	100
25	1930 - 1995 MHz	10, 15, 20	100
28	758 - 803 MHz	10, 15, 20	100
40	2300 - 2400 MHz	10, 15, 20, 25, 30, 40, 50, 60, 80, 100	100
66	2110 - 2200 MHz	10, 15, 20	100
71	617 - 652 MHz	10, 15, 20	100

Table 1

[0037] Table 1 shows that the possible supported NR channel bandwidths for NR and LTE-M coexistence may be: 10, 15, 20, 25, 30, 40, 50, 60, 80, and 100 MHz. Table 1 also lists the channel rasters that represent steps and frequencies that can be used by a UE to determine the radio frequency (RF) channel positions in the uplink and downlink. The channel raster of NR depends on the frequency band. An LTE-M UE searches for LTE-M carriers on a 100 kHz raster grid and, thus, a feasible center frequency for UE can be expressed as 100m, with m being an integer number. As we can see from Table 1, the channel raster step for the considered common bands for NR and LTE-M is 100 kHz.

10 [0038] There are several considerations to take into account. The raster defines a subset of RF reference frequencies that can be used to identify the RF channel position in the uplink and downlink. The RF reference frequency for an RF channel maps to a resource element on the carrier. Hereinafter, the channel raster is referred to as a point on the raster grid that defines the RF reference frequency. One NR RB in the frequency domain consists of 12 subcarriers. Note that an NR resource block is a one-dimensional measure spanning the frequency domain only, while an LTE PRB uses two-dimensional resource blocks of 12 subcarriers in the frequency domain and one slot in the time domain. The number of RBs is denoted by N_{RB} . The indexes of the middle RB for even and odd numbers of RBs are, respectively, $N_{RB}/2$ and $(N_{RB} - 1)/2$.

20 [0039] For NR carriers with an even number of RBs (N_{RB}), the NR channel raster is located at subcarrier index #0 in an RB with index $N_{RB}/2$. For NR carriers with an odd number

of RBs, the NR channel raster is located at subcarrier index #6 in an RB with index $(N_{RB} - 1)/2$. As an example, the pictorial representation of NR raster location for 10 MHz channel bandwidth with 24 RBs and 30 kHz subcarrier spacing is illustrated in FIG. 2.

[0040] Considering the fact that, in NR, the number of subcarriers is an even number,
5 the carrier center is located between the two middle NR subcarriers. In this case, the NR carrier center frequency is related to the channel raster by:

$$F_C = F_{raster} - 15 \text{ kHz} \quad (1)$$

where F_C is the NR carrier center frequency and F_{raster} is the frequency where the NR channel raster is located. Clearly, $F_C = -15 \text{ kHz}$ relative to the NR channel raster.

10 [0041] In LTE-M, there is a subcarrier in the center of the downlink system bandwidth called the DC subcarrier, which is an example of an even number of physical resource blocks (PRBs) within the LTE carrier. In this case, the LTE-M carrier center is placed on the DC subcarrier.

[0042] Now, one step is to find a condition under which the maximum alignment
15 between NR and LTE-M downlink subcarrier grids is achieved. In one scenario, according to an embodiment, due to the different subcarrier spacing (i.e., 15 kHz LTE-M vs. 30 kHz NR) in NR and LTE-M systems, it is not possible to have a full subcarrier grid alignment between NR and LTE-M. Nevertheless, the optimal locations of an LTE-M carrier can be found such that the maximum subcarrier grid alignment is achieved in NR and LTE-M coexistence. As shown
20 in FIG. 3, the maximum alignment between NR and LTE-M subcarrier grids is achieved when every two LTE-M subcarrier aligns with an NR subcarrier. That is, maximum alignment can occur when half of the LTE-M subcarriers align with the NR subcarriers.

Subcarrier orthogonality between NR and LTE-M

[0043] Let F_1 and T_1 be subcarrier spacing and symbol duration (excluding the cyclic
25 prefix) of NR. Also, F_2 and T_2 are subcarrier spacing and symbol duration (excluding the cyclic prefix) of LTE-M. The relationships are expressed as:

$$\begin{aligned} F_1 &= \frac{1}{T_1} = 30 \text{ kHz} \\ F_2 &= \frac{1}{T_2} = 15 \text{ kHz} \\ F_1 &= 2F_2 \\ T_1 &= T_2/2 \end{aligned}$$

30

Now, the orthogonality between NR and LTE-M subcarriers will be explored. Let a_n be an LTE-M modulated symbol on subcarrier n . The interference from subcarrier n of LTE-M on subcarrier m of NR is:

$$I_{2,1} = \frac{1}{T_1} \int_0^{T_1} (e^{j2\pi m F_1 t})^* (a_n e^{j2\pi n F_2 t}) dt$$

$$I_{2,1} = \frac{a_n}{T_1} \int_0^{T_1} (e^{j2\pi(m-\frac{n}{2})t/T_1}) dt$$

To ensure orthogonality and avoid intercarrier interference:

$$m - \frac{n}{2} = \text{integer.}$$

10

Clearly, the above condition can be satisfied when n is even. Therefore, the potential interference from LTE-M on NR is not completely eliminated when both use the same resources.

[0044] Let b_m be an NR modulated symbol on subcarrier m . The interference from subcarrier m of NR on subcarrier n of LTE-M is:

$$I_{1,2} = \frac{1}{T_2} \int_0^{T_2} (e^{j2\pi n F_2 t})^* (b_m e^{j2\pi m F_1 t}) dt$$

$$I_{1,2} = \frac{b_m}{T_2} \int_0^{T_2} (e^{j2\pi(n-2m)t/T_2}) dt$$

20

To ensure orthogonality and avoid intercarrier interference:

$$n - 2m = \text{integer.}$$

The above condition can be always satisfied when n and m are integers. As a result, with the proposed subcarrier alignment scheme, the potential interference from NR on LTE-M is eliminated. Moreover, the proposed approach scientifically mitigates interference from LTE-M on NR by maximizing the number of aligned subcarriers between these two systems.

25

LTE-M carrier placement considering subcarrier grid alignment

[0045] In LTE-M, there is a subcarrier in the center of the downlink system bandwidth called the DC subcarrier, as shown in FIG. 4. In this case, the LTE-M carrier center is placed on the DC subcarrier.

30

[0046] Let k be an integer that represents the NR subcarrier index relative to the NR channel raster (i.e., NR carrier). The NR subcarriers are located at frequencies $100m + 30k$ kHz (m is an integer). As shown in FIG. 5, an LTE-M carrier center (i.e., DC subcarrier) can be placed on two locations relative to an NR subcarrier with index k : 1) on subcarrier k of NR, and 2) 15 kHz higher than subcarrier k of NR. Therefore, an LTE-M carrier center can be placed on the following frequencies, relative to the NR raster: Case 1: $100m+30k$, (kHz); Case 2: $100m+30k+15$ (kHz). In addition, the location of the LTE-M carrier center must satisfy the raster offset requirement.

[0047] Considering the raster requirement, an LTE-M carrier center (which is on the DC subcarrier) can be placed at $100n$ (kHz), where n is an integer. Hence, the feasible locations of an LTE-M carrier center, with respect to NR subcarrier k , should satisfy one of the following equations:

Case 1:

$$100n = 100m + 30k \quad (2)$$

Case 2:

$$100n = 100m + 30k + 15. \quad (3)$$

[0048] However, Case 2 is not feasible since the left side of equation (3) is even while the right side of the equation is odd. Therefore, only Case 1 is feasible for deploying LTE-M inside an NR carrier. In this case, the LTE-M carrier center is placed on an NR subcarrier.

[0049] Now, suppose k^* is a solution to equation (2). Subsequently, the location of an LTE-M carrier center can be identified based on the location of the NR subcarrier with index k^* . Note that k can be index of any NR subcarrier while k^* is the index of a desired subcarrier, which is considered for alignment. In this case, k^* is in a set of all integer numbers generated by:

$$\frac{10r}{3}, \quad (4)$$

where r is an integer. For instance, for $r = 3$, using $\frac{10r}{3}$, the LTE-M carrier center can be placed on an NR subcarrier with index $k^* = 10$ (relative to the channel raster). It can be shown that the LTE-M carrier center can be placed on NR subcarriers with indexes $\{ \dots, -20, -10, 0, 10, 20, \dots \}$, or equivalently $k^* = \pm 10n$, where n is integer (considering 30 kHz subcarrier spacing). The LTE-M carrier center can be placed on the following frequencies (relative to the NR channel raster):

$$F_{LTEM} = 30k^*[\text{kHz}] \quad (5)$$

Table 2 shows possible NR subcarrier indices for the LTE-M carrier center, relative to the NR raster for 30 kHz subcarrier spacing. The possible locations of LTE-M carrier center are for which maximum subcarrier grid alignment may be achieved between NR and LTE-M.

NR channel bandwidth and the number of RBs (N_{RB}) for 30 kHz subcarrier spacing	Possible indices of NR subcarriers k^* (relative to NR raster). LTE-M center is placed on ($30k^*$ kHz) relative to the NR channel raster
10 MHz, $N_{RB}= 24$	-140, -130, ..., -10, 0, 10, ..., 130, 140
15 MHz, $N_{RB}= 38$	-220, -210, ..., -10, 0, 10, ..., 210, 220
20 MHz, $N_{RB}= 51$	-300, -290, ..., -10, 0, 10, ..., 290, 300
25 MHz, $N_{RB}= 65$	-390, -380, ..., -10, 0, 10, ..., 370, 380
30 MHz, $N_{RB}= 78$	-460, -450, ..., -10, 0, 10, ..., 450, 460
40 MHz, $N_{RB}= 106$	-630, -620, ..., -10, 0, 10, ..., 620, 630
50 MHz, $N_{RB}= 133$	-790, -780, ..., -10, 0, 10, ..., 780, 790
60 MHz, $N_{RB}= 162$	-970, -960, ..., -10, 0, 10, ..., 960, 970
80 MHz, $N_{RB}= 217$	-1300, -1290, ..., -10, 0, 10, ..., 1290, 1300
100 MHz, $N_{RB}= 273$	-1630, -1620, ..., -10, 0, 10, ..., 1620, 1630

Table 2

5 [0050] The proposed approach ensures the maximum subcarrier grids alignment for NR and LTE-M. While this approach significantly mitigates potential interference between NR and LTE-M, some level of interference from LTE-M on NR may be observed when both use the same resources.

10 [0051] In order to further reduce any potential interference between LTE-M and NR systems, a guard band can be considered around the LTE-M carrier. Parameter G may be used to indicate the amount guard band used in each side of the LTE-M carrier when it is placed inside the NR carrier. FIG. 6 illustrates an LTE-M carrier with guard band.

15 [0052] In this case, the maximum and minimum possible values of k^* depend on the LTE-M and NR channel bandwidths as well as the guard band G used for LTE-M. According to FIG. 6, the maximum and minimum frequencies that need to be reserved for embedding LTE-M with guard band are, respectively,

$$(F_{LTE-M} + B_L/2 + G), \text{ and } (F_{LTE-M} - B_L/2 - G).$$

To ensure that the LTE-M carrier with guard band is entirely placed in the NR carrier, the following conditions must be met:

$$\begin{aligned} 5 \quad & (F_{LTE-M} + B_L/2 + G) \leq F_C + B_{nr}/2 \\ & (F_{LTE-M} - B_L/2 - G) \geq F_C - B_{nr}/2 \end{aligned}$$

where B_{nr} is the NR channel bandwidth and B_L is the operational bandwidth for LTE-M (e.g.,
10 1095 kHz). Considering equation (1), the feasible range of k^* for deploying an LTE-M carrier inside the NR is:

$$\frac{B_L/2 + G - B_{nr}/2 - 15}{30} \leq k^* \leq \frac{B_{nr}/2 - B_L/2 - G - 15}{30} \quad (6)$$

15 In this example equation, the NR subcarrier spacing N_s is 30 kHz.

LTE-M placement inside NR given the required guard band

[0053] Possible locations of an LTE-M carrier center for which the maximum subcarrier grid alignment is achieved between NR and LTE-M was provided in Table 2. The location of the LTE-M carrier impacts the number of NR resource blocks that overlap with
20 LTE-M resource blocks. In this scenario, it can be assumed that the amount of required guard band G between the LTE-M carrier and NR is given. FIG. 7 illustrates the placing of LTE-M with guard band inside NR.

[0054] One goal is to identify possible locations of the LTE-M carrier center inside an NR carrier so as to occupy the minimum number of NR resource blocks. Among the LTE-M
25 carrier center locations that ensure the maximum subcarrier grid alignment, those locations that lead to the minimum NR resource reservation are identified.

[0055] First, according to some embodiments, the edge frequencies of NR RBs (i.e., the minimum and maximum frequencies of each RB) are found relative to the NR channel raster. FIGS. 8 and 9 illustrate RB edges for even and odd numbers of NR resource blocks,
30 respectively. For an even number of NR RBs, the minimum and maximum frequencies of the first RB, relative to the NR raster is:

$$F_{min} = -15 \text{ kHz}$$

$$F_{max} = F_{min} + 360 = 345 \text{ kHz}$$

In this example, the NR RB bandwidth is 360 kHz, or 12 subcarriers at a spacing of 30 kHz. Therefore, relative to the NR raster, the edge frequencies of RBs can be given by:

$$\text{RB_edge_freq_even} = -15 + 360L \text{ [kHz]} \quad (7)$$

where L is an integer in set $\{-N_{RB}/2+1, \dots, N_{RB}/2+1\}$, with N_{RB} being the total number of NR RBs.

[0056] For an odd number of NR RBs, the minimum and maximum frequencies of the first RB, relative to the NR raster is:

$$F_{min} = -195 \text{ kHz}$$

$$F_{max} = F_{min} + 360 = 165 \text{ kHz}$$

10 Therefore, relative to the NR raster, the edge frequencies of RBs can be given by:

$$\text{RB_edge_freq_odd} = -195 + 360L \text{ [kHz]} \quad (8)$$

where L is an integer in set $\{-(N_{RB}-1)/2, \dots, (N_{RB}-1)/2+1\}$, with N_{RB} being the total number of NR RBs.

[0057] The minimum number of NR RBs that need to be used for deploying an LTE-M carrier is calculated by:

$$N = \left\lceil \frac{\text{total bandwidth occupied by LTE-M}}{\text{NR RB bandwidth}} \right\rceil = \left\lceil \frac{B_L + 2G, \text{ (kHz)}}{360, \text{ (kHz)}} \right\rceil \quad (9)$$

[0058] where $\lceil \cdot \rceil$ is the ceiling function. In this case, N NR RBs must be used for LTE-M deployment. Note that in a non-optimal case, $(N + 1)$ NR RBs must be used. Next, the locations of the LTE-M carrier center are identified such that the minimum number of NR RBs (i.e., N) are occupied. The LTE-M carrier center frequency (relative to NR raster) may be:

$$F_{LTEM} = 30k^* \text{ [kHz]} \quad (10)$$

25 Subsequently, to ensure that the LTE-M resource block overlaps with only N NR RBs, the following applies. For an even number of NR RBs:

$$(-15 + 360L) + (B_L/2 + G) \leq F_{LTEM} \leq (-15 + 360(L + N)) - (B_L/2 + G)$$

30 where $(-N_{RB}/2 + 1) \leq L \leq N_{RB}/2$ is an integer. This leads to:

$$\frac{360L + B_L/2 + G - 15}{30} \leq k^* \leq \frac{360(L + N) - B_L/2 - G - 15}{30} \quad (11)$$

For an LTE-M carrier with 6 RBs and one DC subcarrier (in total 73 subcarriers), $B_L = 1095$ [kHz]. For an odd number of NR RBs:

$$(-195 + 360L) + (B_L/2 + G) \leq F_{LTE-M} \leq (-195 + 360(L + N)) - (B_L/2 + G) \quad (11)$$

where $-(N_{RB} - 1)/2 \leq L \leq (N_{RB} - 1)/2$ is an integer. This leads to:

$$\frac{360L + B_L/2 + G - 195}{30} \leq k^* \leq \frac{360(L + N) - B_L/2 - G - 195}{30} \quad (12)$$

[0059] For example, for $G = 100$ kHz and a 10 MHz NR channel bandwidth (with 24 resource blocks), N and the range of k^* for placing the LTE-M carrier center are computed. Using (9), for an even number of NR resource blocks:

$$N = \left\lceil \frac{1295, (kHz)}{360, (kHz)} \right\rceil = 4$$

$$\frac{360L + 1095/2 + 100 - 15}{30} \leq k^* \leq \frac{360(L + 4) - 1095/2 - 100 - 15}{30} \quad (13)$$

$$12L + 22 \leq k^* \leq 12L + 25 \quad (14)$$

[0060] Considering Table 2, for instance $k^* = 10$ ($10 = 12 \times (-1) + 22$) satisfies the condition in (14). Therefore, placing the LTE-M carrier center on $F_{LTE-M} = 30 \times 10 = 300$ kHz relative to the NR raster, ensures maximum subcarrier grid alignment while overlapping with the minimum number of NR RBs. In this case, four NR RBs are used.

