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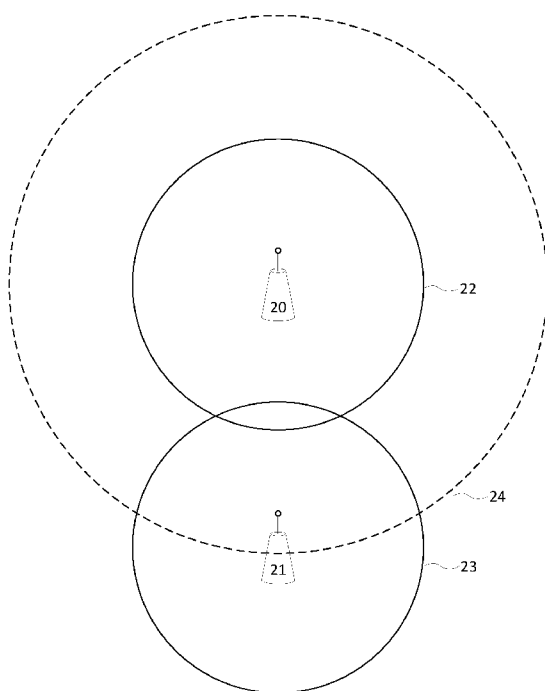


Figure 2

(57) Abstract: Methods for sharing resource utilisation information between base stations to facilitate resource sharing. A first base station, when winning access to transmission resources, transmits an indication of those resources to neighbouring base stations. Those neighbouring base stations may then share the resources if there is no conflict with other devices.



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Transmission Resource Sharing

Technical Field

[1] The following disclosure relates to sharing transmission resources in a cellular wireless network, and in particular to the sharing of unlicensed transmission resources between base stations of a cellular wireless network..

Background

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

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

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

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

[6] In order to share resources a Listen Before Talk (LBT) protocol is proposed in which a gNB or UE monitors the available resources and only commences a transmission if there is no conflict with another device already utilising the resources. Once an LBT process is successful (the resources are "won"), the gNB or UE gains access to the resources for up to the Maximum Channel Occupancy Time (MCOT) provided there is no interruption of transmissions for more than a pre-defined interval (for example 16µs).

[7] Transmissions in unlicensed spectrum must comply with various regulations in force for that spectrum. For example, many regulations specify an Occupied Channel Bandwidth (OCB) and Nominal Channel Bandwidth (NCB) which must be complied with. The NCB defines the widest band of frequencies, including guard bands, allocated to a channel, and the OCB defines the bandwidth containing a defined fraction (typically 99%) of a signal's power. Often the OCB must be between 80% and 100% of the NCB. As an example, ETSI EN 301.893 defines requirements in the EU for the 5GHz band.

[8] LBT processes are effective for sharing transmission resources which are not licensed resources and hence a variety of devices are allowed to use these resources. The fair use regulations and other transmission constraints vary in different countries. Frequency reuse is not straight-forward on unlicensed resources as by nature resources are not the ownership of one device, a group of devices or an operator. Hence access and ownership have to be earned for transmission using agreed clear channel access procedure for a given zone. This may result in difficulty achieving high frequency reuse over in unlicensed resources even if a base station of a cellular operator is able to access the resources in one area. For example, multiple Wi-Fi stations have no coordination and hence must co-ordinate transmissions through LBT procedure to avoid interference on the assumption that only one station can use the resources at a time. In contrast, cellular systems have been developed to share resources with a frequency reuse factor of 1. However, with conventional LBT processes, one cellular base station winning access to resources and transmitting on those resources, may block many neighbouring base stations even if there are no other devices.

[9] Base stations with overlapping transmission areas of the same cellular network (same operator) are able to operate in the same frequency band due to well-developed techniques to manage interference. A conventional LBT process applied to cellular systems thus leads to inefficient use of transmission resources.

[10] An improved LBT process is thus required for cellular systems.

Summary

[11] 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.

