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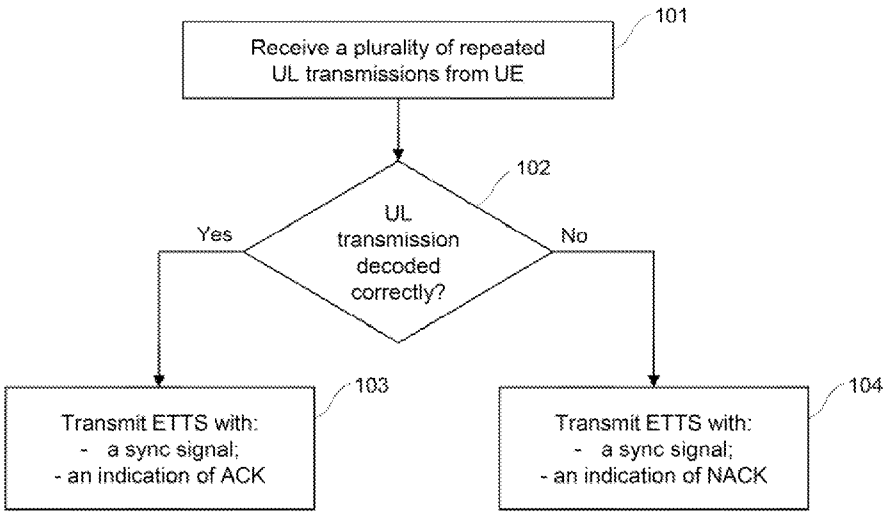


Fig. 9

(57) Abstract: A method of communication between a wireless base station and a wireless device comprises, at the wireless base station, receiving a plurality of repeated uplink transmissions from the wireless device, the plurality of repeated uplink transmissions forming part of a sequence of repeated uplink transmissions. The method determines if the uplink transmission is decoded correctly from the plurality of uplink transmissions and then transmits a downlink signal to the wireless device during an uplink compensation gap after receiving the plurality of uplink transmissions. The downlink signal comprises a synchronization signal to allow the wireless device to re-synchronize with the wireless base station and an indication to the wireless device of whether the uplink transmission was decoded correctly.

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Early Data Termination in a Wireless Communication Network

Technical Field

[0001] The following disclosure relates to a wireless communication network, such as a Narrowband Internet of Things (NB-IoT) or a Long Term Evolution for Machines (LTE-M) network.

Background

[0002] Narrowband Internet of Things (NB-IoT) is a 3rd Generation Partnership Project (3GPP) technology designed to support a type of device which has low complexity, very low throughput and low energy consumption. It is usually used for MTC (Machine Type Communication) services that require low throughput and longer range than standard Long Term Evolution (LTE) devices while being tolerant to high latency. Another 3GPP technology for machine-to-machine communication is Long Term Evolution for Machines (LTE-M), also called Enhanced Machine Type Communication (eMTC). These technologies may be collectively referred to as Long Term Evolution Internet of Things (LTE IoT).

[0003] NB-IoT in the 3GPP specification is similar to legacy LTE. NB-IoT includes several improvements specifically designed for use cases such as extreme coverage. In extreme coverage a base station will experience low SNR due to a maximum coupling loss (MCL) of 164dB. The NB-IoT standard allows the UE to send repetitions of the uplink (UL) data. An UL transmission is defined in several documents of the 3GPP. Technical specifications (TS) 36.101 defined an UL transmission for NB-IoT to be up to 23dBm (200mWt). The number of repetitions is defined in technical specifications 36.213 and can be seen in the table of Figure 1. The maximum number of repetitions is 128, used in case of low signal-to-noise ratio (SNR). This is defined as extreme coverage.

[0004] The minimum time/frequency allocation for an UL transmission unit is called a resource unit (RU). It is defined in 3GPP TS 36.211. An RU is depended on the Narrowband Physical Uplink Shared Channel (NPUSCH) format, and the subcarrier spacing. The different formats are shown in Figure 2. The maximum number of slots per transmission type is 16. The timing information per slot is dependent on the subcarrier spacing. For $\Delta f = 3.75kHz$ each slot requires 2ms and for $\Delta f = 15kHz$ each slot requires 0.5ms. NPUSCH format 1 is used for UL data transmission.

[0005] As NB-IoT UEs are assumed to be implemented with a low-cost hardware, a long transmission time will cause frequency/timing synchronization degradation. To counter this degradation, a NB-IoT UE has regular gaps in uplink transmissions, called Uplink Compensation Gaps (UCG). After a continuous UL transmission of 256ms there is a UCG of 40ms to allow the UE to acquire frequency/time resynchronization. Figure 3 shows RU usage over a period of time

slots (time = 0ms up to time = 4726 ms.) The UL transmission and resynchronization timeline can be viewed, first at RU-level and then at transmission and synchronization blocks.

[0006] 3GPP Release 15 defines several improvements for NB-IoT. One of these improvements is the addition of a Wake-Up Signal (WUS). The WUS functionality is to synchronize NB-IoT UEs with the frequency and time of the LTE base station (BS). This is performed after the UE has been in discontinuous reception (DRX) for some time, thus losing synchronization with the BS. According to the agreement at the 3GPP RAN1#92bis and 3GPPRAN1#93 meetings, the WUS will have the following formula:

$$d_{WUS}(n) = c(m) \cdot e^{-j2\pi\theta n} \cdot e^{\frac{-j\pi u n'(n'+1)}{L_{ZC}}} \quad (1)$$

where:

$$n' = mod(n, L_{ZC}) m = mod(n, L_{code})$$

[0007] The L_{ZC} is the length of the Zadoff-Chu sequence (ZC). The variable L_{code} is used to denote the code length. The code may be by resource element (RE) level cover code or RE level scrambling code. Currently the variables L_{ZC} is agreed to be 131. The other variables (u, L_{code}) are to be agreed.

[0008] The WUS will be used for synchronization of the UE after at least N instances of DRX (N can have values $N \in [1,2,4,8]$ and up to 10.243ms). Using this series, a UE would be able to synchronize by time and frequency to the base station downlink (DL) transmission. This is similarly to the Narrowband Primary Synchronization Signal (NPSS) and the Narrowband Secondary Synchronization Signal (NSSS) used today to synchronize the DL channel between the base station and the UE.

[0009] In NB-IoT a UE in extreme coverage can transmit the same UL signal for 128 times, which lasts ~4.7seconds. While the repeated transmissions can ensure successful communication in difficult conditions, they can consume a significant amount of energy.

Summary

[0010] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0011] There is provided a method of communication between a wireless base station and a wireless device comprising, at the wireless base station:

receiving a plurality of repeated uplink transmissions from the wireless device, the plurality of repeated uplink transmissions forming part of a sequence of repeated uplink transmissions;

determining if the uplink transmission is decoded correctly from the plurality of received uplink transmissions;

transmitting a downlink signal to the wireless device, wherein the downlink signal is transmitted during an uplink compensation gap after receiving the plurality of repeated uplink transmissions, the downlink signal comprising:

a synchronization signal to allow the wireless device to re-synchronize with the wireless base station; and

an indication to the wireless device of whether the uplink transmission was decoded correctly.

[0012] Optionally, there are two types of downlink signal for transmission during an uplink compensation gap:

a first downlink signal type comprising only a synchronization signal to allow the wireless device to re-synchronize with the wireless base station;

a second downlink signal type comprising a synchronization signal to allow the wireless device to re-synchronize with the wireless base station and an indication to the wireless device of whether the uplink transmission was decoded correctly.

[0013] Optionally, the method comprises selectively using the first downlink signal type and the second downlink signal type during uplink compensation gaps.

[0014] Optionally, the first downlink signal type is transmitted during at least a first uplink compensation gap.

[0015] Optionally, the method comprises signalling to the wireless device which type of downlink signal type will be used.

[0016] Optionally, the method supports communication between the wireless base station and a group of wireless devices, the method comprising:

receiving a plurality of repeated uplink transmissions from each of the group of wireless devices;

determining if the uplink transmission is decoded correctly from the plurality of received uplink transmissions from at least one of the group of wireless devices;

transmitting a downlink signal to the group of wireless devices, wherein the downlink signal is transmitted during an uplink compensation gap after receiving the plurality of repeated uplink transmissions, the downlink signal comprising:

a synchronization signal to allow the group of wireless devices to re-synchronize with the wireless base station; and

an indication to the group of wireless devices that the uplink transmission was decoded correctly.

[0017] Optionally, the method comprises transmitting a further downlink signal to the group of wireless devices, wherein the further downlink signal comprises an indication to an individual wireless device in the group of whether the uplink transmission from that wireless device was decoded correctly.

[0018] Optionally, the further downlink signal is a dedicated signal per wireless device which is transmitted at a downlink resource location known to the wireless device.

[0019] Optionally, the further downlink signal is a combined signal for the group of wireless devices which includes an individual indication for each wireless device in the group.

[0020] Optionally, the synchronization signal has a duration which is shorter than a duration of the uplink compensation gap. For example, the synchronization signal may have a duration of 4-6 subframes.

[0021] Optionally, the synchronization signal comprises a pseudo-random noise sequence or a Zadoff-Chu sequence particular to the wireless device, or the group of wireless devices.

[0022] Optionally, the synchronization signal comprises a cover code or a root indicative of whether the uplink transmission was decoded correctly.

[0023] There is provided a method of communication between a wireless base station and a wireless device comprising, at the wireless device:

transmitting a plurality of repeated uplink transmissions from the wireless device, the plurality of uplink transmissions forming part of a sequence of repeated uplink transmissions;

receiving a downlink signal from wireless base station during an uplink compensation gap, the downlink signal comprising:

a synchronization signal to allow the wireless device to re-synchronize with the wireless base station after transmitting the plurality of repeated uplink transmissions; and

an indication of whether the uplink transmission was decoded correctly by the wireless base station; and

continuing uplink transmissions in the sequence of repeated uplink transmissions based on the indication of whether the uplink transmission was decoded correctly by the wireless base station.

[0024] Optionally, the method comprises, if the indication indicates that the uplink transmission was decoded correctly by the wireless base station, discontinuing uplink transmissions in the sequence of repeated uplink transmissions.

[0025] Optionally, the method comprises, if the indication indicates that the uplink transmission was not decoded correctly by the wireless base station, continuing with the next uplink transmission in the sequence of repeated uplink transmissions.

[0026] Optionally, there are two types of downlink signal for transmission during an uplink compensation gap:

a first downlink signal type comprising only a synchronization signal to allow the wireless device to re-synchronize with the wireless base station;

a second downlink signal type comprising a synchronization signal to allow the wireless device to re-synchronize with the wireless base station and an indication to the wireless device of whether the uplink transmission was decoded correctly.

[0027] Optionally, the method comprises receiving signalling indicating which type of downlink signal type will be used during an uplink compensation gap.

[0028] Optionally, the wireless device is part of a group of wireless devices, and wherein the downlink signal comprises:

a synchronization signal to allow the group of wireless devices to re-synchronize with the wireless base station; and

an indication to the group of wireless devices that the uplink transmission from at least one of the wireless devices in the group of wireless devices was decoded correctly.

[0029] Optionally, the method comprises receiving a further downlink signal comprising an indication to an individual wireless device in the group of whether the uplink transmission from that wireless device was decoded correctly.

[0030] Optionally, the further downlink signal is a dedicated signal per wireless device which is transmitted at a downlink resource location known to the wireless device.

[0031] Optionally, the further downlink signal is a combined signal for the group of wireless devices which includes an individual indication for each wireless device in the group.

[0032] Optionally, the synchronization signal has a duration which is shorter than a duration of the uplink compensation gap. For example, the synchronization signal may have a duration of 4-6 subframes. This can allow the UE to conserve energy. For example, the may transition to a light sleep state during the remainder of the UCG.

[0033] Optionally, the synchronization signal comprises a pseudo-random noise sequence or a Zadoff-Chu sequence with a cover code or a root indicative of whether the uplink transmission was decoded correctly.

[0034] Optionally, the communication is half duplex frequency division duplex, HD-FDD.

[0035] Optionally, the communication is one of: Long Term Evolution for Machines, LTE-M; Narrowband Internet of Things, NB-IoT.

[0036] In NB-IoT a transmission can continue for up to ~4.7seconds, when the information is transmitted repeatedly for 128 times. In case the eNB successfully decoded the message

beforehand, there is no way for the UE to know that and to stop the transmission. Using a new signal sent during the UE UCG, the eNB can indicate to the UE the UL transmission was successfully decoded and the UE may then stop the retransmission sequence. This can reduce the UE's energy consumption and free time/frequency resources for other UL communication. In this disclosure, this new signal will be called an Early Transmission Termination Signal (ETTS).

[0037] An advantage of at least one example is conserving energy at UEs. If an UL transmission is successfully received by an eNB the UE will receive an indication of this during a subsequent UCG. This allows the UE to discontinue UL transmissions and therefore conserve energy. An energy conservation of up to 60% per transmission cycle may be possible.

[0038] Examples of the invention may be applied to at least one of: NB-IoT, HD-FDD eMTC UL transmission. Both NB-IoT and HD-FDD eMTC use a similar type of signal. The main difference is how the signal is transmitted regarding frequency/time resource allocation. For example, in NB-IoT only 12 subcarriers are available for transmission per symbol (time). In MTC there are up to 6*12 = 72 subcarriers in a single narrowband (or more, depending on the device type). Therefore, for an MTC device, it is possible to transmit more repetitions of the ETTS in the same time, or use frequency hopping to improve transmission robustness using different subcarriers for each ETTS repetition.

[0039] There is also provided apparatus for performing any of the methods described herein.

Brief description of the drawings

[0040] Further details, aspects and embodiments of the invention will be described, by way of example only, with reference to the drawings. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. Like reference numerals have been included in the respective drawings to ease understanding.

[0041] Figure 1 shows possible transmission repetitions in NB-IoT;

[0042] Figure 2 shows NPUSCH transmission formats in NB-IoT;

[0043] Figure 3 shows some example transmission time lines;

[0044] Figure 4 schematically shows a wireless communication system;

[0045] Figure 5 shows an example of communication between a base station and a UE;

[0046] Figure 6 shows a table of transmission formats and a number of UCGs;

[0047] Figure 7 shows an example of mapping ETTS to a DL resource grid;

[0048] Figure 8 shows an example of detection performance;

[0049] Figure 9 shows an example method performed by a base station;

[0050] Figure 10 shows an example method performed by a UE;

[0051] Figure 11 shows an example of communication between a base station and a UE to implement selective ETTS;

[0052] Figure 12 shows BLER for SNR and repetition combinations;

[0053] Figure 13 shows percentage of energy conservation for Figure 12 data with a BLER less than 0.01;

[0054] Figure 14 shows the Figure 12 table, indicating opportunities for energy conservation of at least 20%;

[0055] Figure 15 shows an example method performed by a base station to implement selective ETTS;

[0056] Figure 16 shows an example method performed by a UE to implement selective ETTS;

[0057] Figure 17 shows an example of communication between a base station and a UE which is part of a group of UEs;

[0058] Figure 18 shows signalling for an ETTS group;

[0059] Figure 19 shows an example method performed by a base station to implement group ETTS;

[0060] Figure 20 shows an example method performed by a UE which is part of a group of UEs;

[0061] Figure 21 shows average energy consumption per SNR for BLER less than 0.01;

[0062] Figure 22 shows percentage of energy conservation for Figure 12 data with a BLER less than 0.1;

[0063] Figure 23 shows average energy consumption per SNR for BLER less than 0.1;

[0064] Figure 24 shows example apparatus at a base station or a UE.