[0061] While for $k^* = 20$ (according to Table 2) and the maximum subcarrier grid alignment between NR and LTE-M, five NR RBs must be used for deploying the LTE-M carrier. FIGS. 10 and 11 illustrate this example for $k^* = 10$ and $k^* = 20$. FIG. 10 illustrates an LTE-M carrier with guard band overlaps with four NR resource blocks ($k^* = 10$). FIG. 11 illustrates an LTE-M carrier with guard band overlaps with five NR resource blocks ($k^* = 20$).

[0062] In summary, the following steps may be used to find optimal locations of an LTE-M carrier center for which the minimum number of NR RBs are used for deploying LTE-M carrier, according to some embodiments. First, find k^* values that lead to the maximum subcarrier grids alignment between LTE-M and NR. Equations (4) and (6) can be used for this step. Second, compute the minimum number of NR RBs which need to be used for deploying an LTE-M carrier. Equation (9) can be used for this step. Third, for an even number of NR resource blocks, use equation (11) to find the range of k^* . For an odd number of NR resource blocks, use equation (12) to find the range of k^* . Fourth, the optimal values of k^* can be found

using the results of the first and third steps. Fifth, the optimal frequencies of an LTE-M carrier center, relative to the NR raster, are: $F_{LTEM} = 30k^*$ [kHz].

[0063] Note that for any given value of LTE-M guard band (i. e., G), this approach can find the best positions of the LTE-M carrier center for which the minimum number of NR RBs is used for deploying the LTE-M carrier inside NR.

[0064] The NR raster may be located at subcarrier #0 in an RB with index $N_{RB}/2$ for an even number of RBs. The NR raster may be located at subcarrier #6 in an RB with index $(N_{RB}-1)/2$ for an odd number of RBs. The subcarrier #0 corresponds to the lowest subcarrier in frequency in an RB and subcarrier index #11 corresponds to the highest subcarrier in frequency in an RB.

Examples with Known Guard Bands

[0065] In the following examples for two different guard bands ($G = 100$ kHz and 300 kHz), the optimal locations of an LTE-M carrier for various NR channel bandwidths are identified.

[0066] In the first example, $G = 100$ kHz, where there is 100 kHz of guard band on each side of the LTE-M carrier. With the proposed approach (optimal case), the minimum number of NR RBs used for deploying the LTE-M carrier is: $N = 4$. In a non-optimal case, $N + 1 = 5$ NR RBs are used. Therefore, this approach enhances the resource utilization by 20%.

[0067] Table 3 shows possible locations, or offset positions, of the LTE-M carrier center, in number of NR subcarriers, relative to the NR raster when $G = 100$ kHz and NR subcarrier spacing is 30 kHz.

NR channel bandwidth and the number of RBs (N_{RB}) for 30 kHz subcarrier spacing	Possible indexes of NR subcarriers k^* (relative to NR raster). LTE-M center is placed on $(30 k^*, \text{kHz})$ relative to the NR channel raster
10 MHz, $N_{RB} = 24$	-120 -110 -60 -50 0 10 60 70 120 130
15 MHz, $N_{RB} = 38$	-180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190
20 MHz, $N_{RB} = 51$	-290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300
25 MHz, $N_{RB} = 65$	-360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370

30 MHz, $N_{RB}= 78$	-420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430
40 MHz, $N_{RB}= 106$	-600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610
50 MHz, $N_{RB}= 133$	-780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 - 120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790
60 MHz, $N_{RB}= 162$	-950 -900 -890 -840 -830 -780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790 840 850 900 910 960 970
80 MHz, $N_{RB}= 217$	-1260 -1250 -1200 -1190 -1140 -1130 -1080 -1070 -1020 -1010 -960 -950 -900 -890 -840 -830 -780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790 840 850 900 910 960 970 1020 1030 1080 1090 1140 1150 1200 1210 1260 1270
100 MHz, $N_{RB}= 273$	-1620 -1610 -1560 -1550 -1500 -1490 -1440 -1430 -1380 -1370 -1320 -1310 -1260 -1250 -1200 -1190 -1140 -1130 -1080 -1070 -1020 -1010 -960 -950 -900 -890 -840 -830 -780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790 840 850 900 910 960 970 1020 1030 1080 1090 1140 1150 1200 1210 1260 1270 1320 1330 1380 1390 1440 1450 1500 1510 1560 1570 1620 1630

Table 3

[0068] Table 4 is another representation of the possible positions for the center of the LTE-M carrier is positioned relative to the NR channel raster, considering 100 kHz guard band, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	n30 for even integers n from -4 to 4; and

	$-20+n30$ for odd integers n from -3 to 5
15	$n30$ for even integers n from -6 to 6 ; and $-20+n30$ for odd integers n from -5 to 7
20	$n30$ for even integers n from -8 to 10 ; and $-20+n30$ for odd integers n from -9 to 9
25	$n30$ for even integers n from -12 to 12 ; and $-20+n30$ for odd integers n from -11 to 13
30	$n30$ for even integers n from -14 to 14 ; and $-20+n30$ for odd integers n from -13 to 15
40	$n30$ for even integers n from -20 to 20 ; and $-20+n30$ for odd integers n from -19 to 21
50	$n30$ for even integers n from -26 to 26 ; and $-20+n30$ for odd integers n from -25 to 27
60	$n30$ for even integers n from -30 to 31 ; and $-20+n30$ for odd integers n from -31 to 33
80	$n30$ for even integers n from -42 to 42 ; and $-20+n30$ for odd integers n from -41 to 43
100	$n30$ for even integers n from -54 to 54 ; and $-20+n30$ for odd integers n from -53 to 55

Table 4

[0069] Note that in the tables, a non-negative integer n as a position of the LTE-M carrier center, in NR subcarriers relative to the NR raster, may indicate that the position of the LTE-M carrier center is above the NR raster (e.g., $30n$ kHz above the raster). Similarly, a negative integer n in claims 2, 3, 4, 5, 6, 8, 9, 11 as a position of the LTE-M carrier center, in NR subcarriers relative to the NR raster, may indicate that the position of the LTE-M carrier center is below the NR raster (e.g., $|30n|$ kHz below the NR raster).

[0070] In a second scenario, $G = 300$ kHz, where there is 300 kHz of guard band on each side of the LTE-M carrier. With the proposed approach (optimal case), the minimum number of NR RBs used for deploying the LTE-M carrier is: $N = 5$. In a non-optimal case, $N + 1 = 6$ NR RBs are used. Therefore, this approach enhances the resource utilization by 16.7%.

[0071] Table 5 shows possible locations, or offset positions, of the LTE-M carrier center when $G = 300$ kHz.

NR channel bandwidth and the number of RBs (N_{RB}) for 30 kHz subcarrier spacing	Possible indexes of NR subcarriers k^* (relative to NR raster). LTE-M center is placed on ($30 k^*$, kHz) relative to the NR channel raster
10 MHz, $N_{RB} = 24$	-90 -80 -30 -20 30 40 90 100
15 MHz, $N_{RB} = 38$	-200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220
20 MHz, $N_{RB} = 51$	-270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280
25 MHz, $N_{RB} = 65$	-330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340
30 MHz, $N_{RB} = 78$	-440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460
40 MHz, $N_{RB} = 106$	-570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630
50 MHz, $N_{RB} = 133$	-750 -740 -690 -680 -630 -620 -570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630 640 690 700 750 760
60 MHz, $N_{RB} = 162$	-930 -920 -870 -860 -810 -800 -750 -740 -690 -680 -630 -620 -570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630 640 690 700 750 760 810 820 870 880 930 940
80 MHz, $N_{RB} = 217$	-1280 -1230 -1220 -1170 -1160 -1110 -1100 -1050 -1040 -990 -980 -930 -920 -870 -860 -810 -800 -750 -740 -690 -680 -630 -620 -570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630 640 690 700 750 760 810 820 870 880 930 940 990 1000 1050 1060 1110 1120 1170 1180 1230 1240 1290 1300

100 MHz, $N_{RB}=273$	-1590	-1580	-1530	-1520	-1470	-1460	-1410	-1400				
	-1350	-1340	-1290	-1280	-1230	-1220	-1170	-1160				
	-1110	-1100	-1050	-1040	-990	-980	-930	-920	-870			
	-860	-810	-800	-750	-740	-690	-680	-630	-620			
	-570	-560	-510	-500	-450	-440	-390	-380	-330			
	-320	-270	-260	-210	-200	-150	-140	-90	-80	-30		
	-20	30	40	90	100	150	160	210	220	270	280	330
	340	390	400	450	460	510	520	570	580	630	640	690
	700	750	760	810	820	870	880	930	940	990	1000	
	1050	1060	1110	1120	1170	1180	1230	1240	1290			
	1300	1350	1360	1410	1420	1470	1480	1530	1540			
	1590	1600										

Table 5

[0072] Table 6 is another representation of the possible positions for the center of the LTE-M carrier positioned relative to the NR channel raster, considering 300 kHz guard band, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-20+n60 for integers n from -1 to 2; and -30+n60 for integers n from -1 to 2
15	-20+n60 for integers n from -3 to 4; and -30+n60 for integers n from -2 to 4
20	-20+n60 for integers n from -4 to 5; and -30+n60 for integers n from -4 to 5
25	-20+n60 for integers n from -5 to 6; and -30+n60 for integers n from -5 to 6
30	-20+n60 for integers n from -7 to 8; and -30+n60 for integers n from -6 to 8
40	-20+n60 for integers n from -9 to 10; and -30+n60 for integers n from -9 to 11
50	-20+n60 for integers n from -12 to 13; and -30+n60 for integers n from -12 to 13
60	-20+n60 for integers n from -15 to 16; and -30+n60 for integers n from -15 to 16
80	-20+n60 for integers n from -21 to 22; and -30+n60 for integers n from -20 to 22

100	-20+n60 for integers n from -26 to 27; and -30+n60 for integers n from -26 to 27
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Table 6***LTE-M placement inside NR given the number of NR RBs that can be reserved***

[0073] In this scenario, the number of NR RBs that can be used for deploying the LTE-M carrier is given. For instance, let q be a fixed number of NR RBs which are reserved for placing the LTE-M carrier. One goal is to find the optimal locations of the LTE-M carrier center such that the maximum guard band can be considered between NR and LTE-M, within the given number of NR RBs. Clearly, having more guard band between NR and LTE-M can lead to a lower inter-subcarrier interference between the two systems.

[0074] This scenario is illustrated in FIG. 12, which shows placement of an LTE-M carrier inside q reserved NR RBs. $F_{nr,min}$ and $F_{nr,max}$ are the minimum and maximum frequencies of NR resource blocks reserved for deploying LTE-M. G_{right} and G_{left} are the maximum guard bands that can be considered between LTE-M and NR, on the right and left sides of the LTE-M carrier. B_L is the LTE-M carrier bandwidth (e.g., $B_L = 1095$ kHz). The LTE-M carrier is placed between NR RBs with indexes L and $(L + q - 1)$, where L and q are integers. N_{RB} may also be used in place of q to represent the number of NR RBs in the equations below.

[0075] Considering FIG. 12 and using equations (7) and (8) for finding the edge frequencies of the NR RBs, for an even number of NR RBs:

$$F_{nr,min} = -15 + 360L \quad (15)$$

$$F_{nr,max} = -15 + 360(L + q) \quad (16)$$

For an odd number of NR RBs:

$$F_{nr,min} = -195 + 360L \quad (17)$$

$$F_{nr,max} = -195 + 360(L + q) \quad (18)$$

As a result, the maximum guard band at left (lower frequency) and right (higher frequency) of the LTE-M carrier are:

$$G_{right} = F_{nr,max} - (F_{LTEM} + B_L/2) \quad (19)$$

$$G_{left} = (F_{LTEM} - B_L/2) - F_{nr,min} \quad (20)$$

For a symmetric guard band case, the maximum guard band between LTE-M and NR, within q NR RBs is given by:

$$G_{sym} = \min\{G_{right}, G_{left}\} \quad (21)$$

[0076] One goal is to maximize G_{sym} by efficiently placing the LTE-M carrier inside the given number of NR RBs. In other words, among the possible locations of the LTE-M carrier center, those that allow using the maximum guard band for LTE-M, while occupying q NR RBs, are selected. The following steps may be used to find the optimal positions of the LTE-M carrier center inside the given number of NR RBs. First, for every possible location of the LTE-M carrier obtained using equation (10), find parameter L that is used to determine NR RBs' edges:

$$L = \left\lfloor \frac{(F_{LTE-M} - B_L/2) + 15}{360} \right\rfloor$$

where $\lfloor . \rfloor$ is the floor function. Second, given L , q and F_{LTE-M} , compute the guard band using equations (15)-(21). Third, select the locations of the LTE-M carrier center (i.e., F_{LTE-M}) for which we can have the maximum guard band.

[0077] In Tables 7-10, for various NR channel bandwidths, the optimal positions of the LTE-M carrier inside 4 and 5 NR RBs to achieve maximum guard band are identified. Moreover, the maximum guard band (G_{sym}) between NR and LTE-M RBs are given.

NR channel bandwidth and the number of RBs (N_{RB}) for 30 kHz subcarrier spacing	Possible indexes of NR subcarriers k^* (relative to NR raster). LTE-M center is placed on ($30 k^*$, kHz) relative to the NR channel raster	Maximum guard band (G_{sym}) that can be considered between LTE-M and NR while occupying 4 NR RBs (kHz)
10 MHz, $N_{RB}= 24$	-120 -60 0 60 120	157.5
15 MHz, $N_{RB}= 38$	-180 -120 -60 0 60 120 180	157.5
20 MHz, $N_{RB}= 51$	-270 -210 -150 -90 -30 30 90 150 210 270	157.5
25 MHz, $N_{RB}= 65$	-390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330	157.5
30 MHz, $N_{RB}= 78$	-420 -360 -300 -240 -180 -120 -60 0 60 120 180 240 300 360 420	157.5
40 MHz, $N_{RB}= 106$	-600 -540 -480 -420 -360 -300 -240 -180 -120 -60 0 60 120 180 240 300 360 420 480 540 600	157.5
50 MHz, $N_{RB}= 133$	-750 -690 -630 -570 -510 -450 -390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330 390 450 510 570 630 690 750	157.5

60 MHz, N _{RB} = 162	-960 -900 -840 -780 -720 -660 -600 -540 -480 -420 -360 -300 -240 -180 -120 -60 0 60 120 180 240 300 360 420 480 540 600 660 720 780 840 900 960	157.5
80 MHz, N _{RB} = 217	-1290 -1230 -1170 -1110 -1050 -990 -930 -870 -810 -750 -690 -630 -570 -510 -450 -390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330 390 450 510 570 630 690 750 810 870 930 990 1050 1110 1170 1230 1290	157.5
100 MHz, N _{RB} = 273	-1590 -1530 -1470 -1410 -1350 -1290 -1230 -1170 -1110 -1050 -990 -930 -870 -810 -750 -690 -630 -570 -510 -450 -390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330 390 450 510 570 630 690 750 810 870 930 990 1050 1110 1170 1230 1290 1350 1410 1470 1530 1590	157.5

Table 7

In Table 7, the maximum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is 157.5 kHz.

- 5 **[0078]** Table 8 is another representation of the possible positions for the center of the LTE-M carrier relative to the NR raster, considering 4 NR resource blocks and 30 kHz NR subcarrier spacing.

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	n60 where n is integer from -2 to 2
15	n60 where n is integer from -3 to 3
20	-30+n60 where n is integer from -4 to 5
25	-30+n60 where n is integer from -6 to 6
30	n60 where n is integer from -7 to 7
40	n60 where n is integer from -10 to 10
50	-30+n60 where n is integer from -12 to 13
60	n60 where n is integer from -16 to 16
80	-30+n60 where n is integer from -21 to 22

100	-30+n60 where n is integer from -26 to 27
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Table 8

[0079] Table 9 shows possible positions for the center of the LTE-M carrier relative to the NR raster, considering 5 NR resource blocks and 30 kHz NR subcarrier spacing, to achieve maximum guard band between NR and LTE-M.

NR channel bandwidth and the number of RBs (N_{RB}) for 30 kHz subcarrier spacing	Possible indexes of NR subcarriers k^* (relative to NR raster). LTE-M center is placed on ($30 k^*$, kHz) relative to the NR channel raster	Maximum guard band (G_{sym}) that can be considered between LTE-M and NR while occupying 5 NR RBs (kHz)
10 MHz, $N_{RB}= 24$	-140 -80 -20 40 100	307.5
15 MHz, $N_{RB}= 38$	-200 -140 -80 -20 40 100 160 220	307.5
20 MHz, $N_{RB}= 51$	-290 -230 -170 -110 -50 10 70 130 190 250	307.5
25 MHz, $N_{RB}= 65$	-350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370	307.5
30 MHz, $N_{RB}= 78$	-440 -380 -320 -260 -200 -140 -80 -20 40 100 160 220 280 340 400 460	307.5
40 MHz, $N_{RB}= 106$	-620 -560 -500 -440 -380 -320 -260 -200 -140 -80 -20 40 100 160 220 280 340 400 460 520 580	307.5
50 MHz, $N_{RB}= 133$	-770 -710 -650 -590 -530 -470 -410 -350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370 430 490 550 610 670 730 790	307.5
60 MHz, $N_{RB}= 162$	-920 -860 -800 -740 -680 -620 -560 -500 -440 -380 -320 -260 -200 -140 -80 -20 40 100 160 220 280 340 400 460 520 580 640 700 760 820 880 940	307.5
80 MHz, $N_{RB}= 217$	-1250 -1190 -1130 -1070 -1010 -950 -890 -830 -770 -710 -650 -590 -530 -470 -410 -350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370 430 490 550 610 670 730 790 850 910 970 1030 1090 1150 1210 1270	307.5

100 MHz, N _{RB} = 273	-1610 -1550 -1490 -1430 -1370 -1310 -1250 -1190 -1130 -1070 -1010 -950 -890 -830 -770 -710 -650 -590 -530 -470 -410 -350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370 430 490 550 610 670 730 790 850 910 970 1030 1090 1150 1210 1270 1330 1390 1450 1510 1570 1630	307.5
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Table 9

In Table 9, the maximum guard band bandwidth is 307.5 kHz.