[12] There is provided a method of resource sharing in a cellular communication system, the method performed by a first base station and comprising the steps of obtaining access to transmission resources for a defined transmission interval; transmitting an indication to a second base station of the cellular communication system of the resources to which the first base station has obtained access.

[13] The transmission resources may be unlicensed spectrum resources.

[14] Access to the transmission resources by the first base station may be obtained by a listen before talk process.

[15] The indication may include scheduling of resources from the first base station.

[16] The indication of resource may be given per physical resource block.

[17] The indication may comprise a bitmap wherein each bit relates to a physical resource block.

[18] The method may further comprise transmitting an indication of transmission power used by the first base station on the transmission resources.

[19] The method may further comprise transmitting an indication of the defined transmission interval.

[20] The method may further comprise transmitting an indication of the end of the defined transmission interval.

- [21] The method may further comprise transmitting an indication that the transmission resources were obtained by the first base station.
- [22] The indication of resources may comprise an indication of the carrier index of those resources.
- [23] There is also provided a method of resource sharing in a cellular communication system, the method performed by a second base station and comprising the steps of receiving an indication of transmission resources obtained by a first base station; sensing transmission power received at the second base station; comparing the sensed transmission power to the indication of transmission resources; and if the comparison indicates the sensed transmission power is only from the first base station, initiating transmission from the second base station.
- [24] The transmission resources may be unlicensed spectrum resources.
- [25] The indication may include scheduling of resources from the first base station.
- [26] The indication of resources may be given per physical resource block.
- [27] The indication may comprise a bitmap wherein each bit relates to a physical resource block.
- [28] The method may further comprise receiving an indication of transmission power used by the first base station on the transmission resources.
- [29] The method may further comprise estimating the path loss between the first base station and the second base station.
- [30] The method may further comprise receiving an indication of the defined transmission interval.
- [31] The method may further comprise receiving an indication of the end of the defined transmission interval.
- [32] The method may further comprise receiving an indication that the transmission resources were obtained by the first base station.
- [33] The indication of resources may comprise an indication of the carrier index of those resources.
- [34] The method may further comprise the step of transmitting the received indication to a third base station.
- [35] The method may further comprise the step indicating the identity of the base station from which the indication was received.
- [36] The second base station may cease transmission on the indicated resources if the first base station ceases transmission on those resources.
- [37] The step of comparing may comprise comparing energy received in resources indicated as being utilised by the first station to a first threshold, and energy received in resources not indicated as being utilised by the first station to a second threshold.
- [38] The first threshold may be higher than the second threshold.
- [39] The comparison may be between indicated physical resource blocks and sensed power in those resource blocks.
- [40] It may be determined that the sensed transmission power is only from the first base station if the sensed physical resource blocks are a subset of the indicated physical resource blocks.

[41] There is also provided a base station configured to perform the methods described herein.

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

Brief description of the drawings

[43] 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.

[44] Figure 1 shows an exemplary cellular network;

[45] Figure 2 shows a pair of base stations potentially sharing resources;

[46] Figure 3 shows a flow chart of a method of resource sharing;

[47] Figure 4 shows three base stations potentially sharing resources;

[48] Figure 5 shows a flow chart of a method of resource sharing;

[49] Figure 6 shows a set of cells for simulation; and

[50] Figure 7 shows simulation results.

Detailed description of the preferred embodiments

[51] 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.

[52] The following disclosure provides an improved mechanism which seeks to enable more efficient sharing of transmission resources between related base stations.

[53] Figure 1 shows a schematic diagram of three base stations (for example, eNB or gNBs depending on the particular cellular standard and terminology) forming a cellular network. Typically, each of the base stations will be deployed by one cellular network operator to provide geographic coverage for UEs in the area. The base stations form a Radio Area Network (RAN). Each base station provides wireless coverage for UEs in its area or cell. The base stations are interconnected via the X2 interface and are connected to the core network via the S1 interface. As will be appreciated only basic details are shown for the purposes of exemplifying the key features of a cellular network.