Detailed description of the preferred embodiments

[0065] Those skilled in the art will recognise and appreciate that the specifics of the examples described are merely illustrative of some embodiments and that the teachings set forth herein are applicable in a variety of alternative settings.

[0066] Figure 4 schematically shows an example of a wireless communications system with a wireless base station 10 (e.g. wireless base station, eNodeB, eNB) and a wireless device UE 11. A wireless device may be called a user equipment (UE) or a terminal. The wireless device UE may be a machine type communication (MTC) device. A machine type communication device is a device which can communicate without necessarily requiring human interaction at the device and/or network side. Examples of machine type communication devices have applications which

include security (e.g. surveillance), tracking, payment (e.g. point of sale), health, metering, remote maintenance/control (e.g. sensors), metering (e.g. electricity, gas, water), consumer devices (e.g. domestic appliances requiring communication with a network).

[0067] Referring again to Figure 3, communication between a NB-IoT UE and eNB comprises a sequence of UL transmissions on the Narrowband Physical Uplink Shared CHannel (NPUSCH). UL transmissions in the sequence are repetitions, i.e. replicas of the first UL transmission. That is, data content in a first transmission is transmitted again in a second transmission, a third transmission etc. until the total number of configured repetitions is reached. The first row of Figure 3 shows UL transmissions for NPUSCH format 1 with $\Delta f = 3.75kHz$ and the second row of Figure 3 shows UL transmissions for NPUSCH format 1 with Δf = 15kHz. The total number of UL transmissions in the sequence may be 1, 2, 4, 8, 16, 32, 64, or 128, as shown in the table of Figure 1. The UE transmits for a first UL transmission period 31 lasting 256ms. After the first UL transmission period 31 the UE stops transmitting to allow for a first uplink compensation gap (UCG) 41. The UCG 41 is a period of time which allows the UE to reacquire synchronization with the eNB. The UCG 41 lasts 40ms. The number of individual transmissions (repetitions) during the first UL transmission period 31 will vary due to factors such as the NPUSCH transmission format, Δf value (3.75kHz or 15kHz), and number of slots reserved for the UL transmission. The base station eNB can combine the plurality of UL transmissions. The eNB attempts to decode the UL transmission from a combination of the UL transmissions received so far.

[0068] In the examples shown in Figure 3, there are 32 individual UL transmissions during the UL transmission period 31 with Δf = 15kHz, and 8 individual UL transmissions during the UL transmission period 31 with Δf = 3.75kHz. At the end of the UCG 41 the UE resumes UL transmissions. The UE transmits for a second UL transmission period 32 lasting 256ms and then stops transmitting to allow for a second UCG 42. The base station eNB can combine the plurality of UL transmissions received during the first UL transmission period 31 and the second UL transmission period 32 and attempt to decode the combination of UL transmissions. This pattern continues until the UE has reached the configured number of transmissions. As shown in Figure 3, the total length of the UL transmission periods and UCGs can be up to 4.7s. The communication between eNB and UE is Half Duplex Frequency Division Duplex (HD-FDD). This means transmission on the uplink (UL) and reception on the downlink (DL) are separated in time. The UL and DL occupy different frequency bands.

[0069] During at least one of the UCGs 41-45 eNB transmits a new signal which combines the functions of: (i) allowing a UE to acquire resynchronization and (ii) acknowledge if the UL transmission was decoded successfully, or decoded unsuccessfully (i.e. Hybrid Automatic Repeat Request Acknowledgment/Negative Acknowledgment (HARQ ACK/NACK)). In this disclosure this new signal will be called an Early Transmission Termination Signal (ETTS). In some

examples, ETTS may be transmitted during each of the UCGs 41-45. In some examples, a conventional synchronization signal (NPSS/NSSS) may be transmitted during some of the UCGs 41-45 and the new signal ETTS may be transmitted during the other UCGs 41-45. For example, a conventional synchronization signal (NPSS/NSSS) may be transmitted during at least the first UCG 41-45 and the new signal ETTS may be transmitted during the other UCGs 41-45. The UE can use the ETTS to acquire resynchronization with the eNB. The UE can also use the ETTS to determine if the eNB successfully decoded the UL transmission. If the eNB did successfully decode the UL transmission the UE can discontinue UL transmissions in the sequence.

ETTS during each synchronizing period

[0070] Figure 5 shows two example time sequences for communication between a UE and eNB. In the first example the UE transmits using NPUSCH format 1 with $\Delta f = 3.75KHz$. This means each RU is 32ms. Therefore, 8 UL transmissions (8 * 32ms = 256ms) occur before a first UCG. The UE transmits a first subset of UL transmissions (1, 2,….8) during UL transmission period 31. The eNB does not successfully decode the UL transmission from UL transmissions 1-8. During the UCG 41 the eNB sends ETTS indicating that the UL transmission was not successfully decoded (ETTS/NACK). The UE transmits the second subset of UL transmissions (9, 10,….16) in the sequence during UL transmission period 32. The eNB does not successfully decode the UL transmission from UL transmissions 9-16, combined with UL transmissions 1-8. During the UCG 42 the eNB sends ETTS indicating that the UL transmission was not successfully decoded (ETTS/NACK). The UE transmits the third subset of UL transmissions (17, 18,….24) in the sequence during UL transmission period 33. The eNB successfully decodes the UL transmission from UL transmissions 17-24, combined with UL transmissions 1-8 and 9-16. During the UCG 43 the eNB sends ETTS indicating that the UL transmission was successfully decoded (ETTS/ACK). The UE does not transmit any further UL transmissions (25-) in the sequence.

[0071] In the second example the UE transmits using NPUSCH format 1 with $\Delta f = 15KHz$ with $N_{slots}^{RU} = 16$. This means each RU is 8ms, and 32 UL transmissions occur before a re-UCG. The UE transmits a first subset of UL transmissions (1, 2,….32) during UL transmission period 31. The eNB does not successfully decode the UL transmission from UL transmissions 1-32. During the UCG 41 the eNB sends ETTS indicating that the UL transmission was not successfully decoded (ETTS/NACK). The UE transmits the second subset of UL transmissions (33, 34,….64) in the sequence during UL transmission period 32. The eNB does not successfully decode the UL transmission from UL transmissions 33-64, combined with UL transmissions 1-32. During the UCG 42 the eNB sends ETTS indicating that the UL transmission was not successfully decoded (ETTS/NACK). The UE transmits the third subset of UL transmissions (65, 66,….96) in the sequence during UL transmission period 33. The eNB successfully decodes the UL transmission from UL transmissions 65-96, in combination with UL transmissions 1-32 and 33-64. During the

UCG 43 the eNB sends ETTS indicating that the UL transmission was successfully decoded (ETTS/ACK). The UE does not transmit any further UL transmissions (97-) in the sequence.

[0072] In general, during each UCG 41, 42, 43 the eNB can either indicate: (i) successful decoding of the UL transmission by sending ETTS/ACK, or (ii) unsuccessful decoding of the UL transmission by sending ETTS/NACK. The UE receives the ETTS/ACK or ETTS/NACK and then either ceases further UL transmissions or continues UL transmissions.

[0073] When UL early data termination is available, the UE does not use NPSS for re-synchronization, but instead looks for ETTS. ETTS may be a UE specific synchronization signal. ETTS may be a WUS-like signal. ETTS may use WUS-like codes to differentiate an ETTS intended for a first UE from an ETTS intended for a second UE.

[0074] ETTS may be multiplied by [-1 1] to indicate ACK and NACK. Thus, the UE would be able to look for the ETTS while trying to re-synch, achieving both resynchronization and receiving feedback from the network about the transmission.

[0075] Figure 6 shows a table of the number of resynchronization occurrences per repetition number and NPUSCH format. The sequence may have different lengths depending on R_{max}. For example, a high R_{max} will result in higher L_{ZC}. The outcome will be more granularity, ZC sequence resources, and lower probability of false detection. Some combinations complete a full sequence of UL transmissions within the first 256ms UL transmission period. These combinations only allow a single instance of transmitting ETTS. In this proposal the ETTS would be utilized as a part of the HARQ process to save time for the resynchronization and processing.

[0076] Some advantages of using ETTS for UL early data termination include:

- Better utilization of resources – time/frequency for UL are now released faster.
- Lower battery drainage – by using ACK/NACK ETTS signalling the UE can save some battery used for UL transmission. Energy conservation is shown in Figures 21 and 23.
- Because ETTS frequency-time location will be known beforehand to the UE, re-synchronization time theoretically can be decreased. Now the whole synchronization signal is transmitted at a bulk. Therefore, there is no need for the whole 40ms for the retransmission – it is possible to start re-transmission earlier resulting in lower latency.

[0077] The ETTS can be defined by any asynchronous signal. ETTS may, for example, use a pseudo-random noise (PN) sequence or a Zadoff-Chu sequence can be decided later. There are several advantages of using this signal for synchronization then using the NPSS for example:

- ETTS contains cover code/has different root depending on transmission status (ACK/NACK);
- The ETTS is condensed into several sequential subframes, thus allowing for faster resynchronization;

- The ETTS may have different length that can vary with the coverage of the UE;
- The ETTS can be implemented both by Zadoff-Chu sequence and by PN sequence.

[0078] An example of a suitable sequence is a Zadoff-Chu sequence of length 65 with up to 12 repetitions (depending on coverage area), with ACK/NACK differentiation using a {+1,-1} cover code. Figure 7 shows the Zadoff-Chu sequence with 8 recurrences mapped to the DL resource map. This sequence will take up to 4 subframes when transmitted with an in-band configuration. The overall signal lasts for 4ms (4 * 1ms subframes). Portion 51 of each of the subframes is an unused part of a subframe. Portion 52 of each of the subframes is a first repetition of the sequence. Portion 53 of each of the subframes is a second repetition of the sequence.

[0079] The example described here of ETTS transmitted over a period of 4 DL subframes can achieve a high detection probability. It will be appreciated that the ETTS may be transmitted over a longer, or a shorter, number of subframes. For example, when channel SNR is high the network may use less repetitions of the PN or Zadoff-Chu sequence to conserve DL resources and allow the UE to conserve energy.

[0080] In a conventional UCG the synchronization signals are spread over several frames. The UE will need to scan the DL channel for a longer time to receive synchronization. In the example of Figure 7 the signal ETTS has a (much) shorter duration than the overall UCG of 40ms. The UE may conserve energy by going to light sleep when finished with synchronization. This is instead of powering on during all of the UCG.

[0081] Figure 8 shows a graph of detection probability over a range of signal to noise ratios (SNR). The range of SNR values represents using 12 repetitions for very low SNR conditions. A first trace shows probability of no detection (ND). Probability of no detection reduces to zero above a SNR of around -16dB. A second trace shows probability of false detection (FD). Probability of false detection is zero across this range of SNRs. When the SNR improves the number of repetitions can be reduced. Also, the detector implementation is very crude and can be improved further to allow for some false alarm in exchange for better detection probability.

[0082] Figure 9 shows an example method performed by a base station. At block 101 the eNB receives a plurality of repeated UL transmissions from a UE. The plurality of UL transmissions form part of a sequence of repeated UL transmissions. Block 102 determines if the UL transmission is decoded correctly from the plurality of UL transmissions. The eNB can combine the plurality of UL transmissions. If the UL transmissions are decoded correctly the method proceeds to block 103. The eNB transmits ETTS with a sync signal and an indication of ACK. If the UL transmission is not decoded correctly the method proceeds to block 104. The eNB transmits ETTS with a sync signal and an indication of NACK.

[0083] Figure 10 shows an example method performed by a UE. The method shows UE-side functions corresponding to the eNB-side functions of Figure 9. At block 151 the eNB transmits a plurality of repeated UL transmissions to the eNB. The plurality of repeated UL transmissions form part of a sequence of repeated UL transmissions. The UE then pauses UL transmissions for an UCG. At block 152 the UE receives ETTS. The UE uses ETTS to acquire synchronization with the eNB. The UE also uses ETTS to determine if the eNB decoded the UL transmission correctly. If ETTS indicates ACK, the UE proceeds to block 154 and discontinues UL transmissions in the sequence as they are not required. If ETTS indicates NACK, the UE proceeds to block 155 and continues UL transmissions in the sequence.

Selective use of ETTS during synchronizing periods

[0084] Figure 11 shows two example time sequences for communication between a UE and eNB. To simplify comparison, these examples use the same transmission formats as Figure 5. In the first example the UE transmits using NPUSCH format 1 with $\Delta f = 3.75KHz$. The UE transmits a first subset of UL transmissions (1, 2,….8) during UL transmission period 31. During the first UCG 41 the eNB transmits a normal synchronization signal (e.g. NPSS/NSSS). This allows the UE to acquire synchronization, but does not inform the UE if the UL transmission was successfully decoded from UL transmissions 1-8. The UE transmits the second subset of UL transmissions (9, 10,….16) in the sequence during UL transmission period 32. During the UCG 42 the eNB transmits a normal synchronization signal (e.g. NPSS/NSSS). The UE transmits the third subset of UL transmissions (17, 18,….24) in the sequence during UL transmission period 33. The eNB successfully decodes the UL transmission from UL transmissions 17-24 in combination with UL transmissions 1-16. During the UCG 43 the eNB sends ETTS indicating that the UL transmission was successfully decoded (ETTS/ACK). The UE does not transmit any further UL transmissions (25-) in the sequence.

[0085] In the second example the UE transmits using NPUSCH format 1 with $\Delta f = 15KHz$ with $N_{slots}^{RU} = 16$. The UE transmits a first subset of UL transmissions (1, 2,….32) during UL transmission period 31. During the first UCG 41 the eNB transmits a normal synchronization signal (e.g. NPSS/NSSS). This allows the UE to acquire synchronization, but does not inform the UE if the UL transmission was successfully decoded from UL transmissions 1-32. The UE transmits the second subset of UL transmissions (33, 34,….64) in the sequence during UL transmission period 32. The eNB does not successfully decode the UL transmission from UL transmissions 33-64 in combination with UL transmissions 1-32. During the UCG 42 the eNB sends ETTS indicating that the UL transmission was not successfully decoded (ETTS/NACK). The UE transmits the third subset of UL transmissions (65, 66,….96) in the sequence during UL transmission period 33. The eNB successfully decodes the UL transmission from UL transmissions 65-96 in combination with UL transmissions 1-32 and 33-64. During the UCG 43

the eNB sends ETTS indicating that the UL transmission was successfully decoded (ETTS/ACK). The UE does not transmit any further UL transmissions (97-) in the sequence.