[0080] Table 10 is another representation of the possible positions for the center of the LTE-M carrier relative to the NR raster, considering 5 NR resource blocks, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-20+n60 where n is integer from -2 to 2
15	-20+n60 where n is integer from -3 to 4
20	-50+n60 where n is integer from -4 to 5
25	-50+n60 where n is integer from -5 to 7
30	-20+n60 where n is integer from -7 to 8
40	-20+n60 where n is integer from -10 to 10
50	-50+n60 where n is integer from -12 to 14
60	-20+n60 where n is integer from -15 to 16
80	-50+n60 where n is integer from -20 to 22
100	-50+n60 where n is integer from -26 to 28

Table 10

[0081] The equations for determining optimal positions for the center of the LTE-M carrier may be applicable to NR subcarrier spacings other than 30 kHz. For example, NR subcarrier spacing may be 60 kHz or greater. The NR subcarrier index k^* relative to the NR raster, where k^* is in a set $k^*=10q$ and where q is an integer, may be shown to be in the range:

$$\frac{B_L/2+G-B_{nr}/2-15}{N_S} \leq k^* \leq \frac{B_{nr}/2-B_L/2-G-15}{N_S},$$

where N_S is NR subcarrier spacing, B_L is operational bandwidth for LTE-M, B_{nr} is the NR bandwidth and G represents bandwidth of the guard bands for the LTE-M carrier. The LTE-M carrier center is positioned at k^* according to one of the following equations, where N_{RB} is the number of NR resource blocks:

$$5 \quad \frac{(12N_S)L + B_L/2 + G - 15}{N_S} \leq k^* \leq \frac{(12N_S)(L + N_{RB}) - B_L/2 - G - 15}{N_S}$$

for an even number of NR resource blocks, where L is an integer and $(-N_{RB}/2 + 1) \leq L \leq N_{RB}/2$; and

$$\begin{aligned} \frac{(12N_S)L + B_L/2 + G - 15 - (12N_S/2)}{N_S} &\leq k^* \\ &\leq \frac{(12N_S)(L + N_{RB}) - B_L/2 - G - 15 - (12N_S/2)}{N_S} \end{aligned}$$

10 for an odd number of NR resource blocks, where L is an integer and $-(N_{RB} - 1)/2 \leq L \leq (N_{RB} - 1)/2$.

In some cases, the minimum number N of NR RBs needed for the LTE-M carrier is:

$$N = \left\lceil \frac{B_L + 2G}{12N_S} \right\rceil$$

where $\lceil \cdot \rceil$ is a ceiling function.

15 **[0082]** Accordingly, the other equations may be, for a minimum frequency $F_{nr,min} = -15 + (12N_S)L$ and a maximum frequency $F_{nr,max} = -15 + (12N_S)(L + N_{RB})$ for an even number of NR resource blocks. For an odd number of NR resource blocks, a minimum frequency $F_{nr,min} = -15 - (12N_S/2) + (12N_S)L$ and a maximum frequency $F_{nr,max} = -15 - (12N_S/2) + (12N_S)(L + N_{RB})$. The maximum guard band at left (lower frequency) and right (higher frequency) sides of the LTE-M carrier are $G_{right} = F_{nr,max} - (F_{LTEM} + B_L/2)$ and $G_{left} = (F_{LTEM} - B_L/2) - F_{nr,min}$, where F_{LTEM} is the LTE-M carrier center. In some cases, L is:

$$L = \left\lfloor \frac{(F_{LTEM} - B_L/2) + 15}{12N_S} \right\rfloor$$

25 where $\lfloor \cdot \rfloor$ is the floor function. The LTE-M carrier center F_{LTEM} is in a position in the range of k^* where L maximizes the G_{left} and the G_{right} .

[0083] FIG. 13 illustrates a method 1300, according to some embodiments, for communicating in a wireless communication network that includes transmitting or receiving

using an LTE-M carrier within the bandwidth of an NR carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth, where the center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and where a maximum number of subcarriers in the LTE-M carrier align
5 with subcarriers in NR. The center of the LTE-M carrier is located within the NR bandwidth such that at least one of: 1) a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and 2) given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum
10 guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is maximized (block 1304).

[0084] In some cases, method 1300 may include generating a signal and the transmitting or receiving may include transmitting the generated signal on the LTE-M carrier
15 within the bandwidth of the NR carrier (block 1302). In other cases, transmitting or receiving may include receiving a signal on the LTE-M carrier within the bandwidth of the NR carrier and method 1300 may further include processing the received signal (block 1306). This may include searching for the LTE-M carrier within the bandwidth of the NR carrier according to the NR channel raster.

20 **[0085]** According to some embodiments, the certain amount of guard band is predetermined and wherein the center of the LTE-M carrier is positioned within the NR carrier, based on the predetermined amount of the guard band, to minimize the number of NR resource blocks occupied by the LTE-M carrier and the guard band.

[0086] In other embodiments, the center of the LTE-M carrier is positioned within the
25 NR carrier so as to minimize the number of NR resource blocks occupied by the LTE-M carrier and the guard band, based on a given number of available NR resource blocks. The center of the LTE-M carrier may be positioned within the NR carrier so as to maximize the certain amount of guard band at both ends of the LTE-M carrier, while using the minimum number of NR resource blocks, as compared to an amount of guard band that would be available at other
30 grid-aligned subcarrier positions for the LTE-M carrier.

[0087] In some embodiments, the center of the LTE-M carrier is positioned at $\pm n10$ kHz relative to the NR channel raster, considering 30 kHz subcarrier spacing, where n is an integer among a set of consecutive integers defined for the NR bandwidth. The relationship between LTE-M and NR can be explained as follows. NR and LTE-M subcarrier alignment

may occur according to the equation: $100n = 100m + 30k$, where $100m$ kHz represents the possible frequencies of NR raster, 30 kHz represents NR subcarrier spacing and $100n$ kHz represents where the LTE-M carrier center is able to be placed, and where m and n are integers and k is an NR subcarrier index.

5 [0088] The network devices may utilize the LTE-M carrier center positions in coexistence with NR bandwidth, as described above, when communicating with other devices or nodes. Examples of such network devices includes network nodes and wireless devices as described below.

[0089] FIG. 14 shows an example network node 30 that may be configured to carry out
10 one or more of these disclosed techniques. Network node 30 may be an evolved Node B (eNodeB), Node B or gNB. While a network node 30 is shown in FIG. 14, the operations can be performed by other kinds of network access nodes, including a radio network node such as base station, radio base station, base transceiver station, base station controller, network controller, NR BS, Multi-cell/multicast Coordination Entity (MCE), relay node, access point,
15 radio access point, Remote Radio Unit (RRU), Remote Radio Head (RRH), or a multi-standard BS (MSR BS). Network node 30 may also, in some cases, be a core network node (e.g., MME, SON node, a coordinating node, positioning node, MDT node, etc.), or even an external node (e.g., 3rd party node, a node external to the current network), etc. Network node 30 may also comprise test equipment.

20 [0090] In the non-limiting embodiments described below, network node 30 will be described as being configured to operate as a cellular network access node in an LTE network or NR network. In some embodiments, the technique can be implemented in the RRC layer. The RRC layer could be implemented by one or more network nodes in a cloud environment and hence some embodiments can be implemented in a cloud environment.

25 [0091] Those skilled in the art will readily appreciate how each type of node may be adapted to carry out one or more of the methods and signaling processes described herein, e.g., through the modification of and/or addition of appropriate program instructions for execution by processing circuits 32.

[0092] Network node 30 facilitates communication between wireless terminals (e.g.,
30 UEs), other network access nodes and/or the core network. Network node 30 may include communication interface circuitry 38 that includes circuitry for communicating with other nodes in the core network, radio nodes, and/or other types of nodes in the network for the purposes of providing data and/or cellular communication services. Network node 30 communicates with wireless devices using antennas 34 and transceiver circuitry 36.

Transceiver circuitry 36 may include transmitter circuits, receiver circuits, and associated control circuits that are collectively configured to transmit and receive signals according to a radio access technology, for the purposes of providing cellular communication services.

5 [0093] Network node 30 also includes one or more processing circuits 32 that are operatively associated with the transceiver circuitry 36 and, in some cases, the communication interface circuitry 38. Processing circuitry 32 comprises one or more digital processors 42, e.g., one or more microprocessors, microcontrollers, Digital Signal Processors (DSPs), Field Programmable Gate Arrays (FPGAs), Complex Programmable Logic Devices (CPLDs), Application Specific Integrated Circuits (ASICs), or any mix thereof. More generally,
10 processing circuitry 32 may comprise fixed circuitry, or programmable circuitry that is specially configured via the execution of program instructions implementing the functionality taught herein, or some mix of fixed and programmed circuitry. Processor 42 may be multi-core, i.e., having two or more processor cores utilized for enhanced performance, reduced power consumption, and more efficient simultaneous processing of multiple tasks.

15 [0094] Processing circuitry 32 also includes a memory 44. Memory 44, in some embodiments, stores one or more computer programs 46 and, optionally, configuration data 48. Memory 44 provides non-transitory storage for the computer program 46 and it may comprise one or more types of computer-readable media, such as disk storage, solid-state memory storage, or any mix thereof. Here, “non-transitory” means permanent, semi-
20 permanent, or at least temporarily persistent storage and encompasses both long-term storage in non-volatile memory and storage in working memory, e.g., for program execution. By way of non-limiting example, memory 44 comprises any one or more of SRAM, DRAM, EEPROM, and FLASH memory, which may be in processing circuitry 32 and/or separate from processing circuitry 32. Memory 44 may also store any configuration data 48 used by the network access
25 node 30. Processing circuitry 32 may be configured, e.g., through the use of appropriate program code stored in memory 44, to carry out one or more of the methods and/or signaling processes detailed hereinafter.

[0095] Processing circuitry 32 of the network node 30 is configured, according to some
30 embodiments, to perform the techniques described herein for one or more network nodes of a wireless communication system serving a plurality of UEs. Processing circuitry 32 is configured to transmit or receive using an LTE-M carrier within the bandwidth of an NR carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth, where the center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and where a maximum number of subcarriers in

the LTE-M carrier align with subcarriers in NR. The center of the LTE-M carrier is located within the NR bandwidth such that at least one of: a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is maximized. Processing circuitry 32 is also configured to perform method 1300, according to some embodiments.

10 [0096] FIG. 15 illustrates a diagram of a wireless device 50 configured to carry out the techniques described above, according to some embodiments. Wireless device 50 may be considered to represent any wireless devices or terminals that may operate in a network, such as a UE in a cellular network. Other examples may include a communication device, target device, MTC device, IoT device, device to device (D2D) UE, machine type UE or UE capable of machine to machine communication (M2M), a sensor equipped with UE, PDA (personal digital assistant), tablet, IPAD tablet, mobile terminal, smart phone, laptop embedded equipped (LEE), laptop mounted equipment (LME), USB dongles, Customer Premises Equipment (CPE), etc.

20 [0097] Wireless device 50 is configured to communicate with a network node or base station in a wide-area cellular network via antennas 54 and transceiver circuitry 56. Transceiver circuitry 56 may include transmitter circuits, receiver circuits, and associated control circuits that are collectively configured to transmit and receive signals according to a radio access technology, for the purposes of using cellular communication services. This radio access technologies can be NR and LTE for the purposes of this discussion.

25 [0098] Wireless device 50 also includes one or more processing circuits 52 that are operatively associated with the radio transceiver circuitry 56. Processing circuitry 52 comprises one or more digital processing circuits, e.g., one or more microprocessors, microcontrollers, DSPs, FPGAs, CPLDs, ASICs, or any mix thereof. More generally, processing circuitry 52 may comprise fixed circuitry, or programmable circuitry that is specially adapted via the execution of program instructions implementing the functionality taught herein, or may comprise some mix of fixed and programmed circuitry. Processing circuitry 52 may be multi-core.

30 [0099] Processing circuitry 52 also includes a memory 64. Memory 64, in some embodiments, stores one or more computer programs 66 and, optionally, configuration data

68. Memory 64 provides non-transitory storage for computer program 66 and it may comprise one or more types of computer-readable media, such as disk storage, solid-state memory storage, or any mix thereof. By way of non-limiting example, memory 64 comprises any one or more of SRAM, DRAM, EEPROM, and FLASH memory, which may be in processing
5 circuitry 52 and/or separate from processing circuitry 52. Memory 64 may also store any configuration data 68 used by wireless device 50. Processing circuitry 52 may be configured, e.g., through the use of appropriate program code stored in memory 64, to carry out one or more of the methods and/or signaling processes detailed hereinafter.

[0100] Processing circuitry 52 of wireless device 50 is configured, according to some
10 embodiments, to transmit or receive using an LTE-M carrier within the bandwidth of an NR carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth, where the center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and where a maximum number of subcarriers in the LTE-M carrier align with subcarriers in NR. The center of the LTE-M carrier is located
15 within the NR bandwidth such that at least one of: a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the
20 respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is maximized. Processing circuitry 52 may also be configured to perform method 1300.

[0101] FIG. 16, according to some embodiments, illustrates a communication system that includes a telecommunication network 1610, such as a 3GPP-type cellular network, which
25 comprises an access network 1611, such as a radio access network, and a core network 1614. The access network 1611 comprises a plurality of base stations 1612a, 1612b, 1612c, such as NBs, eNBs, gNBs or other types of wireless access points, each defining a corresponding coverage area 1613a, 1613b, 1613c. Each base station 1612a, 1612b, 1612c is connectable to the core network 1614 over a wired or wireless connection 1615. A first UE 16161 located in
30 coverage area 1613c is configured to wirelessly connect to, or be paged by, the corresponding base station 1612c. A second UE 1692 in coverage area 1613a is wirelessly connectable to the corresponding base station 1612a. While a plurality of UEs 1691, 1692 are illustrated in this example, the disclosed embodiments are equally applicable to a situation where a sole UE is in the coverage area or where a sole UE is connecting to the corresponding base station 1612.

[0102] The telecommunication network 1610 is itself connected to a host computer 1630, which may be embodied in the hardware and/or software of a standalone server, a cloud-implemented server, a distributed server or as processing resources in a server farm. The host computer 1630 may be under the ownership or control of a service provider, or may be operated
5 by the service provider or on behalf of the service provider. The connections 1621, 1622 between the telecommunication network 1610 and the host computer 1630 may extend directly from the core network 1614 to the host computer 1630 or may go via an optional intermediate network 1620. The intermediate network 1620 may be one of, or a combination of more than one of, a public, private or hosted network; the intermediate network 1620, if any, may be a
10 backbone network or the Internet; in particular, the intermediate network 1620 may comprise two or more sub-networks (not shown).

[0103] The communication system of FIG. 16 as a whole enables connectivity between one of the connected UEs 1691, 1692 and the host computer 1630. The connectivity may be described as an over-the-top (OTT) connection 1650. The host computer 1630 and the
15 connected UEs 1691, 1692 are configured to communicate data and/or signaling via the OTT connection 1650, using the access network 1611, the core network 1614, any intermediate network 1620 and possible further infrastructure (not shown) as intermediaries. The OTT connection 1650 may be transparent in the sense that the participating communication devices through which the OTT connection 1650 passes are unaware of routing of uplink and downlink
20 communications. For example, a base station 1612 may not or need not be informed about the past routing of an incoming downlink communication with data originating from a host computer 1630 to be forwarded (e.g., handed over) to a connected UE 1691. Similarly, the base station 1612 need not be aware of the future routing of an outgoing uplink communication originating from the UE 1691 towards the host computer 1630.

[0104] Example implementations, in accordance with an embodiment, of the UE, base station and host computer discussed in the preceding paragraphs will now be described with reference to FIG. 17. In a communication system 1700, a host computer 1710 comprises hardware 1715 including a communication interface 1716 configured to set up and maintain a
wired or wireless connection with an interface of a different communication device of the
30 communication system 1700. The host computer 1710 further comprises processing circuitry 1718, which may have storage and/or processing capabilities. In particular, the processing circuitry 1718 may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. The host computer 1710 further comprises software 1711,

which is stored in or accessible by the host computer 1710 and executable by the processing circuitry 1718. The software 1711 includes a host application 1712. The host application 1712 may be operable to provide a service to a remote user, such as a UE 1730 connecting via an OTT connection 1750 terminating at the UE 1730 and the host computer 1710. In providing
5 the service to the remote user, the host application 1712 may provide user data which is transmitted using the OTT connection 1750.

[0105] The communication system 1700 further includes a base station 1720 provided in a telecommunication system and comprising hardware 1725 enabling it to communicate with the host computer 1710 and with the UE 1730. The hardware 1725 may include a
10 communication interface 1726 for setting up and maintaining a wired or wireless connection with an interface of a different communication device of the communication system 1700, as well as a radio interface 1727 for setting up and maintaining at least a wireless connection 1770 with a UE 1730 located in a coverage area (not shown in FIG. 17) served by the base station 1720. The communication interface 1726 may be configured to facilitate a connection 1760 to
15 the host computer 1710. The connection 1760 may be direct or it may pass through a core network (not shown in FIG. 17) of the telecommunication system and/or through one or more intermediate networks outside the telecommunication system. In the embodiment shown, the hardware 1725 of the base station 1720 further includes processing circuitry 1728, which may comprise one or more programmable processors, application-specific integrated circuits, field
20 programmable gate arrays or combinations of these (not shown) adapted to execute instructions. The base station 1720 further has software 1721 stored internally or accessible via an external connection.

[0106] The communication system 1700 further includes the UE 1730 already referred to. Its hardware 1735 may include a radio interface 1737 configured to set up and maintain a
25 wireless connection 1770 with a base station serving a coverage area in which the UE 1730 is currently located. The hardware 1735 of the UE 1730 further includes processing circuitry 1738, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. The UE 1730 further comprises software 1731, which is stored
30 in or accessible by the UE 1730 and executable by the processing circuitry 1738. The software 1731 includes a client application 1732. The client application 1732 may be operable to provide a service to a human or non-human user via the UE 1730, with the support of the host computer 1710. In the host computer 1710, an executing host application 1712 may communicate with the executing client application 1732 via the OTT connection 1750 terminating at the UE 1730

and the host computer 1710. In providing the service to the user, the client application 1732 may receive request data from the host application 1712 and provide user data in response to the request data. The OTT connection 1750 may transfer both the request data and the user data. The client application 1732 may interact with the user to generate the user data that it provides.

5 [0107] It is noted that the host computer 1710, base station 1720 and UE 1730 illustrated in FIG. 17 may be identical to the host computer 1630, one of the base stations 1612a, 1612b, 1612c and one of the UEs 1691, 1692 of FIG. 16, respectively. This is to say, the inner workings of these entities may be as shown in FIG. 17 and independently, the surrounding network topology may be that of FIG. 16.

10 [0108] In FIG. 17, the OTT connection 1750 has been drawn abstractly to illustrate the communication between the host computer 1710 and the use equipment 1730 via the base station 1720, without explicit reference to any intermediary devices and the precise routing of messages via these devices. Network infrastructure may determine the routing, which it may be configured to hide from the UE 1730 or from the service provider operating the host computer 1710, or both. While the OTT connection 1750 is active, the network infrastructure may further take decisions by which it dynamically changes the routing (e.g., on the basis of load balancing consideration or reconfiguration of the network).

15 [0109] The wireless connection 1770 between the UE 1730 and the base station 1720 is in accordance with the teachings of the embodiments described throughout this disclosure, such as provided by nodes such as wireless device 50 and network node 30, along with the corresponding method 1300. The embodiments described herein provide for the effective deployment of LTE-M in coexistence with NR. More specially, the embodiments address problems of subcarrier grid alignment and resource efficiency, which are the key issues in the coexistence of NR and LTE-M. The teachings of these embodiments may improve the data rate, capacity, latency and/or power consumption for the network and UE 1730 using the OTT connection 1750 for emergency warning systems and thereby provide benefits such as more efficient and targeted emergency messaging that saves on network and UE resources while improving the ability of users to take safe action.

20 [0110] A measurement procedure may be provided for the purpose of monitoring data rate, latency and other factors on which the one or more embodiments improve. There may further be an optional network functionality for reconfiguring the OTT connection 1750 between the host computer 1710 and UE 1730, in response to variations in the measurement results. The measurement procedure and/or the network functionality for reconfiguring the

OTT connection 1750 may be implemented in the software 1711 of the host computer 1710 or in the software 1731 of the UE 1730, or both. In embodiments, sensors (not shown) may be deployed in or in association with communication devices through which the OTT connection 1750 passes; the sensors may participate in the measurement procedure by supplying values of the monitored quantities exemplified above, or supplying values of other physical quantities from which software 1711, 1731 may compute or estimate the monitored quantities. The reconfiguring of the OTT connection 1750 may include message format, retransmission settings, preferred routing etc.; the reconfiguring need not affect the base station 1720, and it may be unknown or imperceptible to the base station 1720. Such procedures and functionalities may be known and practiced in the art. In certain embodiments, measurements may involve proprietary UE signaling facilitating the host computer's 1710 measurements of throughput, propagation times, latency and the like. The measurements may be implemented in that the software 1711, 1731 causes messages to be transmitted, in particular empty or 'dummy' messages, using the OTT connection 1750 while it monitors propagation times, errors etc.

[0111] FIG. 18 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. 16 and 17. For simplicity of the present disclosure, only drawing references to FIG. 18 will be included in this section. In a first step 1810 of the method, the host computer provides user data. In an optional substep 1811 of the first step 1810, the host computer provides the user data by executing a host application. In a second step 1820, the host computer initiates a transmission carrying the user data to the UE. In an optional third step 1830, the base station transmits to the UE the user data which was carried in the transmission that the host computer initiated, in accordance with the teachings of the embodiments described throughout this disclosure. In an optional fourth step 1840, the UE executes a client application associated with the host application executed by the host computer.

[0112] FIG. 19 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. 16 and 17. For simplicity of the present disclosure, only drawing references to FIG. 19 will be included in this section. In a first step 1910 of the method, the host computer provides user data. In an optional substep (not shown) the host computer provides the user data by executing a host application. In a second step 1920, the host computer initiates a transmission carrying the user data to the UE. The transmission may pass via the base station, in accordance with the

teachings of the embodiments described throughout this disclosure. In an optional third step 1930, the UE receives the user data carried in the transmission.

[0113] FIG. 20 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. 16 and 17. For simplicity of the present disclosure, only drawing references to FIG. 20 will be included in this section. In an optional first step 2010 of the method, the UE receives input data provided by the host computer. Additionally, or alternatively, in an optional second step 2020, the UE provides user data. In an optional substep 2021 of the second step 2020, the UE provides the user data by executing a client application. In a further optional substep 2011 of the first step 2010, the UE executes a client application which provides the user data in reaction to the received input data provided by the host computer. In providing the user data, the executed client application may further consider user input received from the user. Regardless of the specific manner in which the user data was provided, the UE initiates, in an optional third substep 2030, transmission of the user data to the host computer. In a fourth step 2040 of the method, the host computer receives the user data transmitted from the UE, in accordance with the teachings of the embodiments described throughout this disclosure.

[0114] FIG. 21 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. 16 and 17. For simplicity of the present disclosure, only drawing references to FIG. 21 will be included in this section. In an optional first step 2110 of the method, in accordance with the teachings of the embodiments described throughout this disclosure, the base station receives user data from the UE. In an optional second step 2120, the base station initiates transmission of the received user data to the host computer. In a third step 2130, the host computer receives the user data carried in the transmission initiated by the base station.

[0115] According to some embodiments, a communication system including a host computer comprises processing circuitry configured to provide user data and a communication interface configured to forward the user data to a cellular network for transmission to a UE, where the cellular network comprises a network node having a communication interface and processing circuitry, the network node's processing circuitry configured to perform any of the steps described above. The communication system may include the network node and/or the UE, wherein the UE is configured to communicate with the network node.

[0116] The processing circuitry of the host computer may be configured to execute a host application, thereby providing the user data, and the UE may comprise processing circuitry configured to execute a client application associated with the host application.

5 [0117] According to some embodiments, a method implemented in a communication system including a host computer, a network node and a UE includes, at the host computer, providing user data and at the host computer, initiating a transmission carrying the user data to the UE via a cellular network comprising the network node, wherein the network node performs any of the steps described above. The network node may transmit the user data. The user data may be provided at the host computer by executing a host application, the method further
10 comprising, at the UE, executing a client application associated with the host application.

[0118] According to some embodiments, a communication system including a host computer comprises processing circuitry configured to provide user data and a communication interface configured to forward user data to a cellular network for transmission to a UE, where the UE comprises a radio interface and processing circuitry, the UE's components configured
15 to perform any of the steps described above. The cellular network further may include a network node configured to communicate with the UE. The processing circuitry of the host computer may be configured to execute a host application, thereby providing the user data, and the UE's processing circuitry may be configured to execute a client application associated with the host application.

20 [0119] According to some embodiments, a method implemented in a communication system including a host computer, a network node and a UE, includes at the host computer, providing user data and at the host computer, initiating a transmission carrying the user data to the UE via a cellular network comprising the network node, wherein the UE performs any of the steps described above. The UE may receive the user data from the network node.

25 [0120] According to some embodiments, a communication system including a host computer comprises a communication interface configured to receive user data originating from a transmission from a UE to a base station, where the UE comprises a radio interface and processing circuitry, the UE's processing circuitry configured to perform any of the steps described above. The communication system may include the UE and/or the network node,
30 where the network node may comprise a radio interface configured to communicate with the UE and a communication interface configured to forward to the host computer the user data carried by a transmission from the UE to the network node. The processing circuitry of the host computer may be configured to execute a host application, and the UE's processing circuitry may be configured to execute a client application associated with the host application, thereby

providing the user data. The processing circuitry of the host computer may be configured to execute a host application, thereby providing request data, and the UE's processing circuitry may be configured to execute a client application associated with the host application, thereby providing the user data in response to the request data.

5 [0121] According to some embodiments, a method implemented in a communication system including a host computer, a network node and a UE, includes at the host computer, receiving user data transmitted to the network node from the UE, wherein the UE performs any of the steps described above. The UE may provide the user data to the network node and/or execute a client application, thereby providing the user data to be transmitted. The host
10 computer may execute a host application associated with the client application. The UE may execute a client application and/or receive input data to the client application, the input data being provided at the host computer by executing a host application associated with the client application, where the user data to be transmitted is provided by the client application in response to the input data.

15 [0122] According to some embodiments, a communication system including a host computer comprising a communication interface configured to receive user data originating from a transmission from a UE to a network node, where the network node comprises a radio interface and processing circuitry, the network node's processing circuitry configured to perform any of the steps of described above. The communication system may include the
20 network node and/or the UE, where the UE may be configured to communicate with the network node. The processing circuitry of the host computer may be configured to execute a host application, and the UE may be configured to execute a client application associated with the host application, thereby providing the user data to be received by the host computer.

[0123] According to some embodiments, a method implemented in a communication
25 system including a host computer, a network node and a UE, includes at the host computer, receiving, from the base station, user data originating from a transmission which the network node has received from the UE, wherein the UE performs any of the steps described above. The network node may receive the user data from the UE and/or initiate a transmission of the received user data to the host computer.

30 [0124] As discussed in detail above, the techniques described herein, e.g., as illustrated in the process flow diagram of FIG. 13, may be implemented, in whole or in part, using computer program instructions executed by one or more processors. It will be appreciated that a functional implementation of these techniques may be represented in terms of functional modules, where each functional module corresponds to a functional unit of software executing

in an appropriate processor or to a functional digital hardware circuit, or some combination of both.

[0125] FIG. 22 illustrates an example functional module or circuit architecture for a network node, such as network node 30. The functional implementation includes a communicating module 2202 transmitting or receiving using an LTE-M carrier within the bandwidth of an NR carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth, where the center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and where a maximum number of subcarriers in the LTE-M carrier align with subcarriers in NR. The center of the LTE-M carrier is located within the NR bandwidth such that at least one of: a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is maximized..

[0126] FIG. 23 illustrates an example functional module or circuit architecture for wireless device 50 that includes a communicating module 2302 for transmitting or receiving using an LTE-M carrier within the bandwidth of an NR carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth, where the center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and where a maximum number of subcarriers in the LTE-M carrier align with subcarriers in NR. The center of the LTE-M carrier is located within the NR bandwidth such that at least one of: a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands is maximized.

[0127] Many variations and modifications can be made to the embodiments without substantially departing from the principles of the present inventive concepts. All such variations and modifications are intended to be included herein within the scope of present inventive concepts. Accordingly, the above disclosed subject matter is to be considered

illustrative, and not restrictive, and the examples of embodiments are intended to cover all such modifications, enhancements, and other embodiments, which fall within the spirit and scope of present inventive concepts. Thus, to the maximum extent allowed by law, the scope of present inventive concepts is to be determined by the broadest permissible interpretation of the present disclosure including the examples of embodiments and their equivalents, and shall not be
5 restricted or limited by the foregoing detailed description.

CLAIMS

What is claimed is:

1. A network device, comprising:
 - transceiver circuitry; and
 - 5 processing circuitry operatively associated with the transceiver circuitry and configured to:
 - transmit or receive, via the transceiver circuitry, using a Long Term Evolution
 - Machine Type Communication (LTE-M) carrier within the
 - bandwidth of a New Radio (NR) carrier with guard bands that are
 - 10 immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth,
 - wherein the center of the LTE-M carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and wherein a maximum number of subcarriers in the LTE-M carrier align with subcarriers in NR,
 - 15 wherein the center of the LTE-M carrier is located within the NR bandwidth such that at least one of:
 - a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a
 - predetermined bandwidth for each of the guard bands; and
 - 20 given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M
 - 25 carrier and the guard bands is maximized.

2. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 100 kHz guard band and 30 kHz NR subcarrier spacing, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-120 -110 -60 -50 0 10 60 70 120 130

15	-180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190
20	-290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300
25	-360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370
30	-420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430
40	-600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610
50	-780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790
60	-950 -900 -890 -840 -830 -780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790 840 850 900 910 960 970
80	-1260 -1250 -1200 -1190 -1140 -1130 -1080 -1070 -1020 -1010 -960 -950 -900 -890 -840 -830 -780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60

	70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790 840 850 900 910 960 970 1020 1030 1080 1090 1140 1150 1200 1210 1260 1270
100	-1620 -1610 -1560 -1550 -1500 -1490 -1440 -1430 -1380 -1370 -1320 -1310 -1260 -1250 1200 -1190 -1140 -1130 -1080 -1070 -1020 -1010 -960 -950 -900 -890 -840 -830 -780 -770 -720 -710 -660 -650 -600 -590 -540 -530 -480 -470 -420 -410 -360 -350 -300 -290 -240 -230 -180 -170 -120 -110 -60 -50 0 10 60 70 120 130 180 190 240 250 300 310 360 370 420 430 480 490 540 550 600 610 660 670 720 730 780 790 840 850 900 910 960 970 1020 1030 1080 1090 1140 1150 1200 1210 1260 1270 1320 1330 1380 1390 1440 1450 1500 1510 1560 1570 1620 1630

3. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 100 kHz guard band and 30 kHz NR subcarrier spacing,
- 5 according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	n30 for even integers n from -4 to 4; and -20+n30 for odd integers n from -3 to 5
15	n30 for even integers n from -6 to 6; and -20+n30 for odd integers n from -5 to 7
20	n30 for even integers n from -8 to 10; and -20+n30 for odd integers n from -9 to 9
25	n30 for even integers n from -12 to 12; and -20+n30 for odd integers n from -11 to 13

30	n30 for even integers n from -14 to 14; and -20+n30 for odd integers n from -13 to 15
40	n30 for even integers n from -20 to 20; and -20+n30 for odd integers n from -19 to 21
50	n30 for even integers n from -26 to 26; and -20+n30 for odd integers n from -25 to 27
60	n30 for even integers n from -30 to 31; and -20+n30 for odd integers n from -31 to 33
80	n30 for even integers n from -42 to 42; and -20+n30 for odd integers n from -41 to 43
100	n30 for even integers n from -54 to 54; and -20+n30 for odd integers n from -53 to 55

4. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 300 kHz guard band and 30 kHz NR subcarrier spacing,
- 5 according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-90 -80 -30 -20 30 40 90 100
15	-200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220
20	-270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280
25	-330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340
30	-440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460
40	-570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20

	30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630
50	-750 -740 -690 -680 -630 -620 -570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630 640 690 700 750 760
60	-930 -920 -870 -860 -810 -800 -750 -740 -690 -680 -630 -620 -570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630 640 690 700 750 760 810 820 870 880 930 940
80	-1280 -1230 -1220 -1170 -1160 -1110 -1100 -1050 -1040 -990 -980 -930 -920 -870 -860 -810 -800 -750 -740 -690 -680 -630 -620 -570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390 400 450 460 510 520 570 580 630 640 690 700 750 760 810 820 870 880 930 940 990 1000 1050 1060 1110 1120 1170 1180 1230 1240 1290 1300
100	-1590 -1580 -1530 -1520 -1470 -1460 -1410 -1400 -1350 -1340 -1290 -1280 -1230 -1220 -1170 -1160 -1110 -1100 -1050 -1040 -990 -980 -930 -920 -870 -860 -810 -800 -750 -740 -690 -680 -630 -620 -570 -560 -510 -500 -450 -440 -390 -380 -330 -320 -270 -260 -210 -200 -150 -140 -90 -80 -30 -20 30 40 90 100 150 160 210 220 270 280 330 340 390