[0086] In the examples of Figure 11 the new signal is transmitted selectively. During at least one of the UCGs a conventional synchronization signal (e.g. NPSS/NSSS) is transmitted. Energy consumption conservation is fluctuating over time. The network may wish to conserve some transmission resources, and not transmit ETTS in every UCG. Advantageously, the UE knows which UCGs will use the new signal ETTS and which UCGs will use the conventional synchronization signal NPSS/NSSS. This avoids a need for a UE to scan for both types of signal.

[0087] Figure 12 shows a table of Block Error Rate (BLER) for number of repetitions against SNR. The first row shows that, for a SNR of -19dB, the BLER = 1 for 1, 8 and 24 repetitions. The BLER = 0.9 for 32 repetitions. For high values of BLER, the likelihood of a successful transmission is low. In scenarios where the BLER is high, it may be desirable to transmit a conventional synchronization signal. In scenarios where the BLER is less than a threshold value, it may be desirable to transmit ETTS. This can save resources. For example, for a SNR of -19dB, the first 4 or 5 UCGs can use a conventional synchronization signal, and the next UCG(s) can use ETTS. An ETTS may be transmitted only when there is more than some threshold, e.g. 20%, of expected energy consumption reduction. Figure 13 shows a table of energy conservation based on Figure 12. For example, for a SNR = -19dB, 48 repetitions offers an energy conservation of 25%. Figure 14 corresponds to Figure 13, and retains the entries where energy conservation is >20%. These entries indicate the UCGs where it is advantageous to transmit ETTS.

[0088] An advantage of this example is conservation of DL resources. Some additional overhead may be required to signal to a UE the specific location of the ETTS. Signalling may indicate at least one of:

- if eNB and UE agree to use ETTS;
- the periods during which ETTS will be transmitted. There may be a limited number of possible schemes for selectively transmitting the ETTS per UL transmission type. A scheme may indicate the UCGs during which ETTS will be transmitted. One example scheme has been shown in Figure 14, based on occasions when an energy conservation of at least 20% is possible. Other schemes are possible. Other schemes may indicate the UCGs during which ETTS will be transmitted based on a higher (or a lower) value of energy conservation. Other schemes may indicate the UCGs during which ETTS will be transmitted independently of a value of energy conservation.

[0089] The signalling establishes if, and when, ETTS will be transmitted by the eNB. This is signalled to a UE before UL transmission begins. For example, it may be signalled as part of an UL grant by the network.

[0090] Figure 15 shows an example method performed by a base station to implement selective ETTS. Blocks which are the same as the method of Figure 9 are given the same reference numerals. Block 110 establishes with a UE when ETTS will be used. This is completed before UL transmissions begin. As described above, the eNB establishes when ETTS will be transmitted. At block 101 the eNB receives a plurality of repeated UL transmissions from a UE. The plurality of repeated UL transmissions form part of a sequence of repeated UL transmissions. Block 111 determines if a conventional sync signal or ETTS is required for the current UCG. If a conventional sync signal is required, the method proceeds to block 112 and transmits a conventional sync signal during the UCG. If ETTS is required, the method proceeds to block 102 and determines if the UL transmission has been decoded correctly. The eNB can combine the plurality of UL transmissions. If the UL transmission is decoded correctly the method proceeds to block 103. The eNB transmits ETTS with a sync signal and an indication of ACK. If the UL transmission is not decoded correctly the method proceeds to block 104. The eNB transmits ETTS with a sync signal and an indication of NACK.

[0091] Figure 16 shows an example method performed by a UE to implement selective ETTS. Blocks which are the same as the method of Figure 10 are given the same reference numerals. The method shows UE-side functions corresponding to the eNB-side functions of Figure 15. Block 160 establishes with a UE when ETTS will be used. This is completed before UL transmissions begin. As described above, the eNB establishes when ETTS will be transmitted. At block 151 the eNB transmits a plurality of repeated UL transmissions to the eNB. The plurality of UL transmissions form part of a sequence of repeated UL transmissions. The UE then pauses UL transmissions for an UCG. Block 161 determines if a conventional sync signal or ETTS will be transmitted by eNB during the current UCG. If the eNB will transmit a conventional sync signal the method proceeds to block 162. The UE receives the conventional sync signal and uses it to acquire synchronization with the eNB. If the eNB will transmit ETTS, the method proceeds to block 152. At block 152 the UE receives ETTS. The UE uses ETTS to acquire synchronization with the eNB. The UE also uses ETTS to determine if the eNB decoded the UL transmission correctly. If ETTS indicates ACK, the UE proceeds to block 154 and discontinues UL transmissions in the sequence as they are not required. If ETTS indicates NACK, the UE proceeds to block 155 and continues UL transmissions in the sequence.

Group ETTS

[0092] A way to conserve ETTS resources is by creating ETTS groups. A group of UEs share a pair or trio of ACK/NACK ETTS. During a UCG a UE looks for a specific ETTS of that group. As an ETTS is shared by a group of UEs, there is initially some ambiguity on whether the ACK is specific to a UE or not an ACK in the ETTS will direct the UE to search in a specific search space set in advance for a UEs' specific indication, e.g. with a Downlink Control Information (DCI)

message. This message may contain a UE specific ACK or a whole group ACK. Hence the ambiguity will be solved.

[0093] Figure 17 shows two example time sequences for communication between a UE and eNB. To simplify comparison, these examples use the same transmission formats as Figures 5 and 11. In the first example the UE transmits using NPUSCH format 1 with $\Delta f = 3.75KHz$. The UE transmits a first subset of UL transmissions (1, 2,….8) during UL transmission period 31. During the first UCG 41 the eNB transmits ETTS/NACK. This allows each of the UEs in the group to acquire synchronization. It also informs the group of UEs that the UL transmission of each of the UEs was not successfully decoded.

[0094] The UE transmits the second subset of UL transmissions (9, 10,….16) in the sequence during UL transmission period 32. During the UCG 42 the eNB transmits ETTS/NACK. This allows each of the UEs in the group to acquire synchronization. It also informs the group of UEs that the UL transmission of each of the UEs was not successfully decoded.

[0095] The UE transmits the third subset of UL transmissions (17, 18,….24) in the sequence during UL transmission period 33. The eNB successfully decodes the UL transmission from UE1 from UL transmissions 17-24 in combination with UL transmissions 1-16. During the UCG 43 the eNB sends ETTS/ACK indicating that the UL transmission was successfully decoded (ETTS/ACK). The eNB then transmits a signal DCI-ACK to indicate the identity of the UE for which an UL transmission was successfully decoded. Each of the UEs in the group receives DCI-ACK depending on its search space and determines whether its UL transmission was successfully decoded. In this case, an UL transmission from UE1 was successfully decoded. UE1 does not transmit any further UL transmissions (25-) in the sequence. UE2 to UE#N continue to transmit further UL transmissions (25-) in the sequence.

[0096] The second example is similar, but the UE transmits using NPUSCH format 1 with $\Delta f = 15KHz$ with $N_{slots}^{RU} = 16$.

[0097] In general, the eNB transmits an ETTS-ACK and then transmits another DCI message with the specific ACK to identify the UE. If two UEs from the same group are transmitting at the same time, and the eNB decoded an UL transmission from only one of the UEs, the DCI-ACK will identify the specific UE. If the eNB decoded both UE transmissions at the same time, a group ACK will be sent. If the eNB could not decode any UL transmission it transmits an ETTS/NACK.

[0098] An example of how a group of UEs behave and search for their respective ACK/NACK is shown in Figure 18. Instead of sending a specific DCI per UE, it is possible to send a special message with the group number of bits, where each bit will translate to a UE's ACK/NACK. The advantage of this is that once a bit is set to '1' the message can either be shorter, or the network might leave it for error correcting processes as this bit will not change.

[0099] For a UE to belong to a group it is advantageous the following conditions are met:

Timing is the same – the resynchronization begins at the same time, or within a threshold value.

All UEs in the group know they belong to the same group. This could be configured by higher layers or by an UL grant message.

Each UE knows where to find an ACK/NACK message in case of ETTS/ACK. For example, each UE may be configured with a particular offset in frequency and/or time to a space where the ACK/NACK is transmitted, as shown in Figure 18. This avoids false detection and conserves processing power.

[00100] An advantage of implementing as a group is the conservation of radio resources to transmit ETTS.

[00101] Figure 19 shows an example method performed by a base station to implement group ETTS. Block 200 establishes with a group of UEs how ETTS will be used. This is completed before UL transmissions begin. At block 201 the eNB receives a plurality of repeated UL transmissions from each of UE1 and UE2. The plurality of repeated UL transmissions form part of a sequence of repeated UL transmissions from each UE. Block 202 determines if the UL transmission has been decoded correctly from UE1 or UE2. If the UL transmission is decoded correctly the method proceeds to block 203. At block 203 the eNB transmits ETTS with a sync signal and an indication of ACK. At block 204 the eNB transmits an indication of ACK/NACK per UE. One example of this signalling is shown in Figure 18. If the UL transmissions are not decoded correctly the method proceeds to block 205. The eNB transmits ETTS with a sync signal and an indication of NACK. There is no need for a per UE indication.

[00102] Figure 20 shows an example method performed by a UE to implement group ETTS. The UE can be considered UE1 in a group of UEs which communicate with the same eNB. The group comprises UE1 and UE2. Block 250 establishes with eNB how ETTS will be used. This is completed before UL transmissions begin. At block 251 the UE transmits a plurality of repeated UL transmissions. The plurality of repeated UL transmissions form part of a sequence of UL transmissions from UE1. UE1 then pauses UL transmissions for an UCG. At block 252 the UE receives a group ETTS. UE1 uses ETTS to acquire synchronization with the eNB. The UE receives the group ACK/NACK indication. At block 252 UE1 receives a per UE indication of ACK/NACK. If the per UE ACK/NACK indication indicates ACK, the UE proceeds to block 255 and discontinues UL transmissions in the sequence as they are not required. If the per UE ACK/NACK indication indicates NACK, the UE proceeds to block 256 and continues UL transmissions in the sequence.

[00103] Group ETTS may be combined with selective ETTS. Similar to Figures 15 and 16, the eNB and UEs only receive ACK/NACK during an UCG when ETTS is transmitted.

Energy conservation calculation

[00104] Using 3GPP UL transmission power requirements, it can be seen a transmission can take up to 200[mWatts]*4096[ms] = 0.8192 [Joule]. Assuming early transmission termination (ETT) is possible, one could calculate the probability of detection depending on the repetition. With each iteration, the probability of correct decoding increases. By having a way to stop transmission early, one would like to calculate the expected energy conservation. This calculation will be performed according to the following formula:

$$EC(R, R_{max}) = EP_{Single} \cdot P(R)(R - R_{max}) \quad (2)$$

where:

EC represents the energy conservation for a designated repetition.

R represents the repetition number, it can receive the values [1,2, 3,…128].

$P_{decode}(R)$ represents the probability of decoding the signal given repetition number.

R_{max} represents the maximum number of re-transmissions set for this transmission. Values can be seen in Figure 1.

EP_{Single} represents the transmitted energy for a single repetition.

[00105] To calculate the energy conservation amount let us assume a scenario. For a transmitter operating at different SNR's, we will calculate the block error rate (BLER). The BLER is the equivalent of $P(R) - 1$. For each SNR point we will run the decoder at different repetition numbers. The result of this simulation can be viewed in Figure 12. For RU type 1 with $\Delta f = 3.75KHz$ a group of 8 UL transmissions (repetitions) are equivalent to 256ms.

[00106] Using the simulation results gathered from Figure 12 the percentage of energy conservation per Simulation and R_{max} set in the last column in Figure 13. A conservative computation for R_{max} is used for the closest repetition that will enable BLER of 0.01.

[00107] When looking at the data it is possible to calculate average energy consumption per scenario. This is shown in Figure 21. Figure 22 shows energy conservation using the Figure 12 simulation results specifying BLER less than 0.1. This will lead to a smaller energy consumption conservation per SNR point as seen in Figure 23.

[00108] Although not shown in detail any of the devices or apparatus that form part of the network may include at least a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method of any aspect of the present invention.

[00109] Figure 24 shows apparatus which can be used to implement a UE or a base station (eNB). The apparatus which may be implemented as any form of a computing and/or electronic device. Processing apparatus 500 comprises one or more processors 501 which may

be microprocessors, controllers or any other suitable type of processors for executing instructions to control the operation of the device. The processor 501 is connected to other components of the device via one or more buses 506. Processor-executable instructions 503 may be provided using any computer-readable media, such as memory 502. The processor-executable instructions 503 can comprise instructions for implementing the functionality of the described methods. The memory 502 is of any suitable type such as read-only memory (ROM), random access memory (RAM), a storage device of any type such as a magnetic or optical storage device. Data 504 used by the processor may be stored in memory 502, or in additional memory. The processing apparatus 500 comprises one or more wireless transceivers 508.

[00110] Further options and choices are described below. The signal processing functionality of the embodiments of the invention may be achieved using computing systems or architectures known to those who are skilled in the relevant art. Computing systems such as, a desktop, laptop or notebook computer, hand-held computing device (PDA, cell phone, palmtop, etc.), mainframe, server, client, or any other type of special or general purpose computing device as may be desirable or appropriate for a given application or environment can be used. The computing system can include one or more processors which can be implemented using a general or special-purpose processing engine such as, for example, a microprocessor, microcontroller or other control module.

[00111] The computing system can also include a main memory, such as random access memory (RAM) or other dynamic memory, for storing information and instructions to be executed by a processor. Such a main memory also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor. The computing system may likewise include a read only memory (ROM) or other static storage device for storing static information and instructions for a processor.

[00112] The computing system may also include an information storage system which may include, for example, a media drive and a removable storage interface. The media drive may include a drive or other mechanism to support fixed or removable storage media, such as a hard disk drive, a floppy disk drive, a magnetic tape drive, an optical disk drive, a compact disc (CD) or digital video drive (DVD) read or write drive (R or RW), or other removable or fixed media drive. Storage media may include, for example, a hard disk, floppy disk, magnetic tape, optical disk, CD or DVD, or other fixed or removable medium that is read by and written to by media drive. The storage media may include a computer-readable storage medium having particular computer software or data stored therein.

[00113] In alternative embodiments, an information storage system may include other similar components for allowing computer programs or other instructions or data to be loaded into the computing system. Such components may include, for example, a removable storage unit

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

[00114] The computing system can also include a communications interface. Such a communications interface can be used to allow software and data to be transferred between a computing system and external devices. Examples of communications interfaces can include a modem, a network interface (such as an Ethernet or other NIC card), a communications port (such as for example, a universal serial bus (USB) port), a PCMCIA slot and card, etc. Software and data transferred via a communications interface are in the form of signals which can be electronic, electromagnetic, and optical or other signals capable of being received by a communications interface medium.