400	450	460	510	520	570	580	630	640	690
700	750	760	810	820	870	880	930	940	990
1000	1050	1060	1110	1120	1170	1180	1230		
1240	1290	1300	1350	1360	1410	1420	1470		
1480	1530	1540	1590	1600					

5. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 300 kHz guard band and 30 kHz NR subcarrier spacing, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-20+n60 for integers n from -1 to 2; and -30+n60 for integers n from -1 to 2
15	-20+n60 for integers n from -3 to 4; and -30+n60 for integers n from -2 to 4
20	-20+n60 for integers n from -4 to 5; and -30+n60 for integers n from -4 to 5
25	-20+n60 for integers n from -5 to 6; and -30+n60 for integers n from -5 to 6
30	-20+n60 for integers n from -7 to 8; and -30+n60 for integers n from -6 to 8
40	-20+n60 for integers n from -9 to 10; and -30+n60 for integers n from -9 to 11
50	-20+n60 for integers n from -12 to 13; and -30+n60 for integers n from -12 to 13
60	-20+n60 for integers n from -15 to 16; and -30+n60 for integers n from -15 to 16
80	-20+n60 for integers n from -21 to 22; and -30+n60 for integers n from -20 to 22
100	-20+n60 for integers n from -26 to 27; and -30+n60 for integers n from -26 to 27

6. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 4 NR resource blocks and 30 kHz NR subcarrier spacing, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-120 -60 0 60 120
15	-180 -120 -60 0 60 120 180
20	-270 -210 -150 -90 -30 30 90 150 210 270
25	-390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330
30	-420 -360 -300 -240 -180 -120 -60 0 60 120 180 240 300 360 420
40	-600 -540 -480 -420 -360 -300 -240 -180 -120 -60 0 60 120 180 240 300 360 420 480 540 600
50	-750 -690 -630 -570 -510 -450 -390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330 390 450 510 570 630 690 750
60	-960 -900 -840 -780 -720 -660 -600 -540 -480 -420 -360 -300 -240 -180 -120 -60 0 60 120 180 240 300 360 420 480 540 600 660 720 780 840 900 960
80	-1290 -1230 -1170 -1110 -1050 -990 -930 -870 -810 -750 -690 -630 -570 -510 -450 -390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330 390 450 510 570 630 690 750 810 870 930 990 1050 1110 1170 1230 1290
100	-1590 -1530 -1470 -1410 -1350 -1290 -1230 -1170 -1110 -1050 -990 -930 -870 -810 -750 -690 -630 -570 -510 -450 -390 -330 -270 -210 -150 -90 -30 30 90 150 210 270 330 390 450 510 570 630 690 750 810 870 930

	990	1050	1110	1170	1230	1290	1350	1410
	1470	1530	1590					

7. The network device of claim 6, wherein the maximum guard band bandwidth is 157.5 kHz.

5

8. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 4 NR resource blocks and 30 kHz NR subcarrier spacing, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	n60 where n is integer from -2 to 2
15	n60 where n is integer from -3 to 3
20	-30+n60 where n is integer from -4 to 5
25	-30+n60 where n is integer from -6 to 6
30	n60 where n is integer from -7 to 7
40	n60 where n is integer from -10 to 10
50	-30+n60 where n is integer from -12 to 13
60	n60 where n is integer from -16 to 16
80	-30+n60 where n is integer from -21 to 22
100	-30+n60 where n is integer from -26 to 27

10

9. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 5 NR resource blocks and 30 kHz NR subcarrier spacing, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-140 -80 -20 40 100
15	-200 -140 -80 -20 40 100 160 220
20	-290 -230 -170 -110 -50 10 70 130 190 250

25	-350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370
30	-440 -380 -320 -260 -200 -140 -80 -20 40 100 160 220 280 340 400 460
40	-620 -560 -500 -440 -380 -320 -260 -200 -140 -80 -20 40 100 160 220 280 340 400 460 520 580
50	-770 -710 -650 -590 -530 -470 -410 -350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370 430 490 550 610 670 730 790
60	-920 -860 -800 -740 -680 -620 -560 -500 -440 -380 -320 -260 -200 -140 -80 -20 40 100 160 220 280 340 400 460 520 580 640 700 760 820 880 940
80	-1250 -1190 -1130 -1070 -1010 -950 -890 -830 -770 -710 -650 -590 -530 -470 -410 -350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370 430 490 550 610 670 730 790 850 910 970 1030 1090 1150 1210 1270
100	-1610 -1550 -1490 -1430 -1370 -1310 -1250 -1190 -1130 -1070 -1010 -950 -890 -830 -770 -710 -650 -590 -530 -470 -410 -350 -290 -230 -170 -110 -50 10 70 130 190 250 310 370 430 490 550 610 670 730 790 850 910 970 1030 1090 1150 1210 1270 1330 1390 1450 1510 1570 1630

10. The network device of claim 9, wherein the maximum guard band bandwidth is 307.5 kHz.

11. The network device of claim 1, wherein the center of the LTE-M carrier is positioned relative to an NR raster, considering 5 NR resource blocks and 30 kHz NR subcarrier spacing, according to any offset position in the following table:

NR bandwidth (MHz)	Offset positions of the LTE-M carrier center, in number of NR subcarriers relative to the NR raster
10	-20+n60 where n is integer from -2 to 2
15	-20+n60 where n is integer from -3 to 4
20	-50+n60 where n is integer from -4 to 5
25	-50+n60 where n is integer from -5 to 7
30	-20+n60 where n is integer from -7 to 8
40	-20+n60 where n is integer from -10 to 10
50	-50+n60 where n is integer from -12 to 14
60	-20+n60 where n is integer from -15 to 16
80	-50+n60 where n is integer from -20 to 22
100	-50+n60 where n is integer from -26 to 28

5

12. The network device of claim 1, wherein the center of the LTE-M carrier is located at an NR subcarrier index k^* relative to an NR raster, where k^* is in a set $k^*=10q$, where q is an integer,

wherein k^* is in the range:

$$10 \quad \frac{B_L/2+G-B_{nr}/2-15}{N_S} \leq k^* \leq \frac{B_{nr}/2-B_L/2-G-15}{N_S},$$

where N_S is NR subcarrier spacing, B_L is operational bandwidth for LTE-M, B_{nr} is the NR bandwidth and G represents bandwidth of the guard bands for the LTE-M carrier,

wherein the LTE-M carrier center is positioned at k^* according to one of the

15 following equations, where N_{RB} is the number of NR resource blocks (RBs):

$$\frac{(12N_S)L + B_L/2 + G - 15}{N_S} \leq k^* \leq \frac{(12N_S)(L + N_{RB}) - B_L/2 - G - 15}{N_S}$$

for an even number of NR resource blocks, where L is an integer and

$$(-N_{RB}/2 + 1) \leq L \leq N_{RB}/2; \text{ and}$$

$$\frac{(12N_S)L + B_L/2 + G - 15 - (12N_S/2)}{N_S} \leq k^*$$

$$\leq \frac{(12N_S)(L + N_{RB}) - B_L/2 - G - 15 - (12N_S/2)}{N_S}$$

for an odd number of NR resource blocks, where L is an integer and $-(N_{RB} - 1)/2 \leq L \leq (N_{RB} - 1)/2$.

- 5 13. The network device of claim 12, wherein the minimum number N of NR resource blocks needed for the LTE-M carrier is:

$$N = \left\lceil \frac{B_L + 2G}{12N_S} \right\rceil$$

where $\lceil \cdot \rceil$ is a ceiling function.

10

14. The network device of claim 12,

wherein a minimum frequency $F_{nr,min} = -15 + (12N_S)L$ and a maximum frequency

$F_{nr,max} = -15 + (12N_S)(L + N_{RB})$ for an even number of NR resource

blocks, a minimum frequency $F_{nr,min} = -15 - (12N_S/2) + (12N_S)L$ and a

15

maximum frequency $F_{nr,max} = -15 - (12N_S/2) + (12N_S)(L + N_{RB})$ for an odd number of NR resource blocks, and

wherein the maximum guard band bandwidth at left (lower frequency) and right

(higher frequency) sides of the LTE-M carrier are $G_{right} = F_{nr,max} -$

$(F_{LTEM} + B_L/2)$ and $G_{left} = (F_{LTEM} - B_L/2) - F_{nr,min}$, where F_{LTEM} is the

20

LTE-M carrier center.

15. The network device of claim 14, wherein L is:

$$L = \left\lfloor \frac{(F_{LTEM} - B_L/2) + 15}{12N_S} \right\rfloor$$

where $\lfloor \cdot \rfloor$ is the floor function, and

25

wherein the LTE-M carrier center F_{LTEM} is in a position in the range of k^* where L

maximizes the G_{left} and the G_{right} .

16. The network device of claim 1, wherein NR and LTE-M subcarrier alignment occurs according to the equation: $100n = 100m + 30k$, where $100m$ kHz represents the possible

30

frequencies of an NR raster, considering 30 kHz NR subcarrier spacing, and $100n$ kHz

represents where the LTE-M carrier center is able to be placed, where m and n are integers and k is an NR subcarrier index.

17. The network device of claim 1, wherein NR subcarrier spacing is 60 kHz.

5

18. The network device of claim 1, wherein an NR raster is located at subcarrier #0 in a resource block with index $N_{RB}/2$ for an even number of resource blocks, wherein the NR raster is located at subcarrier #6 in a resource block with index $(N_{RB}-1)/2$ for an odd number of resource blocks, wherein N_{RB} is the number of resource blocks, and wherein subcarrier #0 corresponds to the lowest subcarrier in frequency in a resource block and subcarrier index #11 corresponds to the highest subcarrier in frequency in a resource block.

10

19. The network device of claim 1, wherein the network device is a wireless device.

15

20. The network device of claim 1, wherein the network device is a radio network node.

21. The network device of claim 1, wherein the processing circuitry is configured to generate a signal and transmit the generated signal on the LTE-M carrier within the bandwidth of the NR carrier.

20

22. The network device of claim 1, wherein the processing circuitry is configured to receive a signal on the LTE-M carrier within the bandwidth of the NR carrier and process the received signal.

25

23. The network device of claim 22, wherein the processing circuitry is configured to search for the LTE-M carrier within the bandwidth of the NR carrier according to an NR raster.

24. A method for communicating in a wireless communication network, comprising:

30

transmit or receive, via the transceiver circuitry, using a Long Term Evolution - Machine Type Communication (LTE-M) carrier within the bandwidth of a New Radio (NR) carrier with guard bands that are immediately adjacent to each end of the LTE-M carrier and that fit entirely within the NR bandwidth,

wherein the center of the LTE-M carrier is aligned with an NR subcarrier on a 100kHz NR raster grid, and wherein a maximum number of subcarriers in the LTE-M carrier align with subcarriers in NR,

wherein the center of the LTE-M carrier is located within the NR bandwidth such that at least one of:

a minimum number of NR resource blocks are occupied by any part of the LTE-M carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and

given a predetermined number of NR resource blocks that can be occupied by any part of the LTE-M carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE-M carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE-M carrier and the guard bands at each end is maximized.

25. The method of claim 24, wherein the method further comprises generating a signal and the transmitting or receiving comprises transmitting the generated signal on the LTE-M carrier within the bandwidth of the NR carrier.

26. The method of claim 24, wherein the transmitting or receiving comprises receiving a signal on the LTE-M carrier within the bandwidth of the NR carrier and wherein the method further comprises processing the received signal.

27. A network device adapted to:

transmit or receive, via the transceiver circuitry, using a Long Term Evolution (LTE) carrier within the bandwidth of a New Radio (NR) carrier with guard bands that are immediately adjacent to each end of the LTE carrier and that fit entirely within the NR bandwidth,

wherein the center of the LTE carrier is aligned with an NR subcarrier on a 100 kHz NR raster grid, and wherein a maximum number of subcarriers in the LTE carrier align with subcarriers in NR,

wherein the center of the LTE carrier is located within the NR bandwidth such that at least one of:

a minimum number of NR resource blocks are occupied by any part of the LTE carrier and the guard bands at each end, given a predetermined bandwidth for each of the guard bands; and
given a predetermined number of NR resource blocks that can be occupied by any part of the LTE carrier and the guard bands at each end, a minimum guard band bandwidth from each end of the LTE carrier to the respective immediately adjacent NR resource block not occupied by any of part of the LTE carrier and the guard bands is maximized.

5

10

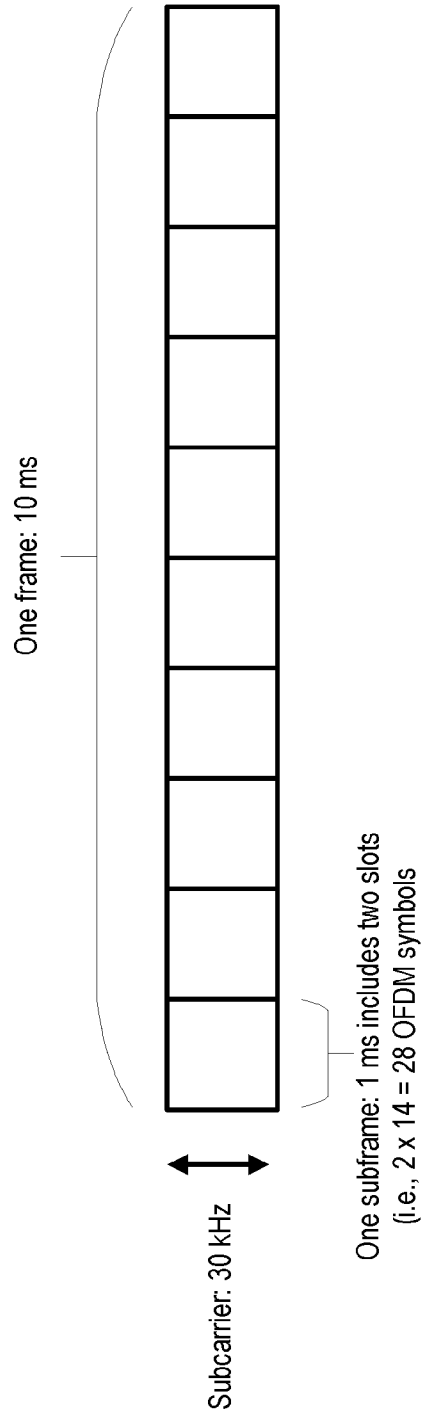


FIG. 1

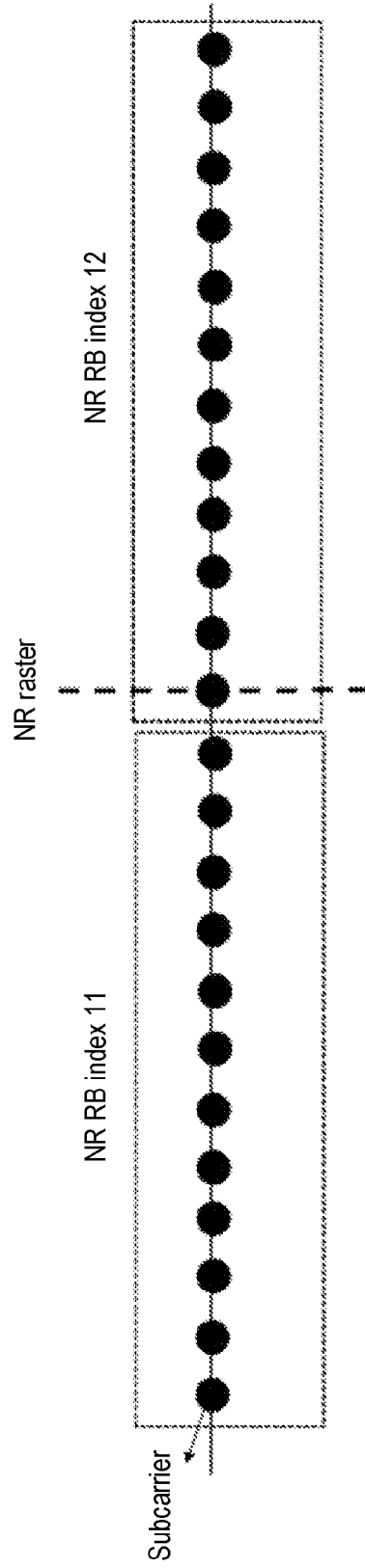


FIG. 2

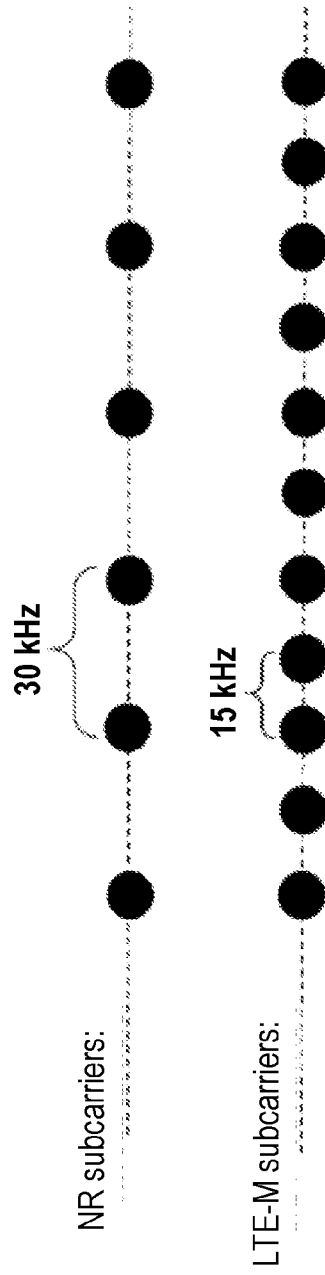


FIG. 3

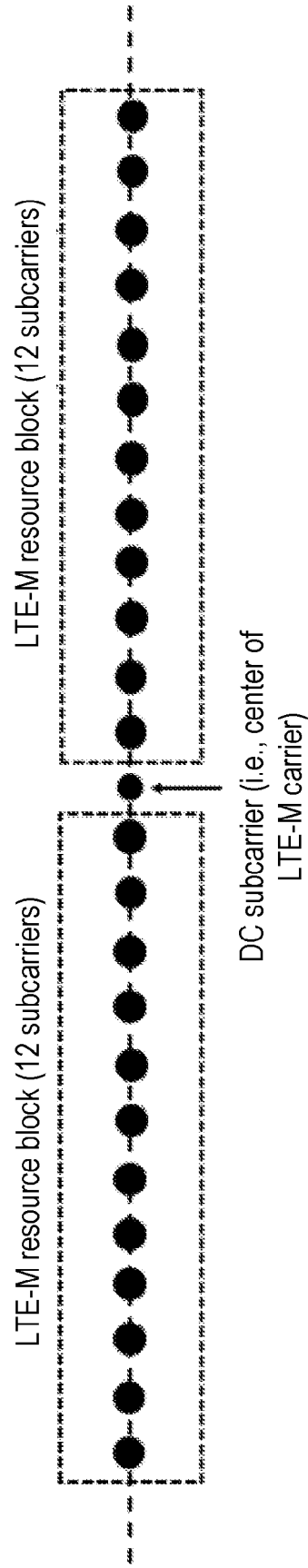


FIG. 4

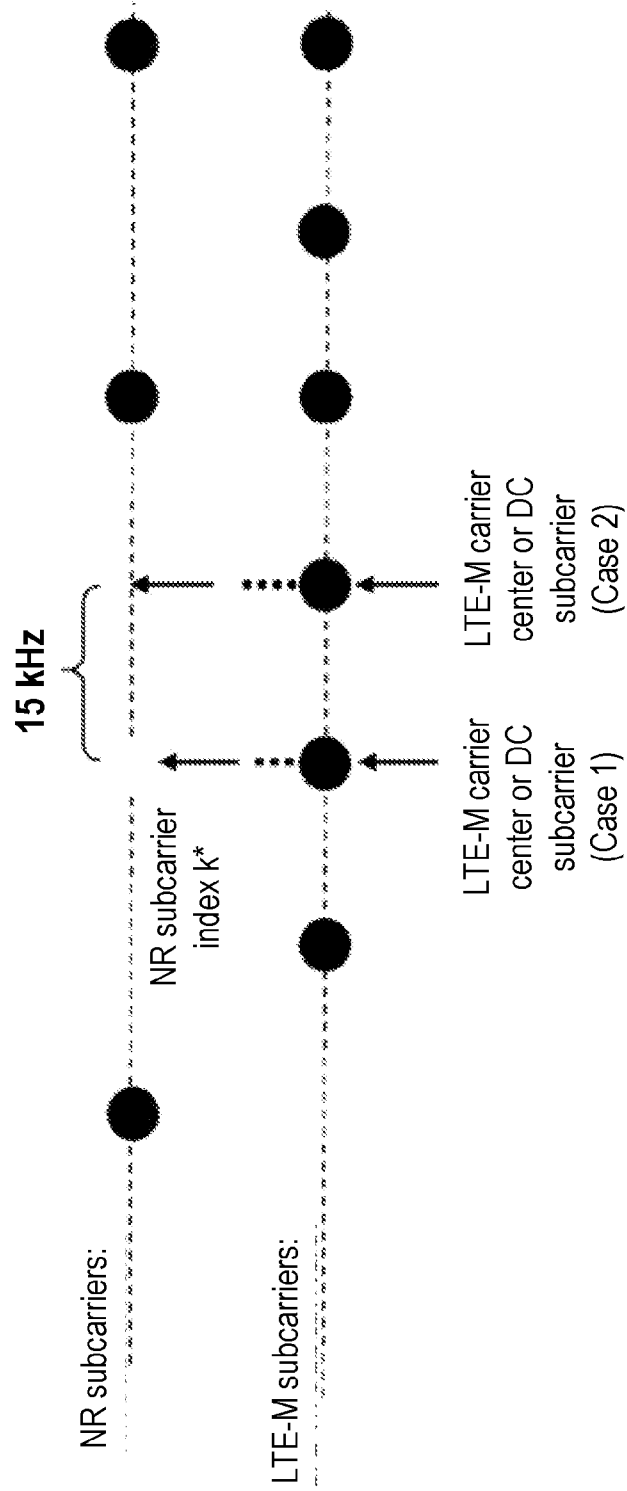


FIG. 5

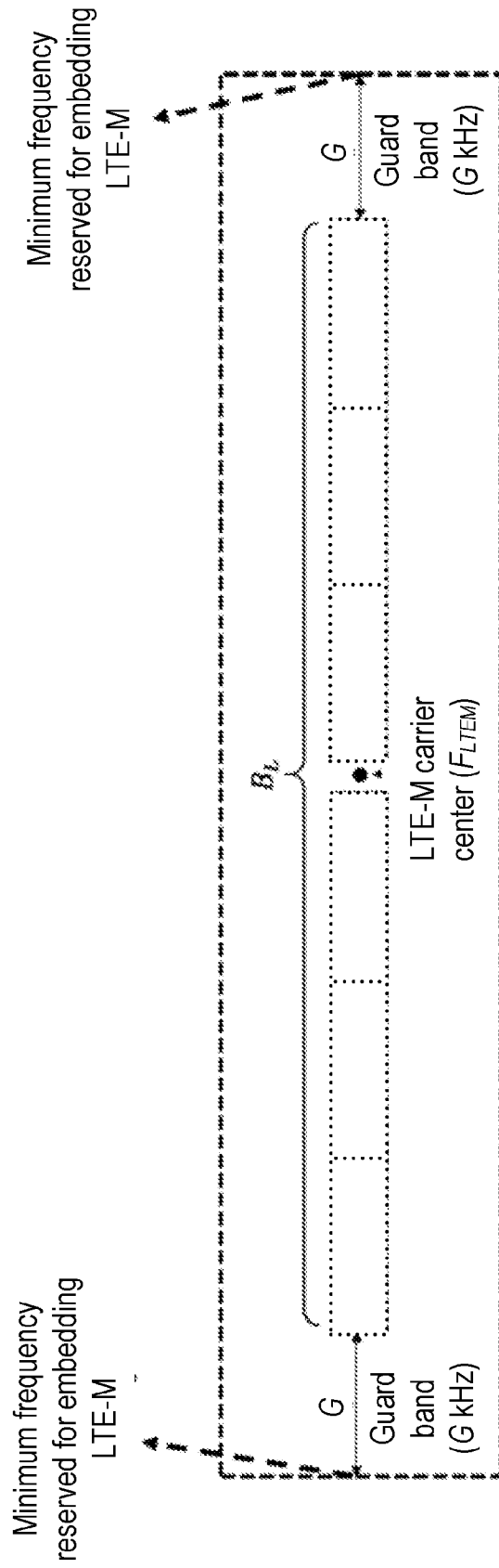


FIG. 6