[00115] In this document, the terms 'computer program product', 'computer-readable medium' and the like may be used generally to refer to tangible media such as, for example, a memory, storage device, or storage unit. These and other forms of computer-readable media may store one or more instructions for use by the processor comprising the computer system to cause the processor to perform specified operations. Such instructions, generally 45 referred to as 'computer program code' (which may be grouped in the form of computer programs or other groupings), when executed, enable the computing system to perform functions of embodiments of the present invention. Note that the code may directly cause a processor to perform specified operations, be compiled to do so, and/or be combined with other software, hardware, and/or firmware elements (e.g., libraries for performing standard functions) to do so.

[00116] The non-transitory computer readable medium may comprise at least one from a group consisting of: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory and a Flash memory. In an embodiment where the elements are implemented using software, the software may be stored in a computer-readable medium and loaded into computing system using, for example, removable storage drive. A control module (in this example, software instructions or executable computer program code), when executed by the processor in the computer system, causes a processor to perform the functions of the invention as described herein.

[00117] Furthermore, the inventive concept can be applied to any circuit for performing signal processing functionality within a network element. It is further envisaged that, for example, a semiconductor manufacturer may employ the inventive concept in a design of a stand-alone device, such as a microcontroller of a digital signal processor (DSP), or application-specific integrated circuit (ASIC) and/or any other sub-system element.

[00118] It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to a single processing logic. However, the inventive concept may equally be implemented by way of a plurality of different functional units and processors to provide the signal processing functionality. Thus, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organisation.

[00119] Aspects of the invention may be implemented in any suitable form including hardware, software, firmware or any combination of these. The invention may optionally be implemented, at least partly, as computer software running on one or more data processors and/or digital signal processors or configurable module components such as FPGA devices.

[00120] Thus, the elements and components of an embodiment of the invention may be physically, functionally and logically implemented in any suitable way. Indeed, the functionality may be implemented in a single unit, in a plurality of units or as part of other functional units. Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term 'comprising' does not exclude the presence of other elements or steps.

[00121] Furthermore, although individually listed, a plurality of means, elements or method steps may be implemented by, for example, a single unit or processor. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined, and the inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather indicates that the feature is equally applicable to other claim categories, as appropriate.

[00122] Furthermore, the order of features in the claims does not imply any specific order in which the features must be performed and in particular the order of individual steps in a method claim does not imply that the steps must be performed in this order. Rather, the steps may be performed in any suitable order. In addition, singular references do not exclude a plurality. Thus, references to 'a', 'an', 'first', 'second', etc. do not preclude a plurality.

[00123] Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although

a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term ‘comprising’ or “including” does not exclude the presence of other elements.

Claims

1. A method of communication between a wireless base station and a wireless device comprising, at the wireless base station:

receiving a plurality of repeated uplink transmissions from the wireless device, the plurality of repeated uplink transmissions forming part of a sequence of repeated uplink transmissions;

determining if the uplink transmission is decoded correctly from the plurality of received uplink transmissions;

transmitting a downlink signal to the wireless device, wherein the downlink signal is transmitted during an uplink compensation gap after receiving the plurality of repeated uplink transmissions, the downlink signal comprising:

a synchronization signal to allow the wireless device to re-synchronize with the wireless base station; and

an indication to the wireless device of whether the uplink transmission was decoded correctly.

2. A method according to claim 1 wherein there are two types of downlink signal for transmission during an uplink compensation gap:

a first downlink signal type comprising only a synchronization signal to allow the wireless device to re-synchronize with the wireless base station;

a second downlink signal type comprising a synchronization signal to allow the wireless device to re-synchronize with the wireless base station and an indication to the wireless device of whether the uplink transmission was decoded correctly.

3. A method according to claim 2 comprising selectively using the first downlink signal type and the second downlink signal type during uplink compensation gaps.

4. A method according to claim 2 or 3 wherein the first downlink signal type is transmitted during at least a first uplink compensation gap.

5. A method according to any one of claims 2 to 4 comprising signalling to the wireless device which type of downlink signal type will be used.

6. A method according to any one of the preceding claims which supports communication between the wireless base station and a group of wireless devices, the method comprising:

receiving a plurality of repeated uplink transmissions from each of the group of wireless devices;

determining if the uplink transmission is decoded correctly from the plurality of received uplink transmissions from at least one of the group of wireless devices;

transmitting a downlink signal to the group of wireless devices, wherein the downlink signal is transmitted during an uplink compensation gap after receiving the plurality of repeated uplink transmissions, the downlink signal comprising:

a synchronization signal to allow the group of wireless devices to re-synchronize with the wireless base station; and

an indication to the group of wireless devices that the uplink transmission was decoded correctly.

7. A method according to claim 6 comprising transmitting a further downlink signal to the group of wireless devices, wherein the further downlink signal comprises an indication to an individual wireless device in the group of whether the uplink transmission from that wireless device was decoded correctly.

8. A method according to claim 7 wherein the further downlink signal is a dedicated signal per wireless device which is transmitted at a downlink resource location known to the wireless device.

9. A method according to claim 7 wherein the further downlink signal is a combined signal for the group of wireless devices which includes an individual indication for each wireless device in the group.

10. A method according to any one of the preceding claims wherein the synchronization signal has a duration which is shorter than a duration of the uplink compensation gap.

11. A method according to any one of the preceding claims wherein the synchronization signal comprises a pseudo-random noise sequence or a Zadoff-Chu sequence particular to the wireless device, or the group of wireless devices.

12. A method according to claim 11 wherein the synchronization signal comprises a cover code or a root indicative of whether the uplink transmission was decoded correctly.

13. A method of communication between a wireless base station and a wireless device comprising, at the wireless device:

transmitting a plurality of repeated uplink transmissions from the wireless device, the plurality of uplink transmissions forming part of a sequence of repeated uplink transmissions;

receiving a downlink signal from wireless base station during an uplink compensation gap, the downlink signal comprising:

a synchronization signal to allow the wireless device to re-synchronize with the wireless base station after transmitting the plurality of repeated uplink transmissions; and

an indication of whether the uplink transmission was decoded correctly by the wireless base station; and

continuing uplink transmissions in the sequence of repeated uplink transmissions based on the indication of whether the uplink transmission was decoded correctly by the wireless base station.

14. A method according to claim 13 wherein if the indication indicates that the uplink transmission was decoded correctly by the wireless base station, discontinuing uplink transmissions in the sequence of repeated uplink transmissions.

15. A method according to claim 13 or 14 wherein if the indication indicates that the uplink transmission was not decoded correctly by the wireless base station, continuing with the next uplink transmission in the sequence of repeated uplink transmissions.

16. A method according to any one of claims 13 to 15 wherein there are two types of downlink signal for transmission during an uplink compensation gap:

a first downlink signal type comprising only a synchronization signal to allow the wireless device to re-synchronize with the wireless base station;

a second downlink signal type comprising a synchronization signal to allow the wireless device to re-synchronize with the wireless base station and an indication to the wireless device of whether the uplink transmission was decoded correctly.

17. A method according to claim 16 comprising receiving signalling indicating which type of downlink signal type will be used during an uplink compensation gap.

18. A method according to any one of claims 13 to 17 wherein the wireless device is part of a group of wireless devices, and wherein the downlink signal comprises:

a synchronization signal to allow the group of wireless devices to re-synchronize with the wireless base station; and

an indication to the group of wireless devices that the uplink transmission from at least one of the wireless devices in the group of wireless devices was decoded correctly.

19. A method according to claim 18 comprising receiving a further downlink signal comprising an indication to an individual wireless device in the group of whether the uplink transmission from that wireless device was decoded correctly.

20. A method according to claim 19 wherein the further downlink signal is a dedicated signal per wireless device which is transmitted at a downlink resource location known to the wireless device.

21. A method according to claim 19 wherein the further downlink signal is a combined signal for the group of wireless devices which includes an individual indication for each wireless device in the group.

22. A method according to any one of claims 13 to 21 wherein the synchronization signal has a duration which is shorter than a duration of the uplink compensation gap.

23. A method according to any one of claims 13 to 22 wherein the synchronization signal comprises a pseudo-random noise sequence or a Zadoff-Chu sequence with a cover code or a root indicative of whether the uplink transmission was decoded correctly.

24. A method according to any one of the preceding claims wherein the communication is half duplex frequency division duplex, HD-FDD.

25. A method according to any one of the preceding claims wherein the communication is one of: Long Term Evolution for Machines, LTE-M; Narrowband Internet of Things, NB-IoT.

26. Apparatus configured to perform the method according to any one of the preceding claims.

I_{Rep}	N_{Rep}
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128

Fig. 1

NPUSCH format	Δf	N_{sc}^{RU}	N_{slots}^{UL}	N_{symb}^{UL}
1	3.75 kHz	1	16	7
	15 kHz	1	16	
		3	8	
		6	4	
		12	2	
2	3.75 kHz	1	4	
	15 kHz	1	4	

Fig. 2

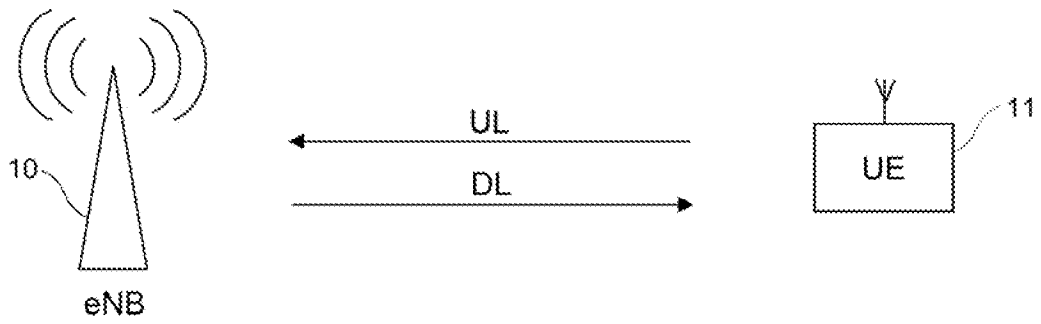


Fig. 4

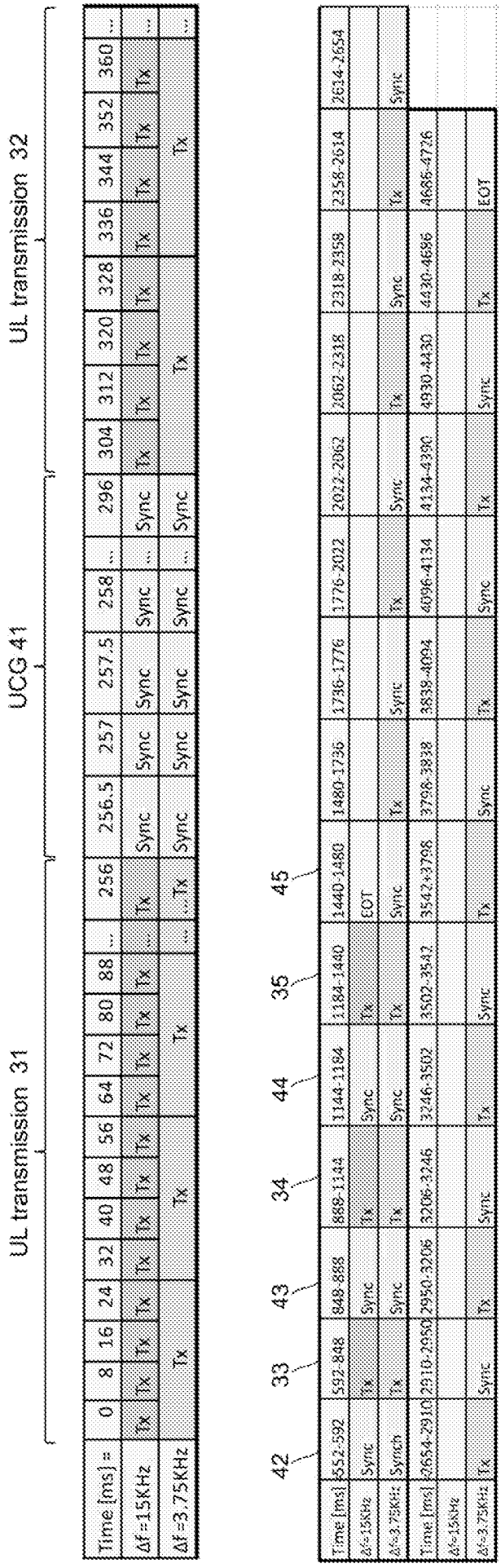

UL transmission 31
UCG 41
UL transmission 32
Time [ms] = 0 8 16 24 32 40 48 56 64 72 80 88 ... 256 256.5 257 257.5 258 ... 296 304 312 320 328 336 344 352 360 ...
Δf =15KHz Tx Tx Tx Tx Tx Tx Tx Tx Tx Tx Tx Tx .. Tx Sync Sync Sync .. Sync Tx Tx Tx Tx Tx Tx Tx ..
Δf =3.75KHz Tx Tx ... Tx Sync Sync Sync ... Sync Tx ...
42 33 43 34 44 35 45
Time [ms] 552-592 592-848 848-888 888-1144 1144-1184 1184-1440 1440-1480 1480-1736 1736-1776 1776-2022 2022-2062 2062-2318 2318-2358 2358-2614 2614-2654
Δf=15KHz Sync Tx Sync Tx Sync Tx EOT Tx Sync Tx Sync Tx Sync Tx
Δf=3.75KHz Synch Tx Sync Tx Sync Tx Sync Tx Sync Tx Sync Tx Sync Tx Sync
Time [ms] 2654-2910 2910-2950 2950-3206 3206-3246 3246-3502 3502-3542 3542+3798 3798-3838 3839-4094 4096-4134 4134-4390 4390-4430 4430-4686 4686-4726
Δf=15KHz
Δf=3.75KHz Tx Sync Tx Sync Tx Sync Tx Sync Tx Sync Tx Sync Tx EOT