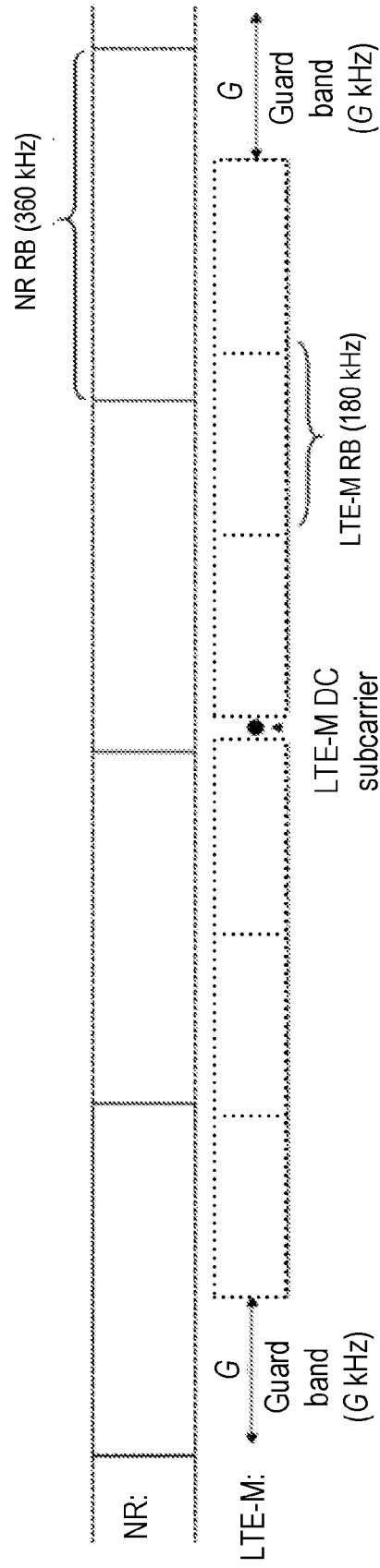


FIG. 7

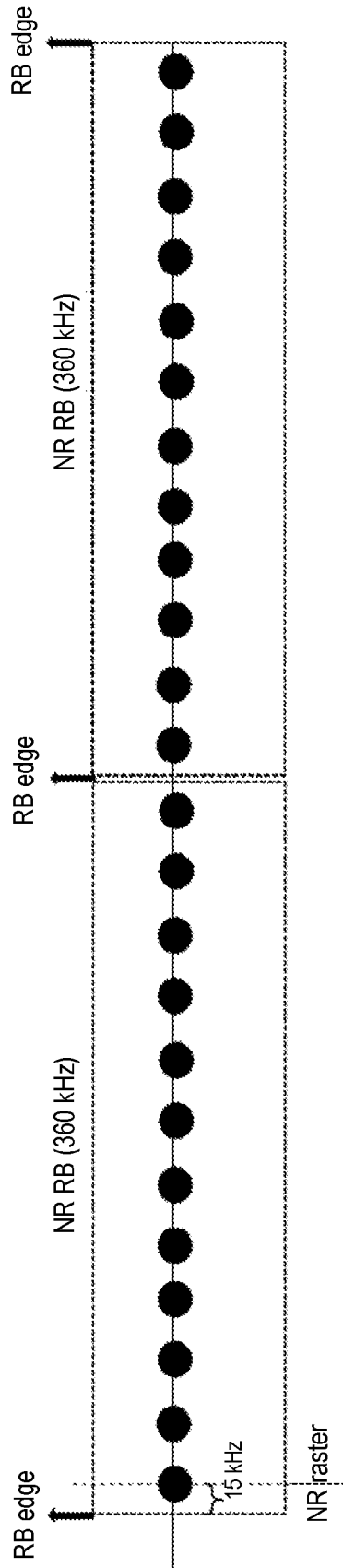


FIG. 8

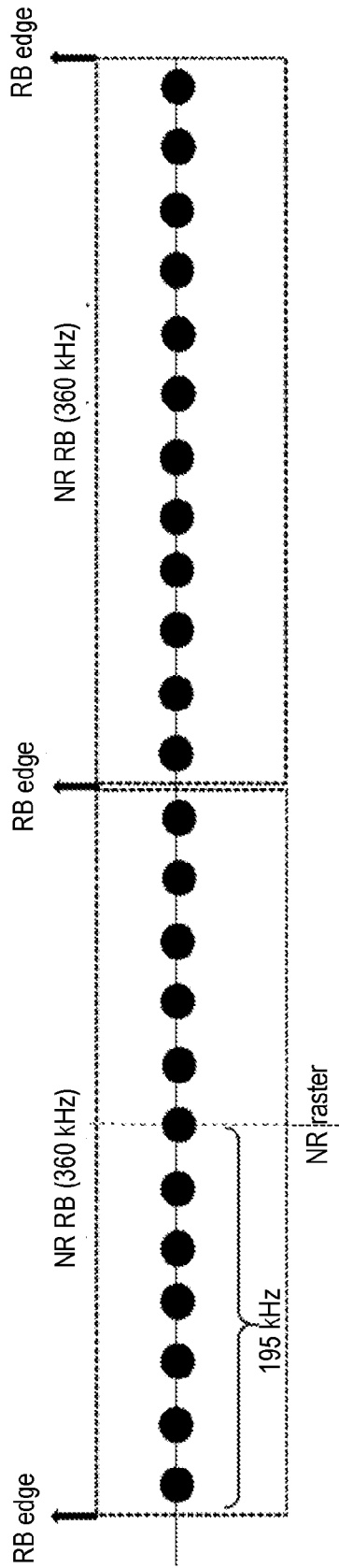


FIG. 9

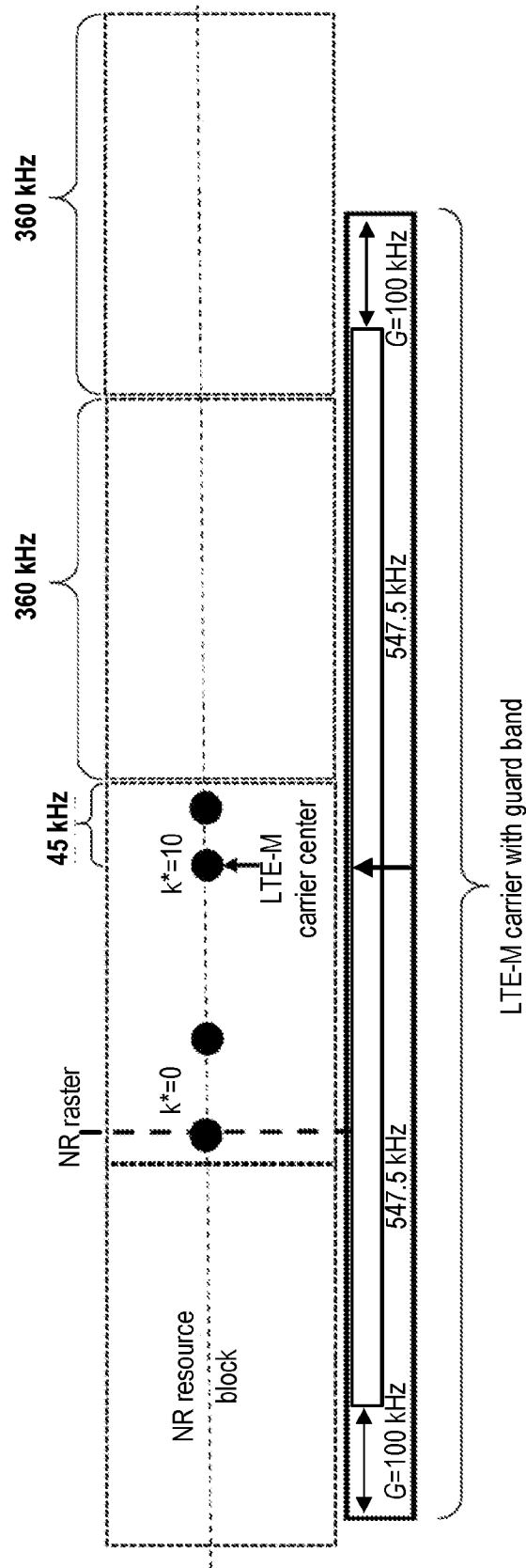


FIG. 10

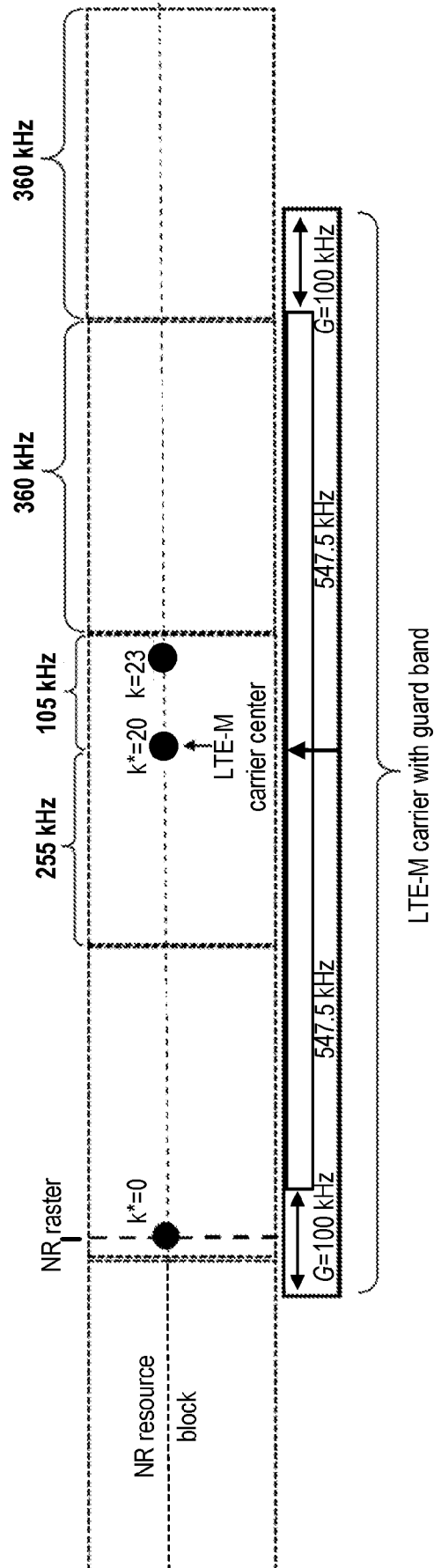


FIG. 11

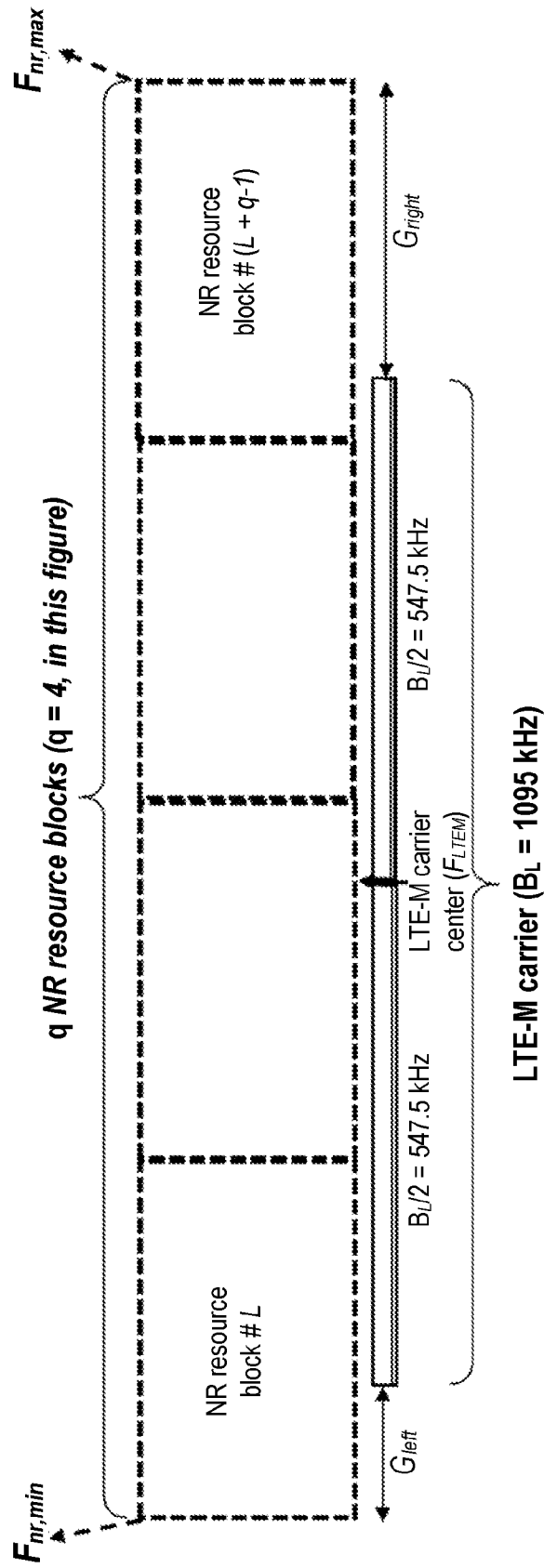
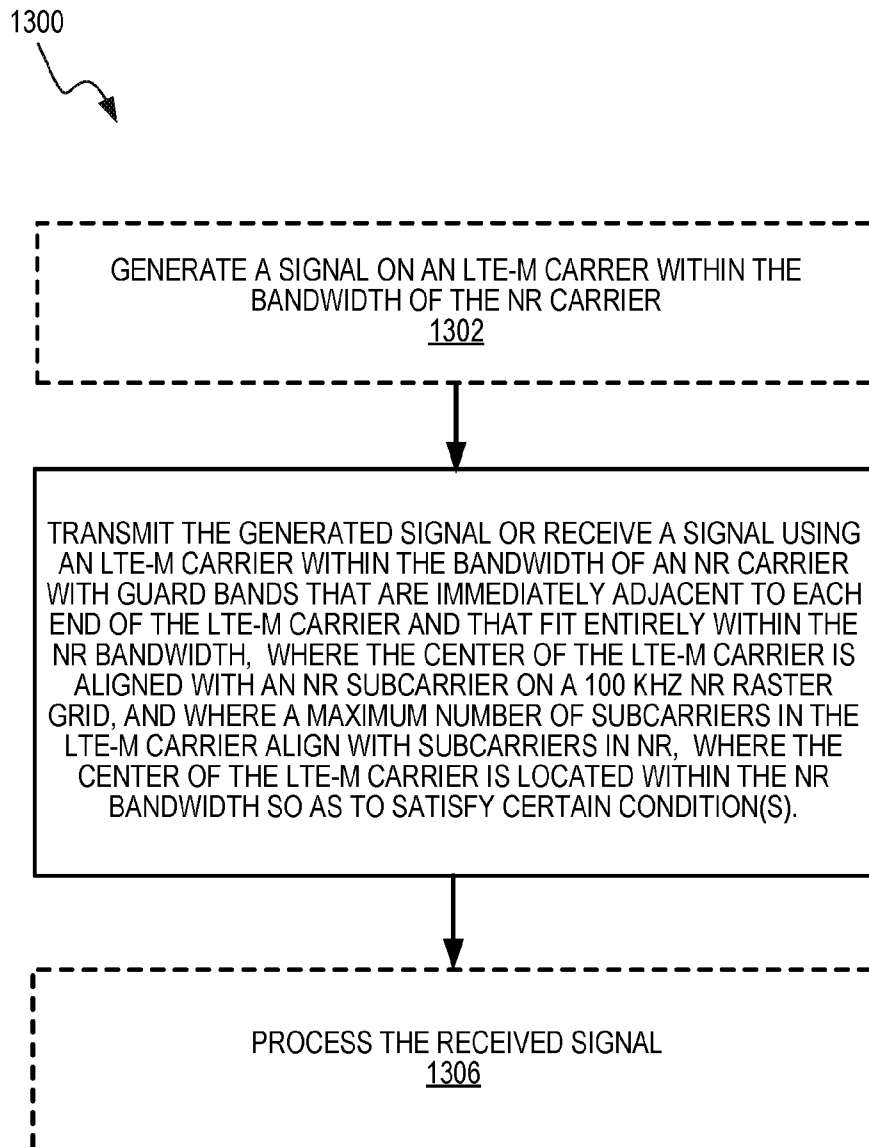


FIG. 12

**FIG. 13**

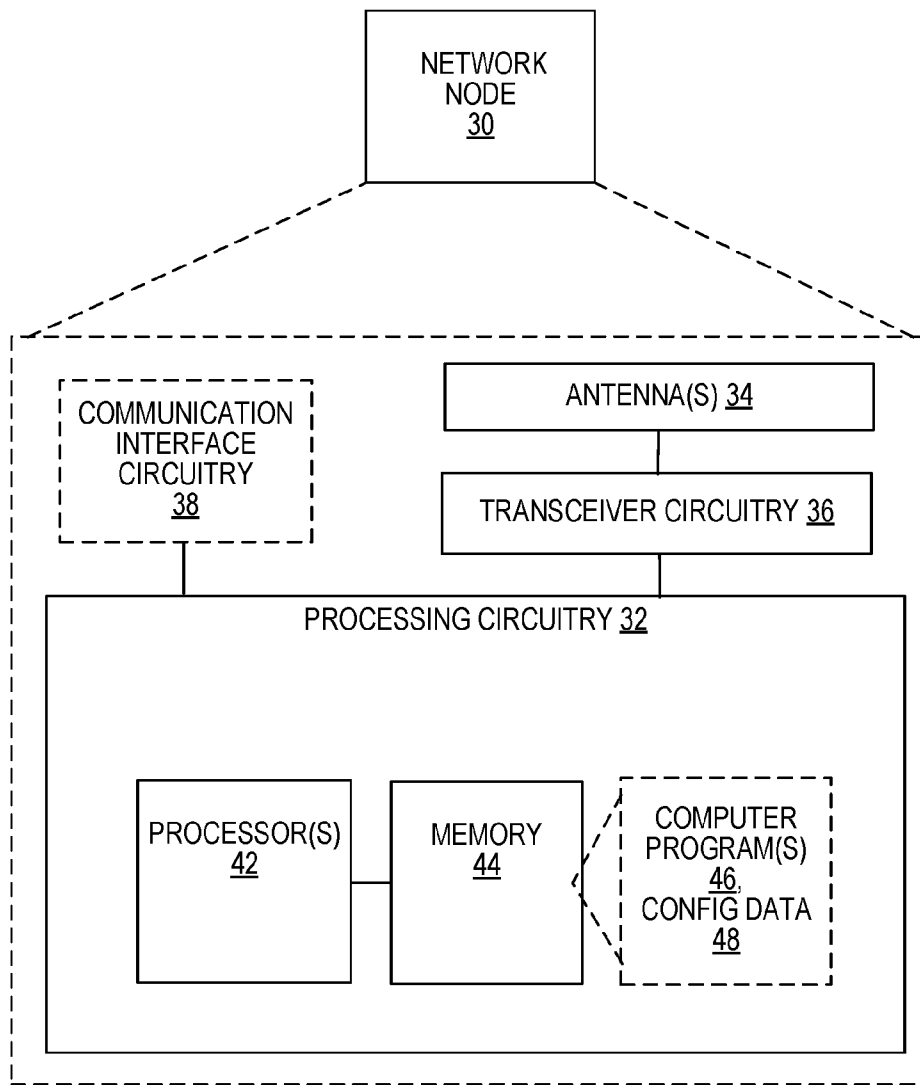


FIG. 14

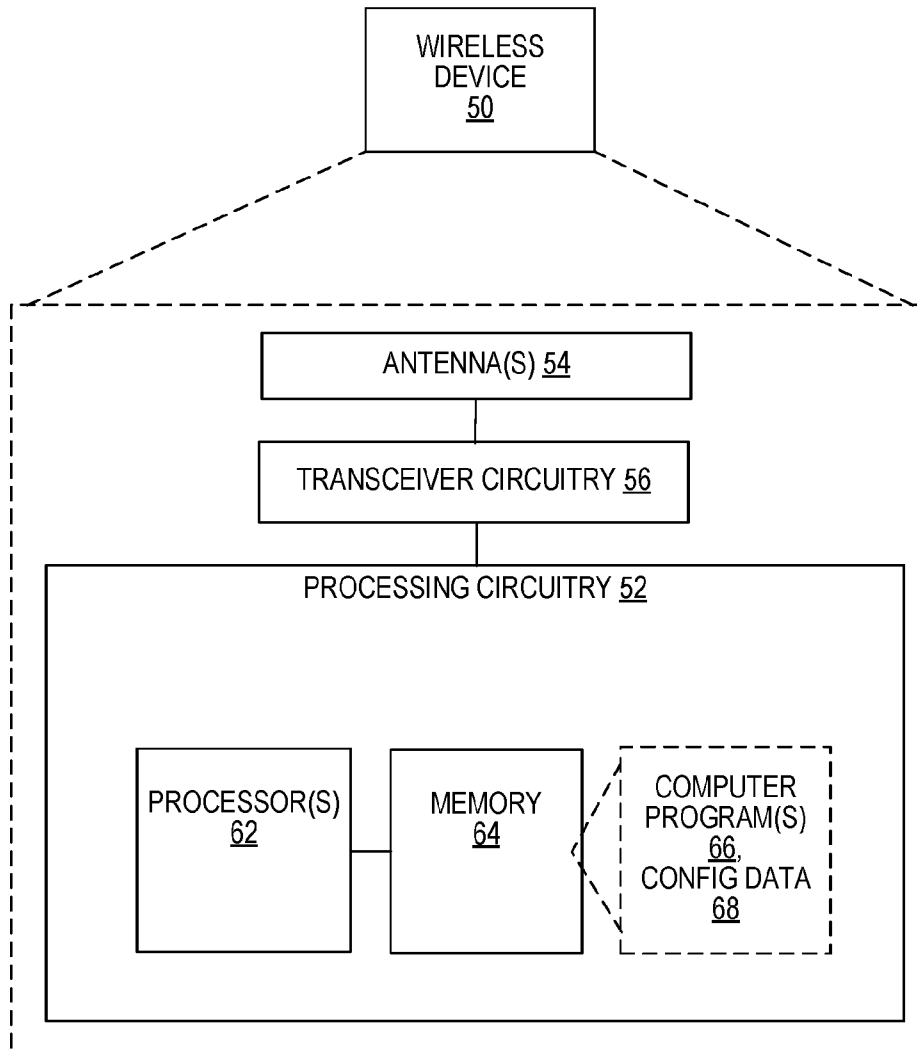


FIG. 15

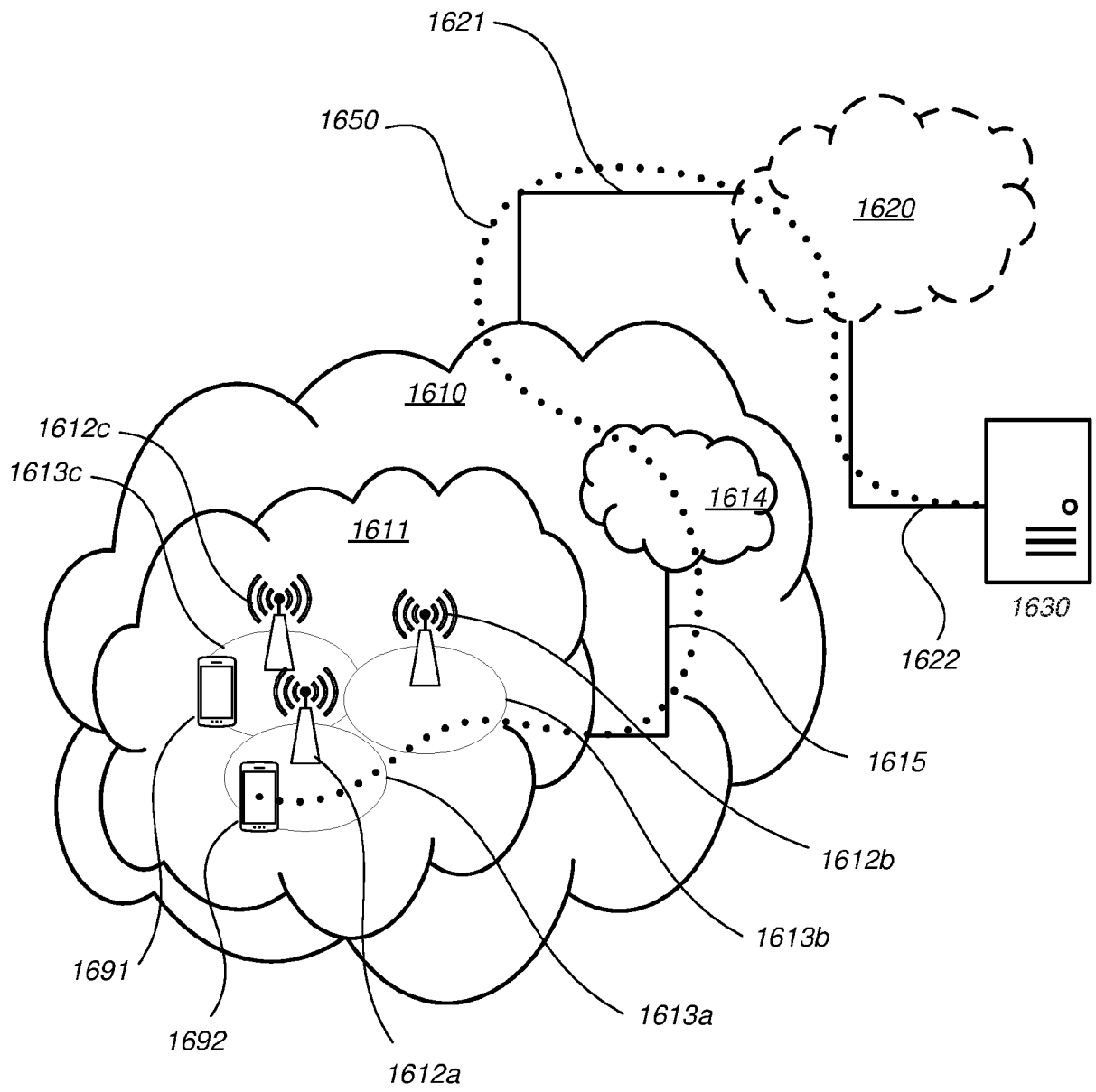


FIG. 16

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1700

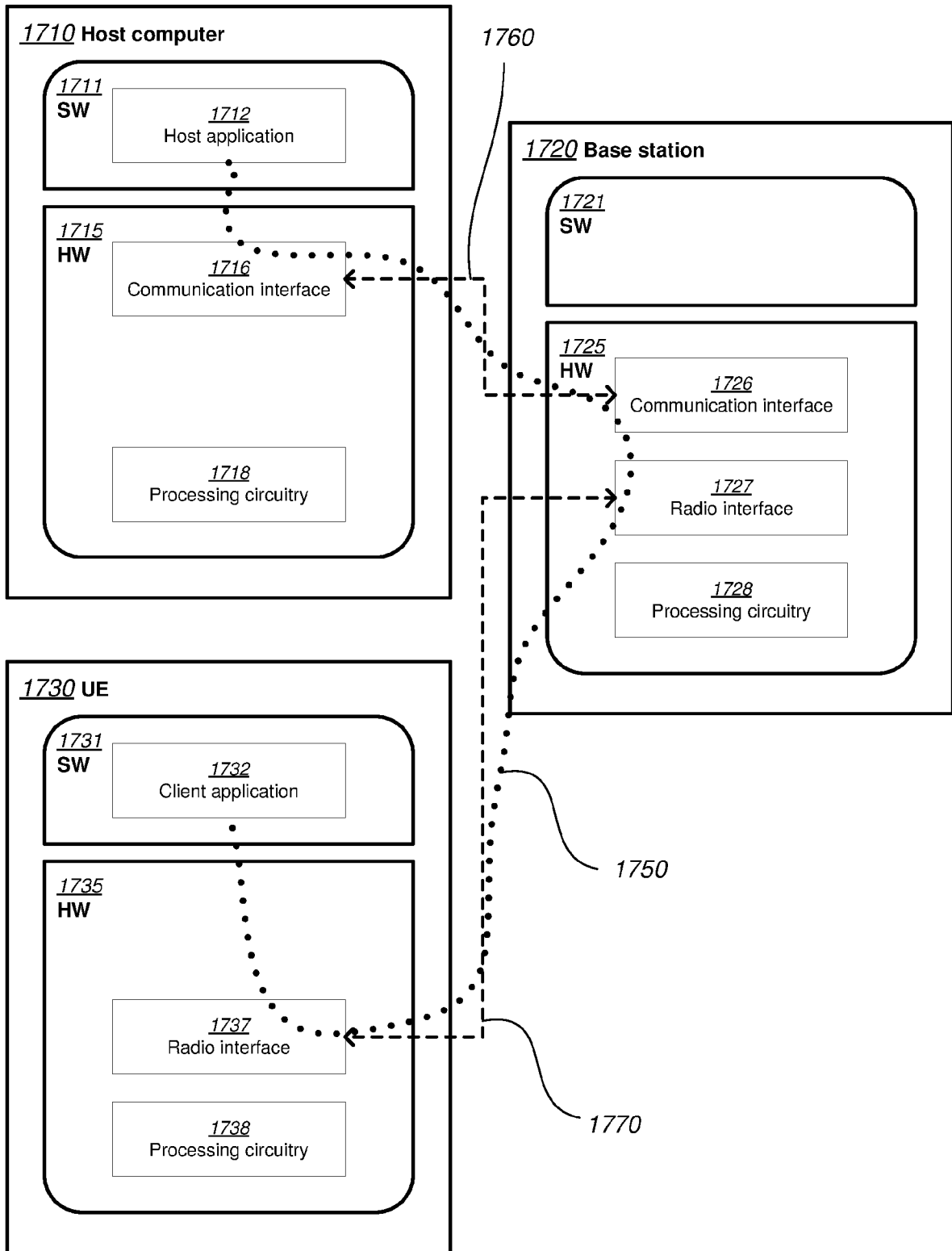


FIG. 17

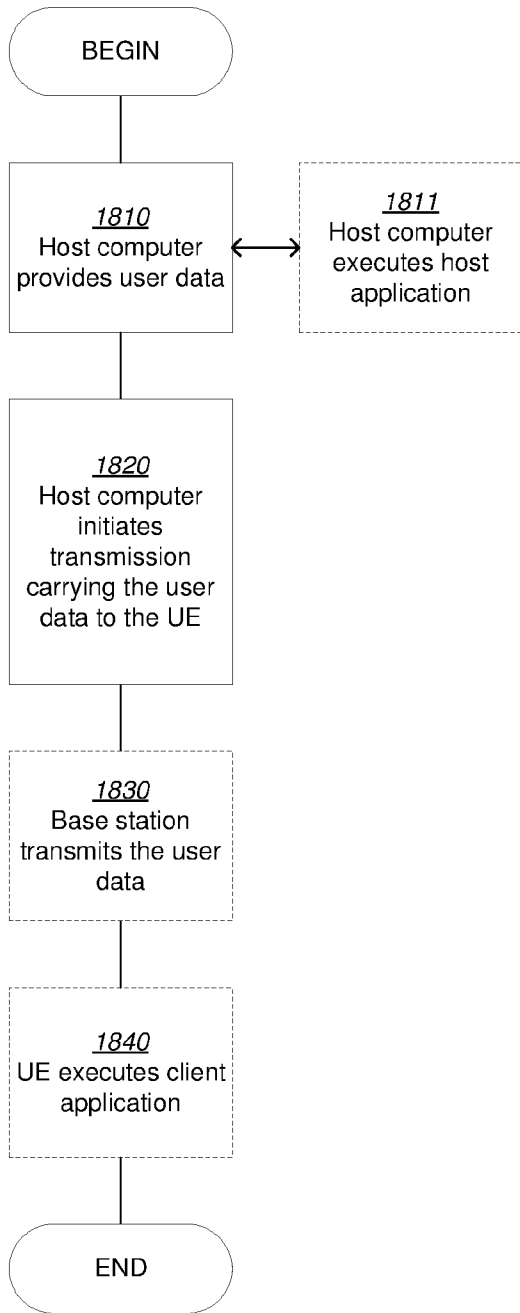


FIG. 18

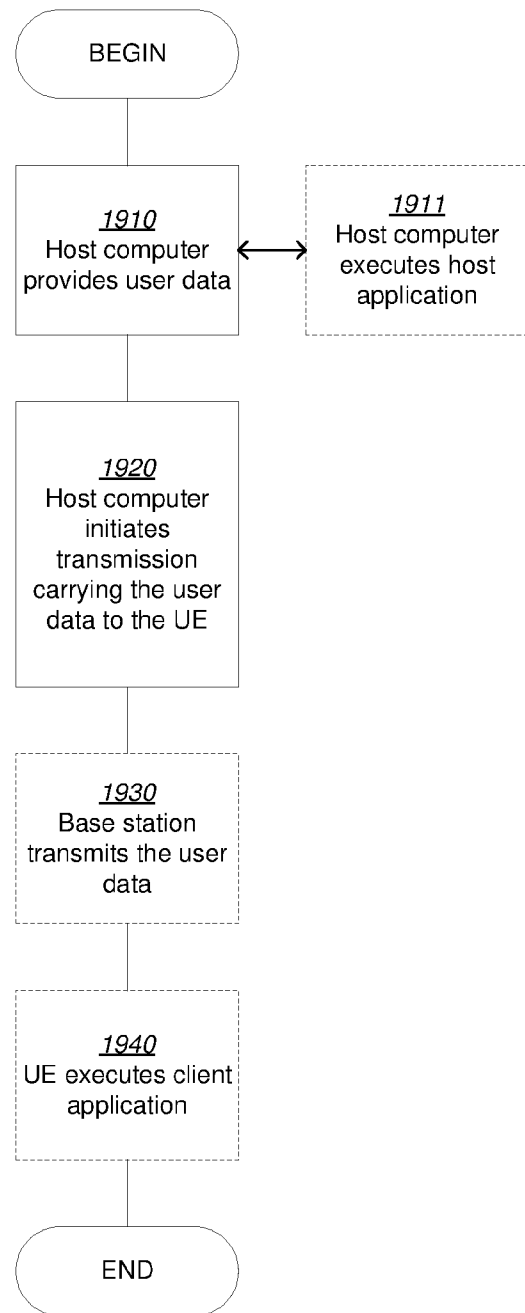


FIG. 19

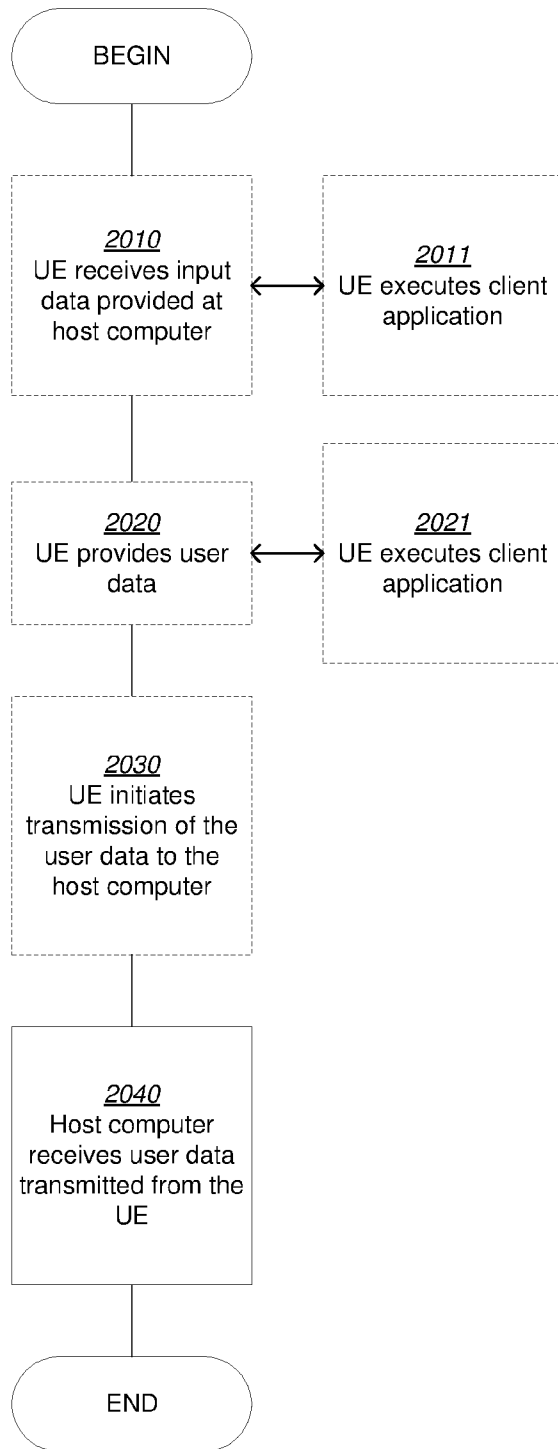


FIG. 20

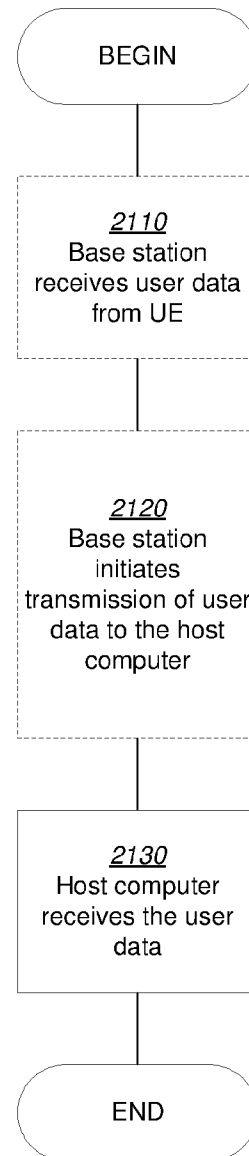


FIG. 21

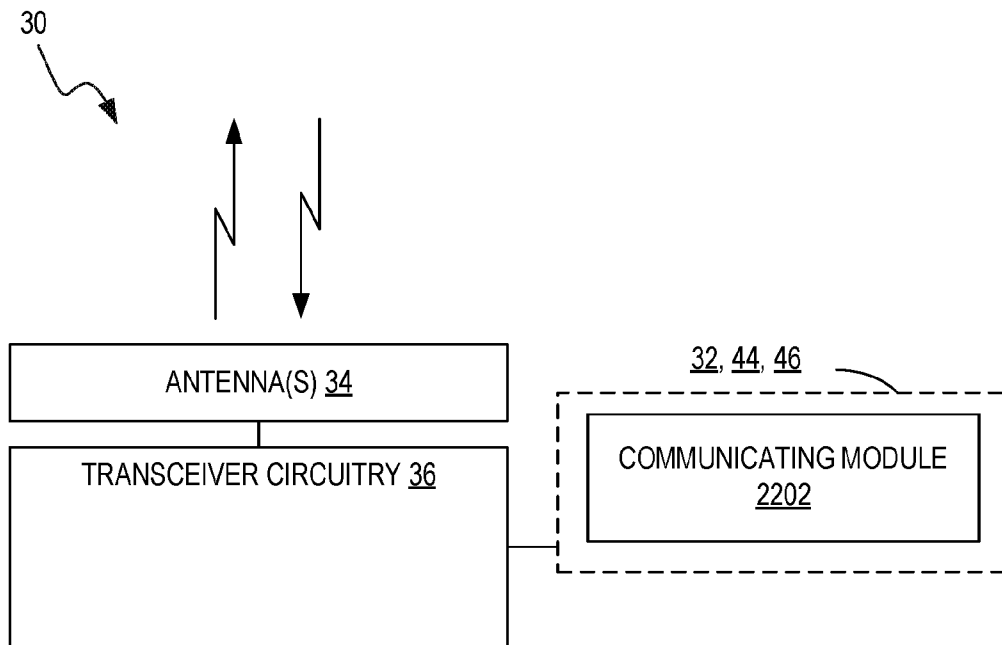


FIG. 22

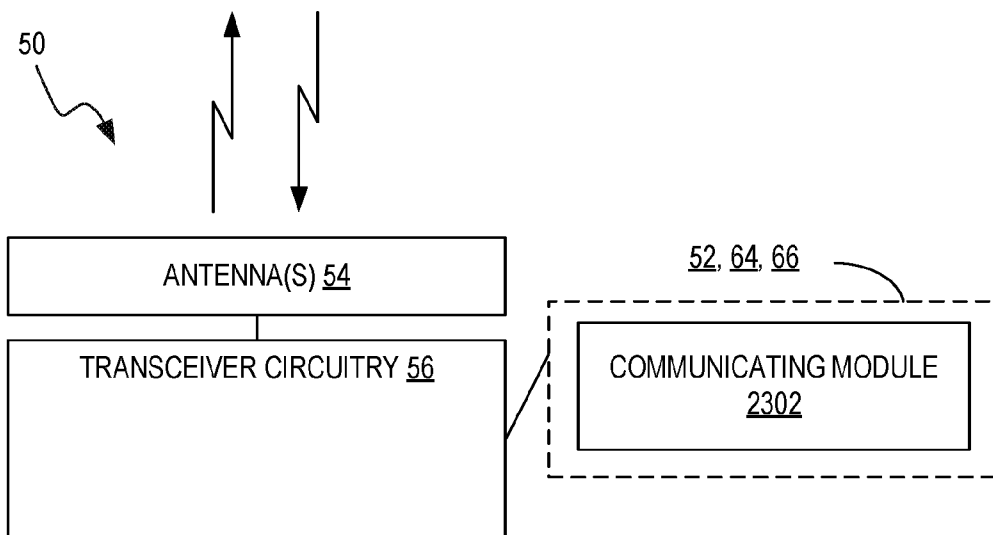


FIG. 23

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/050880

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H04L5/00
 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)
 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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ERICSSON: "Coexistence of LTE-MTC with NR", 3GPP DRAFT; R1-1812122 COEXISTENCE OF LTE-MTC WITH NR, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Spokane, USA; 20181112 - 20181117 11 November 2018 (2018-11-11), XP051553963, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings%5F3GP P%5FSYNC/RAN1/Docs/R1%2D1812122%2Ezip [retrieved on 2018-11-11] sections 1 and 2 ----- -/--	1-27

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

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"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	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 15 April 2020	Date of mailing of the international search report 23/04/2020
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Losada Corderí, Iker
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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/050880

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>ERICSSON: "Feature lead summary for Coexistence of LTE-MTC with NR", 3GPP DRAFT; R1-1813723 FEATURE LEAD SUMMARY FOR COEXISTENCE OF LTE-MTC WITH NR, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS</p> <p>, vol. RAN WG1, no. Spokane, USA; 20181112 - 20181116 14 November 2018 (2018-11-14), XP051494313, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg%5Fran/WG1%5FRL1/TSGR1%5F95/Docs/R1%2D1813723%2Ezip [retrieved on 2018-11-14] section 2</p>	1-27
A	<p>-----</p> <p>QUALCOMM INCORPORATED: "Coexistence of LTE-MTC with NR", 3GPP DRAFT; R1-1813041_COEXISTENCE, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE</p> <p>, vol. RAN WG1, no. Spokane, USA; 20181112 - 20181116 11 November 2018 (2018-11-11), XP051555022, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings%5F3GP%5FSYNC/RAN1/Docs/R1%2D1813041%2Ezip [retrieved on 2018-11-11] section 2.1</p> <p>-----</p>	1-27