Fig. 3

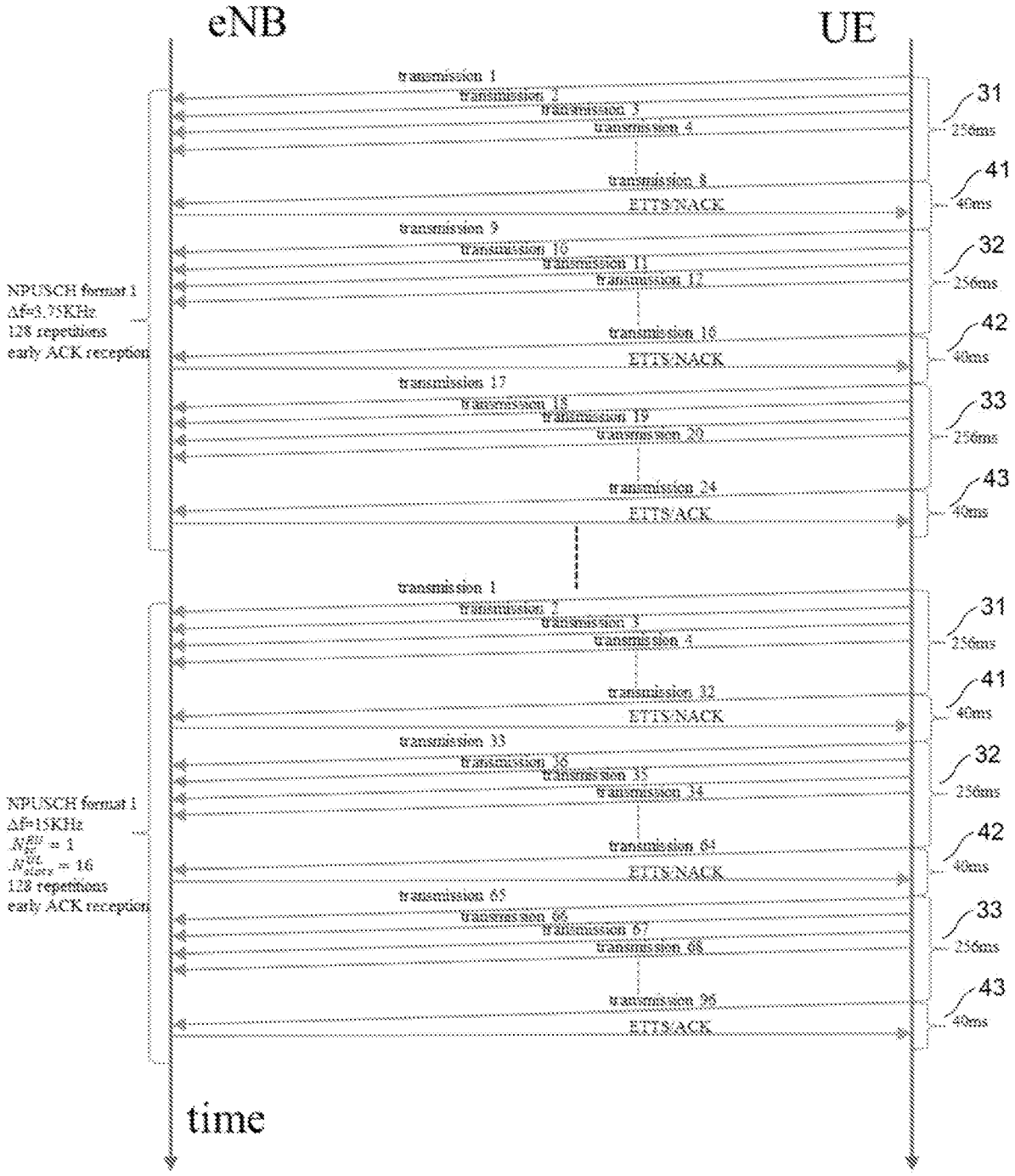

eNB
UE
NPUSCH format 1
Δf=3.75KHz
128 repetitions
early ACK reception
transmission 1
transmission 2
transmission 3
transmission 4
transmission 8
ETTS/NACK
transmission 9
transmission 10
transmission 11
transmission 12
transmission 16
ETTS/NACK
transmission 17
transmission 18
transmission 19
transmission 20
transmission 24
ETTS/ACK
31
256ms
41
40ms
32
256ms
42
40ms
33
256ms
43
40ms
NPUSCH format 1
Δf=15KHz
N_{sc}^{RU} = 1
N_{slots}^{UL} = 16
128 repetitions
early ACK reception
transmission 1
transmission 2
transmission 3
transmission 4
transmission 32
ETTS/NACK
transmission 33
transmission 34
transmission 35
transmission 36
transmission 64
ETTS/NACK
transmission 65
transmission 66
transmission 67
transmission 68
transmission 96
ETTS/ACK
31
256ms
41
40ms
32
256ms
42
40ms
33
256ms
43
40ms
time

Fig. 5

NPUSCH format\Repetitions	16	32	64	128
$\Delta f = 3.75Khz, N_{slots}^{RU} = 16$	2	4	8	16
$\Delta f = 15Khz, N_{slots}^{RU} = 16$	-	1	2	4
$\Delta f = 15Khz, N_{slots}^{RU} = 8$	-	-	1	2
$\Delta f = 15Khz, N_{slots}^{RU} = 4$	-	-	-	1
$\Delta f = 15Khz, N_{slots}^{RU} = 2$	-	-	-	-

Number of ETTS occurrences per NPUSCH format and repetitions

Fig. 6

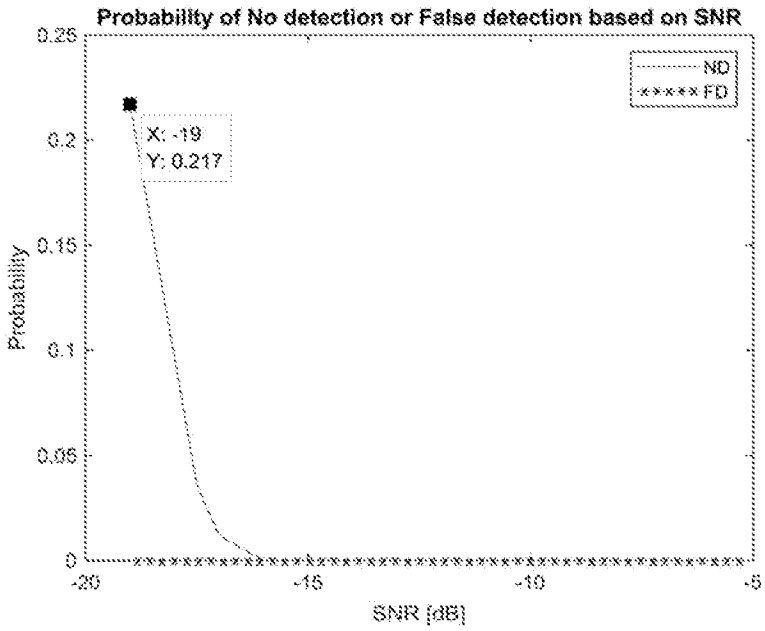
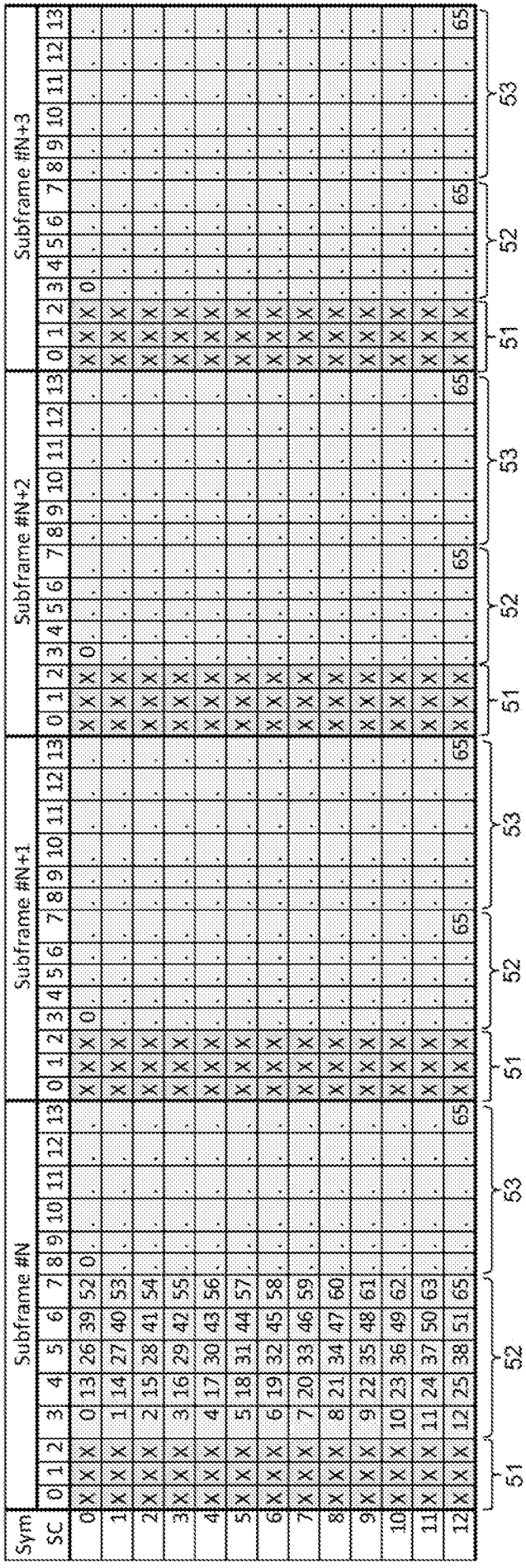


Fig. 8



Mapping of example ETTS (8 repetitions) to DL Resource Grid for NB-IoT

Fig. 7

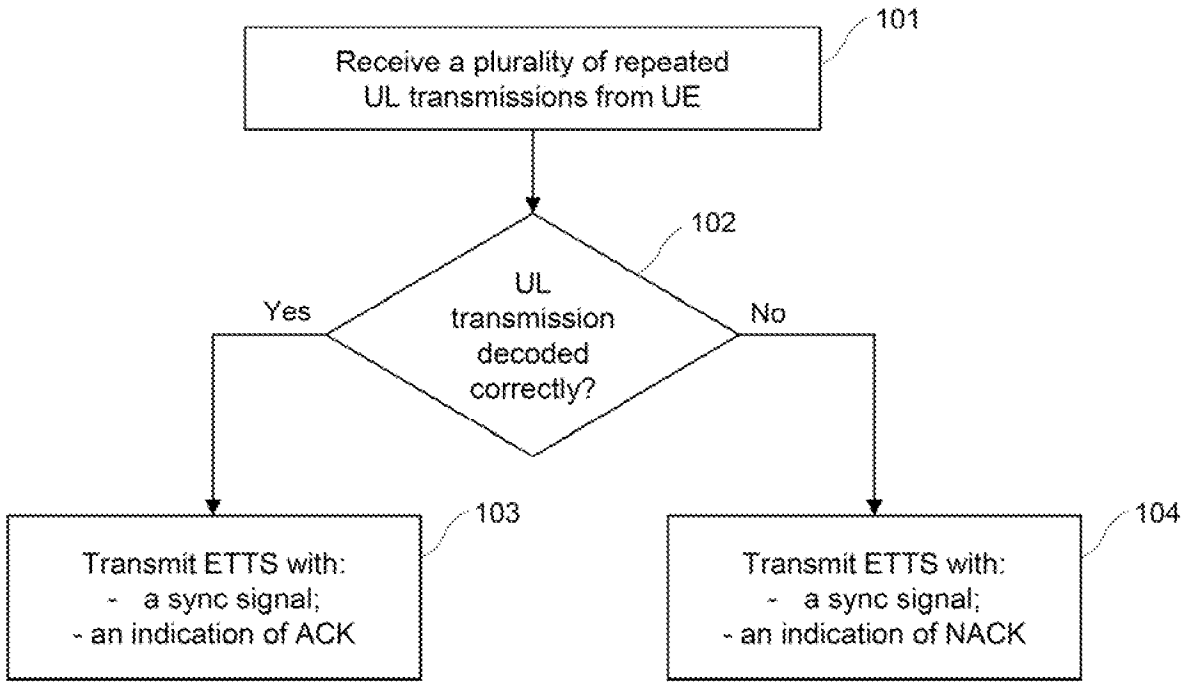

Receive a plurality of repeated UL transmissions from UE
101
UL transmission decoded correctly?
102
Yes
No
Transmit ETTS with:
- a sync signal;
- an indication of ACK
103
Transmit ETTS with:
- a sync signal;
- an indication of NACK
104

Fig. 9

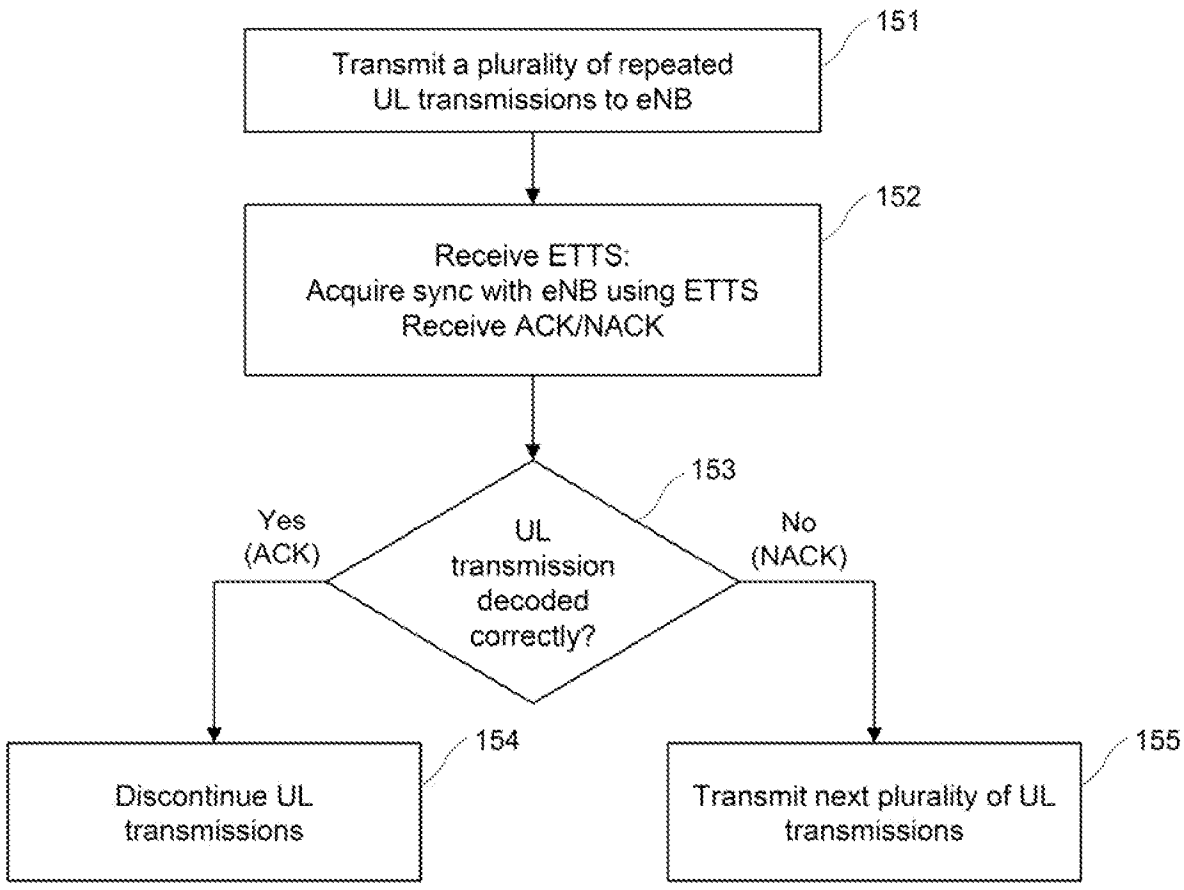

Transmit a plurality of repeated UL transmissions to eNB
151
Receive ETTS:
Acquire sync with eNB using ETTS
Receive ACK/NACK
152
UL transmission decoded correctly?
153
Yes (ACK)
No (NACK)
Discontinue UL transmissions
154
Transmit next plurality of UL transmissions
155

Fig. 10

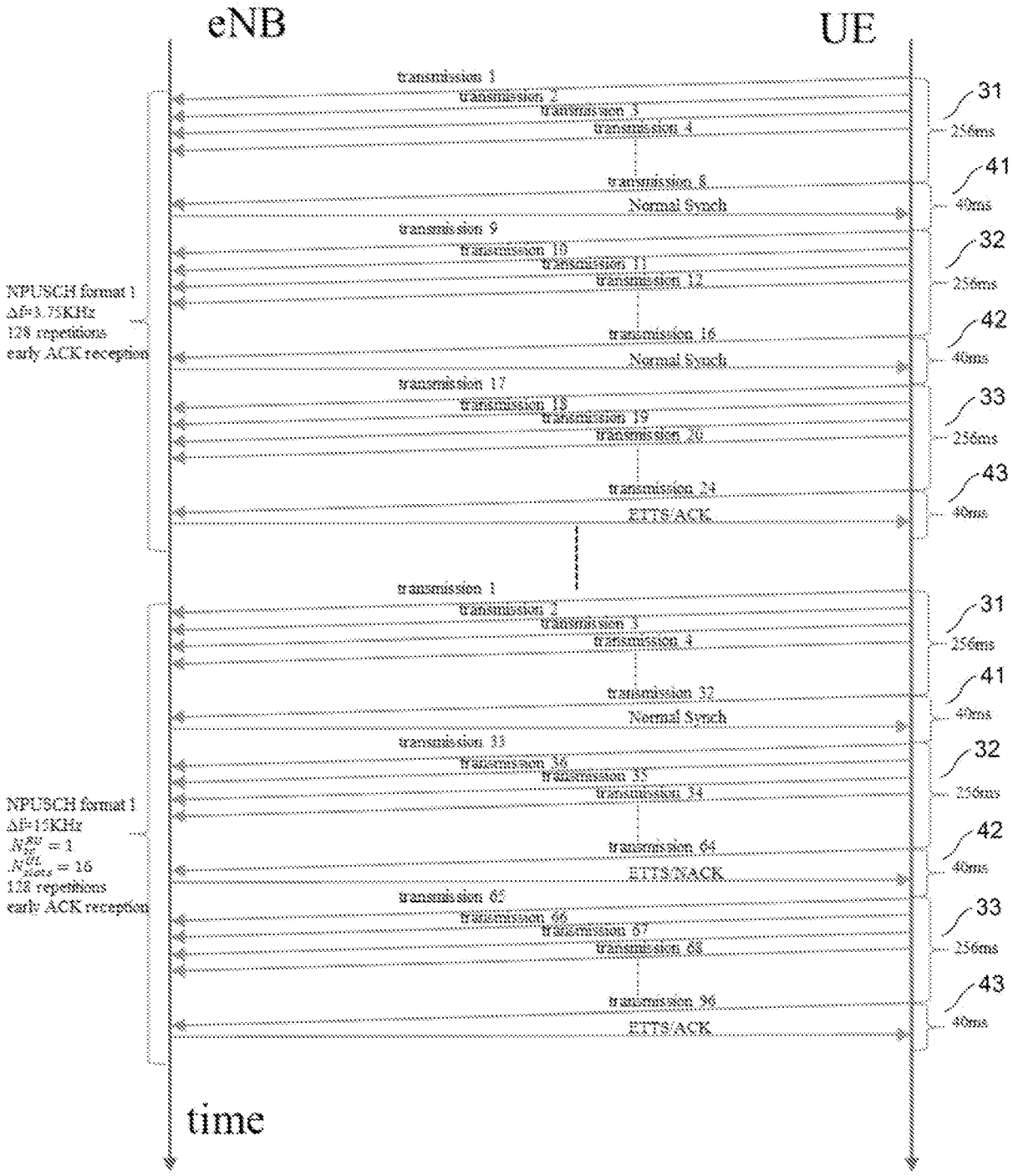

eNB
UE
transmission 1
transmission 2
transmission 3
transmission 4
31
256ms
transmission 8
Normal Synch
41
40ms
transmission 9
transmission 10
transmission 11
transmission 12
32
256ms
NPUSCH format 1
ΔF=3.75KHz
128 repetitions
early ACK reception
transmission 16
Normal Synch
42
40ms
transmission 17
transmission 18
transmission 19
transmission 20
33
256ms
transmission 24
ETTS/ACK
43
40ms
transmission 1
transmission 2
transmission 3
transmission 4
31
256ms
transmission 32
Normal Synch
41
40ms
transmission 33
transmission 34
transmission 35
transmission 36
32
256ms
NPUSCH format 1
ΔF=15KHz
128 repetitions
early ACK reception
transmission 64
ETTS/ACK
42
40ms
transmission 65
transmission 66
transmission 67
transmission 68
33
256ms
transmission 96
ETTS/ACK
43
40ms
time

Fig. 11

Reps SNR	1	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	128
-19	1	1	1	0.97	0.9	0.78	0.6	0.43	0.29	0.19	0.1	0.05	0.03	0.02	0.01	0.01	0
-17.5	1	1	0.98	0.87	0.66	0.41	0.23	0.11	0.05	0.03	0.02	0.01	0.01	0	0	0	0
-17	1	1	0.97	0.8	0.53	0.27	0.14	0.07	0.03	0.01	0	0	0	0	0	0	0
-16	1	1	0.88	0.57	0.26	0.09	0.03	0.01	0	0	0	0	0	0	0	0	0
-14	1	0.96	0.53	0.13	0.03	0.01	0	0	0	0	0	0	0	0	0	0	0
-13	1	0.91	0.27	0.04	0.01	0	0	0	0	0	0	0	0	0	0	0	0
-12.6	1	0.85	0.18	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
-12	1	0.78	0.11	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
-11	1	0.56	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10	1	0.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7.5	1	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5	0.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

BLER for SNR & Repetition combination transmitting PUSCH with RU type 1 *Δf=3.75KHz*

Fig. 12

Reps SNR	1	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	R_{max}
-19	0	0	0.26	2.36	7.5	15.4	25.19	31.67	35.55	35.53	33.6	29.72	24.35	18.36	12.34	6.21	128
-17.5	0	0	1.84	10.97	25.8	40.7	48.31	50.01	47.35	42.57	36.75	30.84	24.8	18.60	12.49	6.24	128
-17	0	0	2.63	15.93	35.33	49.98	53.63	52.84	48.75	43.4	37.35	31.22	25	18.73	12.49	6.25	128
-16	0	0.35	8.7	26.94	37.05	34.09	24.25	12.33	-	-	-	-	-	-	-	-	64
-14	0	3.68	35.33	54.5	48.6	37.2	25	12.5	-	-	-	-	-	-	-	-	64
-13	0	8.14	54.53	60.19	49.55	37.5	25	12.5	-	-	-	-	-	-	-	-	64
-12.6	0	11.63	60.85	24.58	-	-	-	-	-	-	-	-	-	-	-	-	32
-12	0	16.2	64.4	24.85	-	-	-	-	-	-	-	-	-	-	-	-	32
-11	0	32.85	48.5	25	-	-	-	-	-	-	-	-	-	-	-	-	32
-10	0	54	49.05	24.98	-	-	-	-	-	-	-	-	-	-	-	-	32
-7.5	0.28	49.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
-5	1.55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2

Percentage of energy conservation using Fig. 12 information, BLER less than 0.01

Fig. 13

R SNR	1	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	R_{max}
-19	-	-	-	-	-	-	25.188	31.669	35.55	35.525	33.6	29.719	24.35	-	-	-	128
-17.5	-	-	-	-	35.8	40.7	48.313	50.006	47.35	42.569	36.75	30.844	24.8	-	-	-	128
-17	-	-	-	-	35.325	49.981	53.625	52.838	48.75	43.4	37.35	31.219	25	-	-	-	128
-16	-	-	-	26.938	37.05	34.088	24.25	-	-	-	-	-	-	-	-	-	64
-14	-	-	35.325	54.5	48.6	37.2	25	-	-	-	-	-	-	-	-	-	64
-13	-	-	54.525	60.188	49.55	37.5	25	-	-	-	-	-	-	-	-	-	64
-12.6	-	-	60.85	24.575	-	-	-	-	-	-	-	-	-	-	-	-	32
-12	-	-	64.4	24.85	-	-	-	-	-	-	-	-	-	-	-	-	32
-11	-	32.85	48.5	25	-	-	-	-	-	-	-	-	-	-	-	-	32
-10	-	54	49.05	24.975	-	-	-	-	-	-	-	-	-	-	-	-	32
-7.5	-	49.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2

Percentage of energy conservation for optimized performance of at least 20% gain for required min BLER of 0.01

Fig. 14

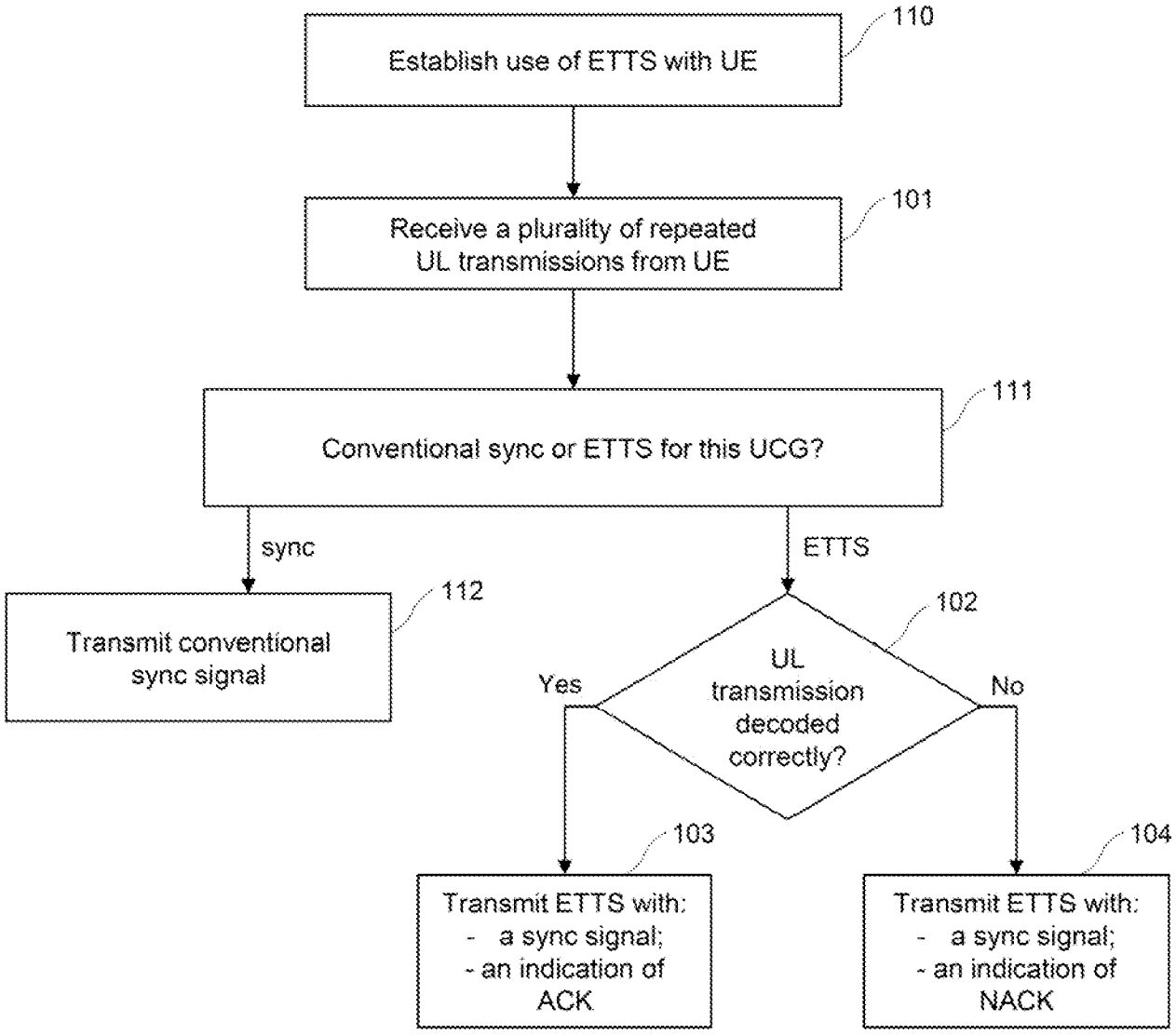

Establish use of ETTS with UE
110
Receive a plurality of repeated UL transmissions from UE
101
Conventional sync or ETTS for this UCG?
111
sync
ETTS
Transmit conventional sync signal
112
UL transmission decoded correctly?
102
Yes
No
Transmit ETTS with:
- a sync signal;
- an indication of ACK
103
Transmit ETTS with:
- a sync signal;
- an indication of NACK
104

Fig. 15

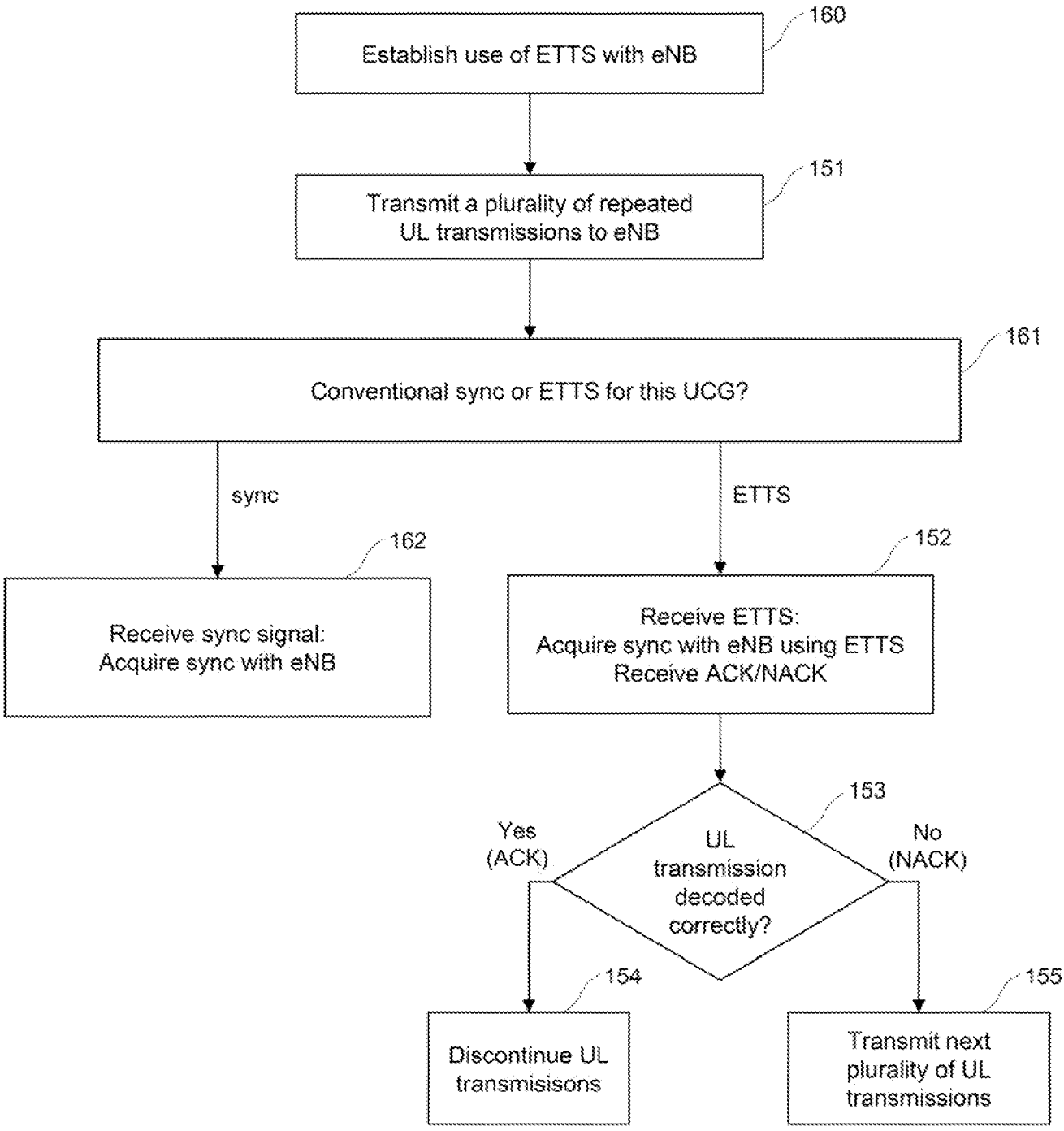

Establish use of ETTS with eNB
160
Transmit a plurality of repeated UL transmissions to eNB
151
Conventional sync or ETTS for this UCG?
161
sync
ETTS
Receive sync signal: Acquire sync with eNB
162
Receive ETTS: Acquire sync with eNB using ETTS Receive ACK/NACK
152
UL transmission decoded correctly?
153
Yes (ACK)
No (NACK)
Discontinue UL transmisisons
154
Transmit next plurality of UL transmissions
155

Fig. 16

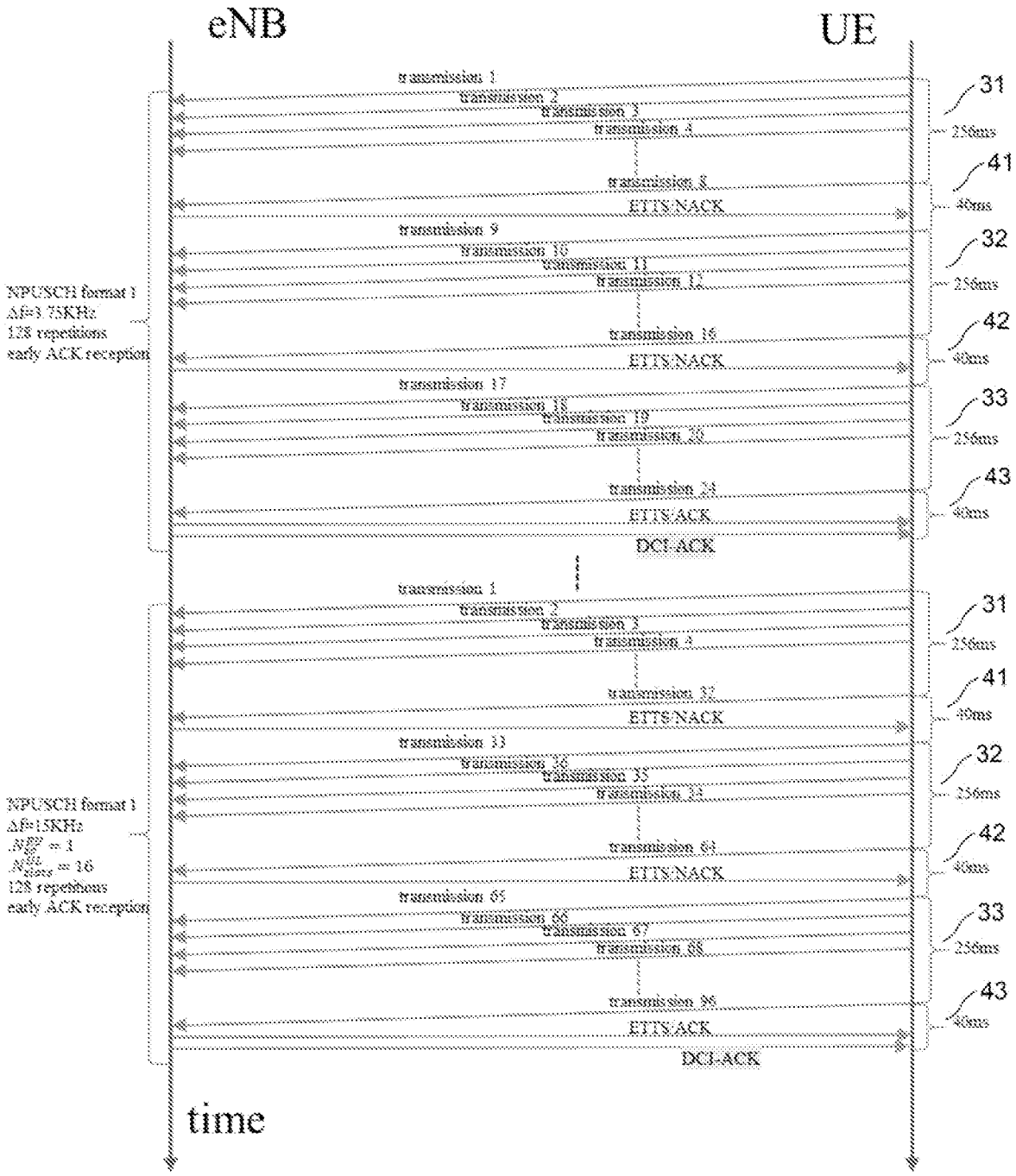

eNB
UE
NPUSCH format 1
Δf=3.75KHz
128 repetitions
early ACK reception
transmission 1
transmission 2
transmission 3
transmission 4
transmission 8
ETTS:NACK
transmission 9
transmission 10
transmission 11
transmission 12
transmission 16
ETTS:NACK
transmission 17
transmission 18
transmission 19
transmission 20
transmission 24
ETTS:ACK
DCI-ACK
NPUSCH format 1
Δf=15KHz
128 repetitions
early ACK reception
transmission 1
transmission 2
transmission 3
transmission 4
transmission 32
ETTS:NACK
transmission 33
transmission 34
transmission 35
transmission 36
transmission 64
ETTS:NACK
transmission 65
transmission 66
transmission 67
transmission 68
transmission 96
ETTS:ACK
DCI-ACK
time
31
256ms
41
40ms
32
256ms
42
40ms
33
256ms
43
40ms
31
256ms
41
40ms
32
256ms
42
40ms
33
256ms
43
40ms

Fig. 17

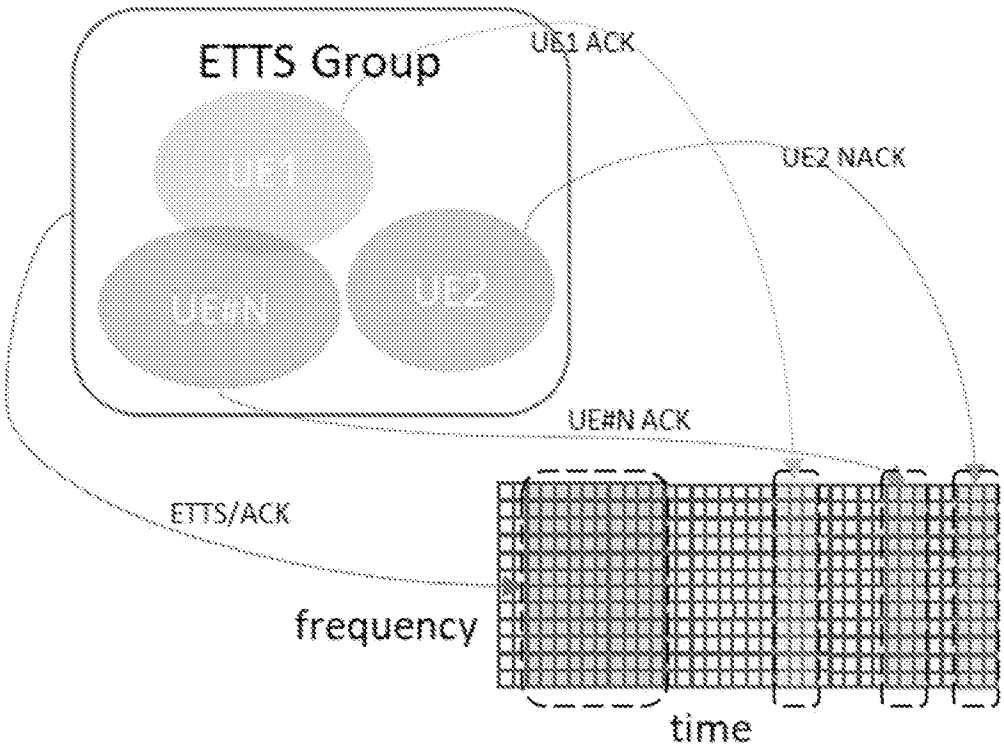

ETTS Group
UE1
UE#N
UE2
UE1 ACK
UE2 NACK
UE#N ACK
ETTS/ACK
frequency
time

Fig. 18

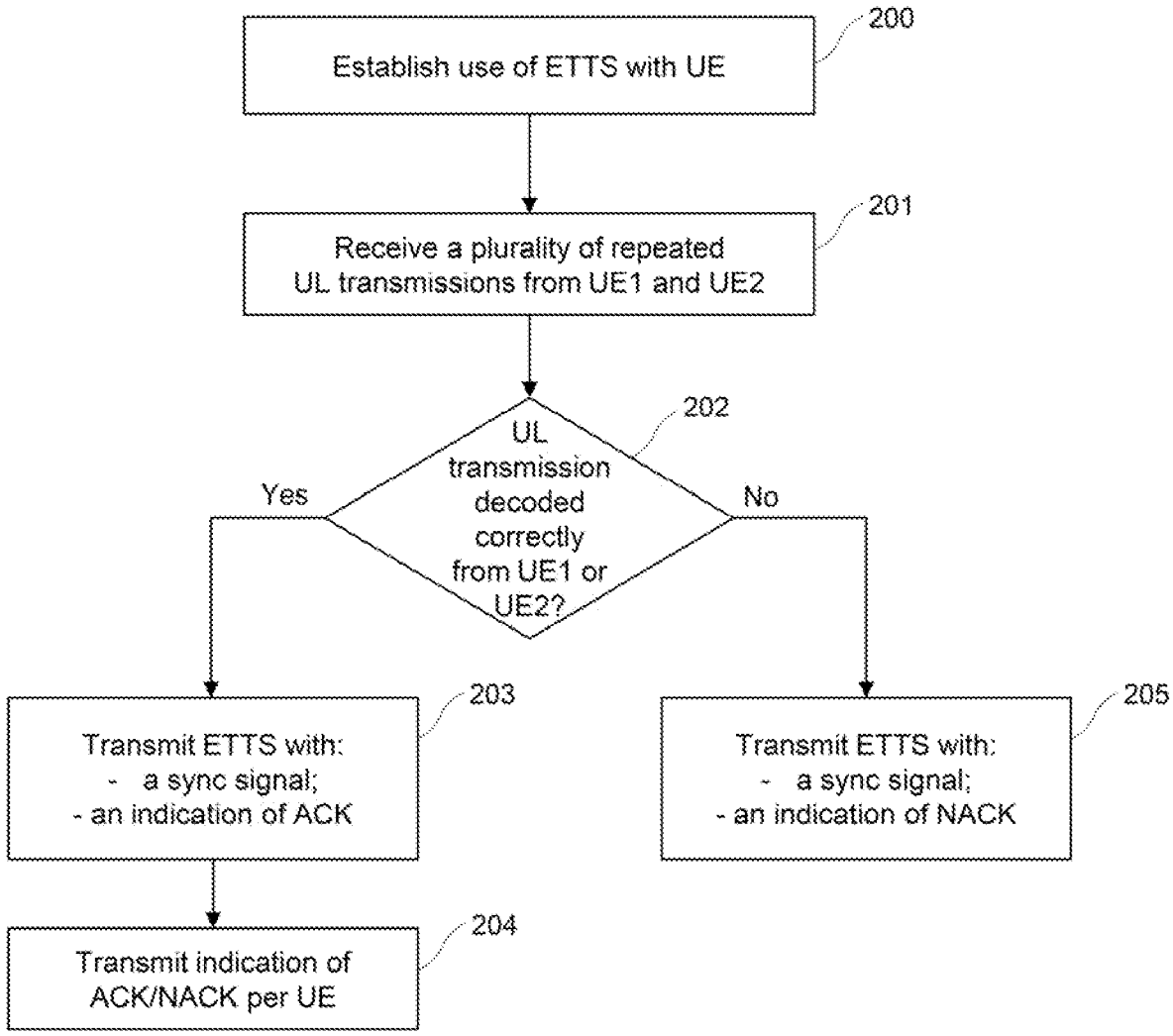

Establish use of ETTS with UE
200
Receive a plurality of repeated UL transmissions from UE1 and UE2
201
UL transmission decoded correctly from UE1 or UE2?
202
Yes
No
Transmit ETTS with:
- a sync signal;
- an indication of ACK
203
Transmit indication of ACK/NACK per UE
204
Transmit ETTS with:
- a sync signal;
- an indication of NACK
205

Fig. 19

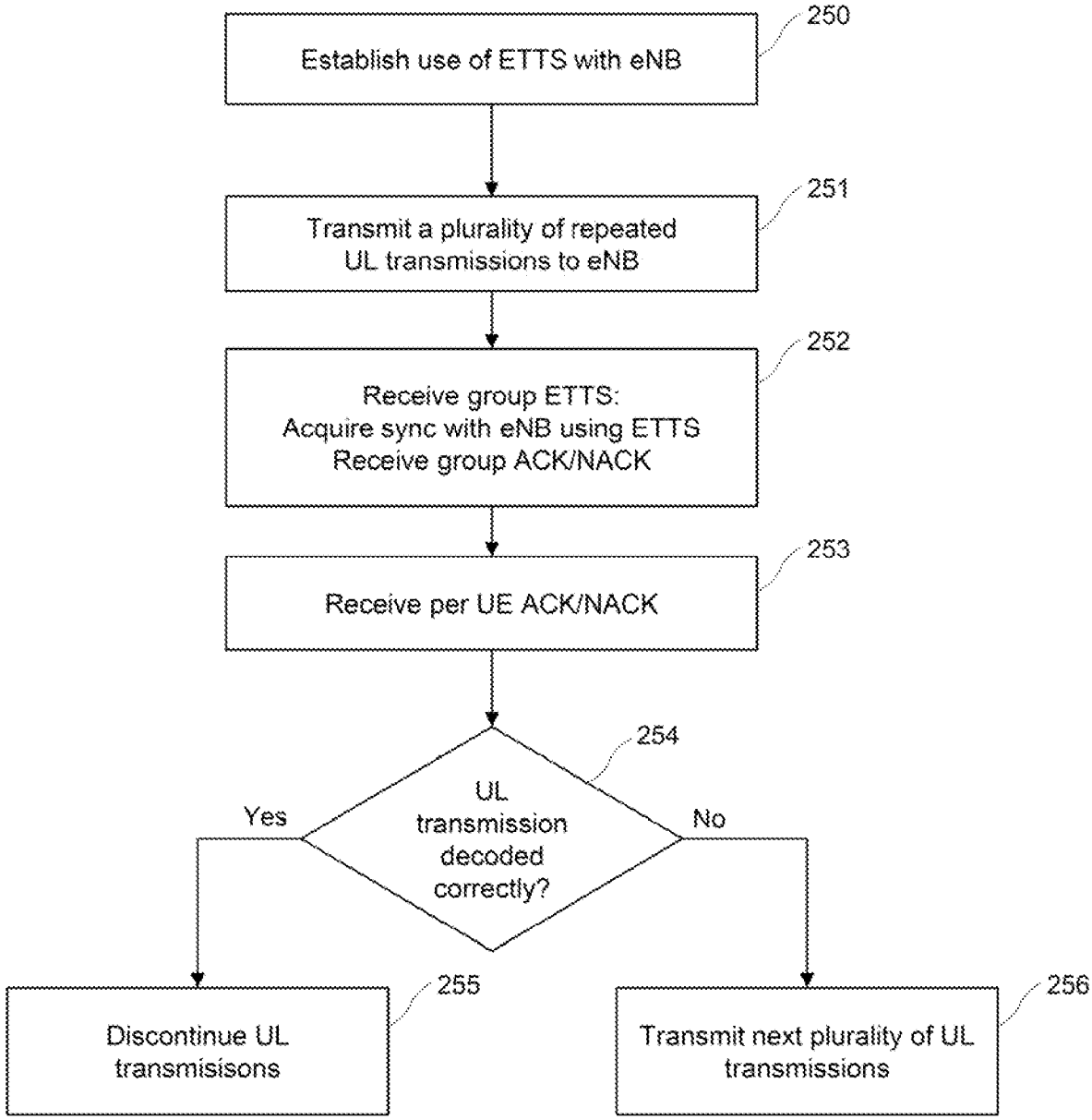

Establish use of ETTS with eNB
250
Transmit a plurality of repeated UL transmissions to eNB
251
Receive group ETTS:
Acquire sync with eNB using ETTS
Receive group ACK/NACK
252
Receive per UE ACK/NACK
253
UL transmission decoded correctly?
254
Yes
No
Discontinue UL transmisisons
255
Transmit next plurality of UL transmissions
256

Fig. 20

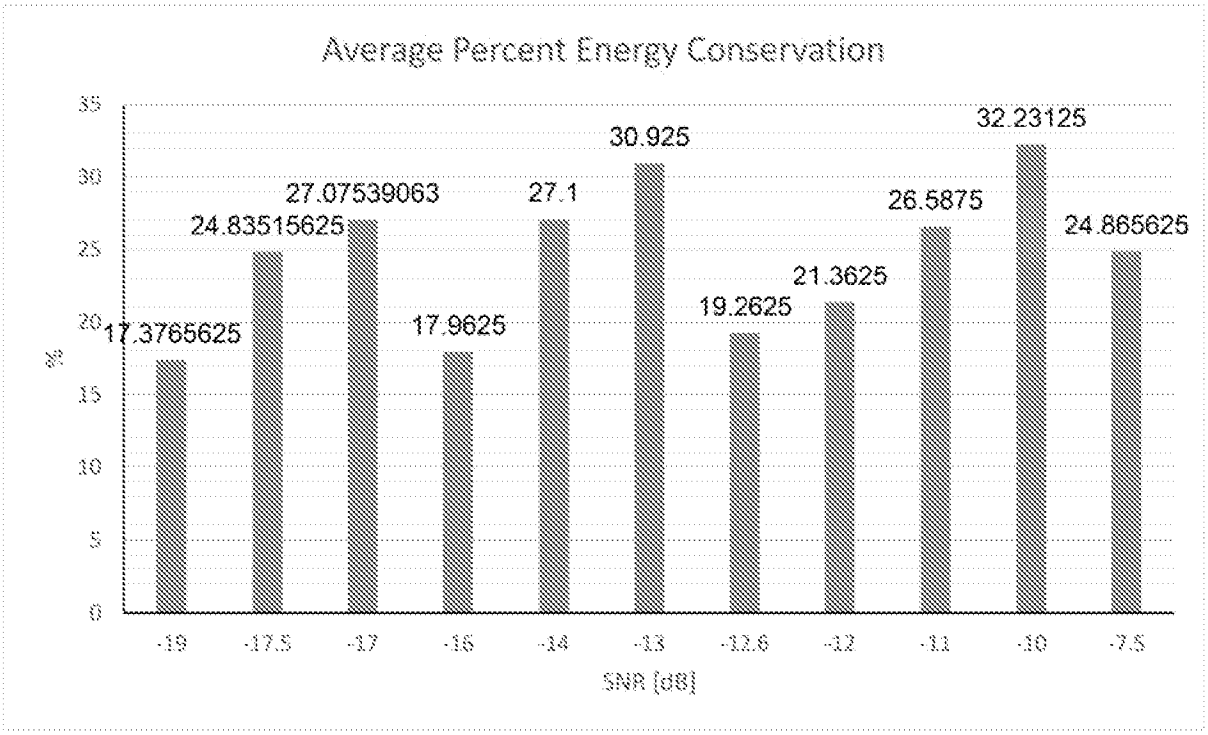


Fig. 21

R / SNR	1	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	R_{max}
-19	-	-	0.26	2.36	7.5	15.4	25.19	31.67	35.55	35.53	33.6	29.72	24.35	18.36	12.34	6.21	128
-17.5	-	-	1.58	8.44	17.2	22.2	19.33	11.11	-	-	-	-	-	-	-	-	64
-17	-	-	2.25	12.35	23.55	27.26	21.45	11.68	-	-	-	-	-	-	-	-	64
-16	-	0.35	8.7	26.94	37.05	34.09	24.25	12.33	-	-	-	-	-	-	-	-	64
-14	-	3.15	23.55	21.8	-	-	-	-	-	-	-	-	-	-	-	-	32
-13	-	6.98	36.35	24.08	-	-	-	-	-	-	-	-	-	-	-	-	32
-12.6	-	11.63	40.85	24.58	-	-	-	-	-	-	-	-	-	-	-	-	32
-12	-	16.2	44.4	24.85	-	-	-	-	-	-	-	-	-	-	-	-	32
-11	-	21.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
-10	-	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16

Percentage of energy conservation using Fig. 12 information BLER of less 0.1

Fig. 22

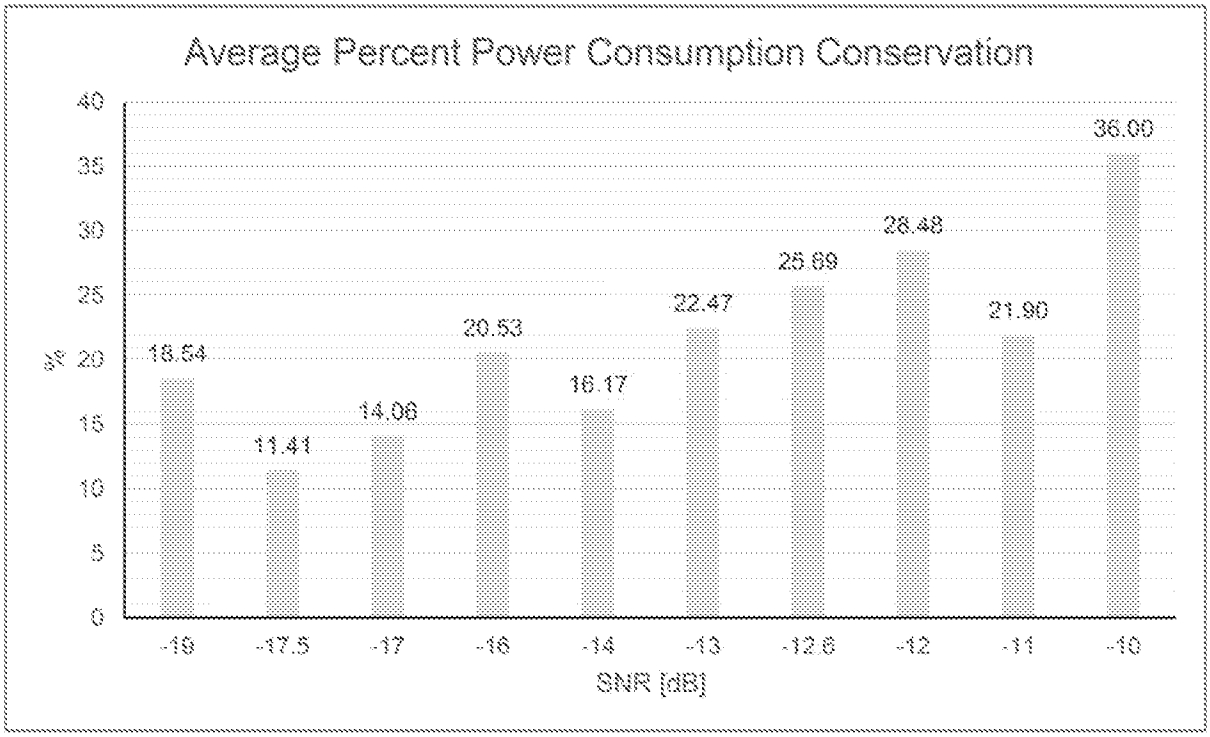

Average Percent Power Consumption Conservation
40
35
30
25
20
15
10
5
0
%
18.54
11.41
14.06
20.53
16.17
22.47
25.69
28.48
21.90
36.00
-19
-17.5
-17
-16
-14
-13
-12.6
-12
-11
-10
SNR [dB]

Fig. 23

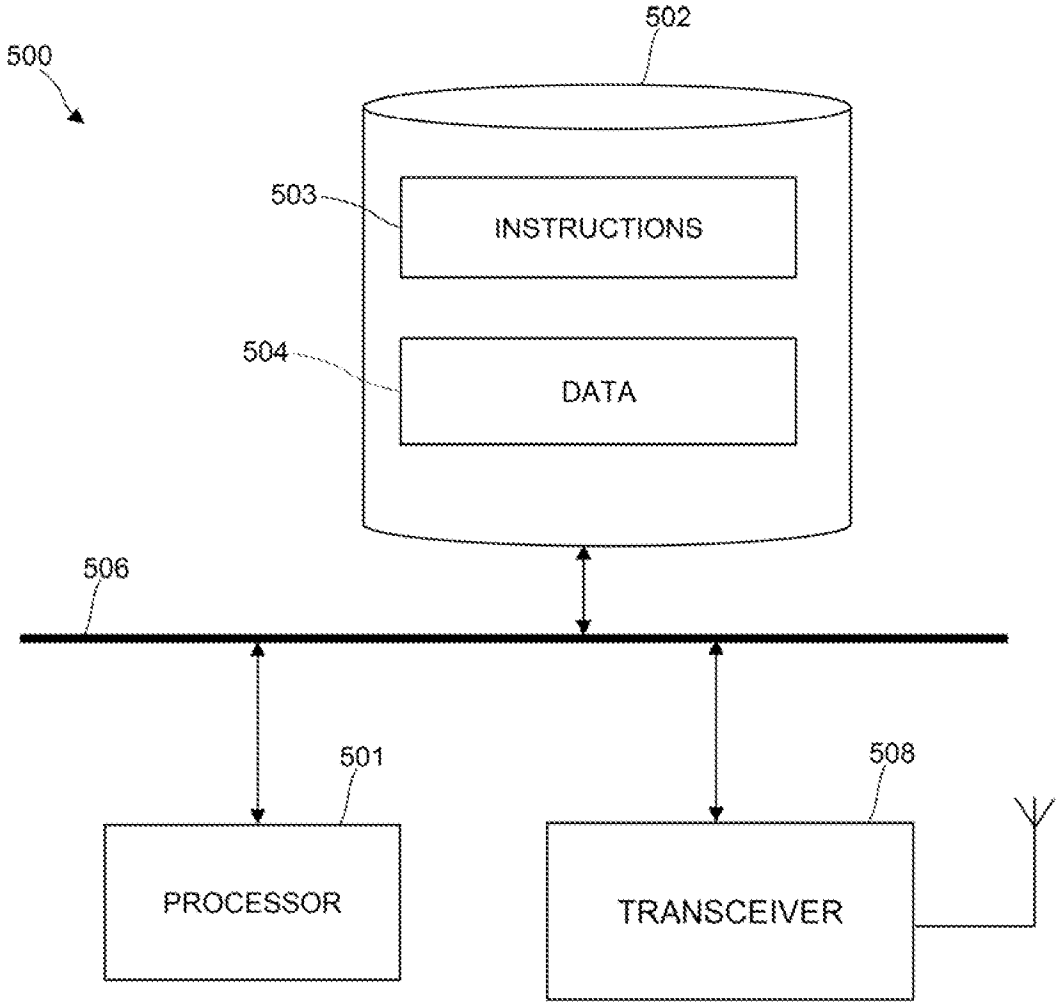

500
502
503
INSTRUCTIONS
504
DATA
506
501
PROCESSOR
508
TRANSCEIVER

Fig. 24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2019/098514

A. CLASSIFICATION OF SUBJECT MATTER

H04W 56/00(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W

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)

WPI;EPODOC;CNPAT;CNKI;3GPP:early, termination, repetition, HARQ, ACK, NACK, UCG, uplink compensation gap+, synchronization

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SONY. "Early termination for PUSCH repetition" *3GPP TSG RAN WG1 Meeting #91 R1-1720468*, 01 December 2017 (2017-12-01), sections 1, 2	1-26
X	SONY. "Using Uplink HARQ feedback for early PUSCH repetitions termination" *3GPP TSG RAN WG1 Meeting #92 R1-1802057*, 02 March 2018 (2018-03-02), sections 1, 2	1-26
X	SONY. "Early termination of uplink repetitions in HD-FDD" *3GPP TSG RAN WG1 Meeting #88bis R1-1705201*, 07 April 2017 (2017-04-07), sections 1, 2	1-26
X	SONY. "On early uplink early termination of PUSCH repetitions" *3GPP TSG RAN WG1 Meeting #89 R1-1708248*, 19 May 2017 (2017-05-19), sections 1, 2	1-26

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

* Special categories of cited documents:

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 September 2019	**29 October 2019**

Name and mailing address of the ISA/CN	Authorized officer
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