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

[55] Figure 2 shows a schematic diagram of 2 base stations, 20 & 21, which provide service to areas 22 & 23 respectively. However, the transmissions of base station 20 propagate further than

the area of service 22 as indicated schematically by ring 24. If these base stations use unlicensed resources, and base station 20 is transmitting, and base station 21 performs an LBT process it will detect the transmissions of base station 20 and will be prevented from transmitting as it appears a device has seized the transmission resources. However, since the transmissions, in fact, originate from a base station of the same cellular network, resource sharing may be possible for communications between base station 21 and UEs connected to that base station 21. Most modern cellular systems like 3G WCDMA, 4G LTE, LTE-A, and initial releases of 5G NR have been designed for a frequency reuse factor of 1 which means that they use the same frequency resources for transmission in all the base stations.

[56] As set out in relation to Figure 1, base stations of a cellular network are interconnected and can communicate data between themselves, either via the X2 interface, or via the S1 interface and core network. These interfaces can be utilised to share information between base stations regarding resource utilisation to enable more efficient sharing of resources over the unlicensed resources.

[57] Figure 3 shows a co-operative method of resource sharing. When a base station performs an LBT procedure, and obtains access to transmission resources, it is entitled to use those resources for up to the Maximum Channel Occupancy Time (MCOT). A base station (for example, base station 20) obtains access to transmission resources at step 30 and it may indicate its access to neighbouring base stations at step 31, via the X2/S1 interface or other suitable communication mechanism. For example, a message may be transmitted wirelessly via the spectrum being shared. A specific time and/or frequency resource may be agreed over which resource utilisation messages are broadcast such that neighbouring base stations can listen to receive the information when it may be useful for them. For example, similar techniques to the transmission of DRS or SRB on a specific portion of a carrier may be utilised. However, this does utilise transmission resources and so may reduce access to the resources for traffic transmission. Another method to share this information could be via the other licensed carrier if these base stations are using licensed carrier as well.

[58] For ease of explanation, a base station which obtains access to unlicensed transmission resources will be named an initiating base station, and base stations receiving that indication will be named receiving base stations.

[59] The receiving base stations (for example, base station 21) receive the indication at step 32, are thus aware of signals that they may detect when performing their own LBT process at step 33. The results of that LBT process may be verified at step 34 against the details received from the other base station, and if there is correlation (as discussed in more detail below) the base station may consider the transmission resources usable and proceed to transmit at step 35. If the LBT results and received details are not correlated (as discussed in more detail below) the base station may conclude that the detected transmissions are from a different source and hence decide that the transmission resources cannot be utilised at step 36.

[60] The method of Figure 3 thus allows base stations to share details of the transmission resources they are using following a successful LBT process, and hence improve utilisation of those resources by sharing them using existing resource sharing techniques with the other base stations of the cellular network.

[61] The indication of resource utilisation may include various items of information to assist other base stations in correlating their LBT results to the information and enabling efficient utilisation of the resources. When the unlicensed resources have a very wide bandwidth, consisting of many channels or carriers, the initiating base station may transmit the carrier index in the indication so that the neighbouring base stations may identify the carrier to which the

initiating base station has won access. To help facilitate frequency reuse for the channel/carrier, the initiating base station may transmit information on which narrow band frequency resources it is transmitting within the carrier bandwidth. These narrow band frequency resources can be in the form of a group of physical resource blocks (PRBs), where the size of group of PRBs can be selected to make the indication meaningful. To provide very fine details, a group of size 1 can be selected implying that initiating base station sends the utilization information of each single PRB. In principle any indicator that allows a receiving base station to determine the channel details may be utilised. This enables a receiving base station to determine if the detected signals are from the initiating base station. For example, if the receiving base station detects power across a wide range of frequency resources, but the initiating base station only indicated a subset of these resources being utilised it would be determined the detected transmission are from another device (for example a Wi-Fi device).

[62] The initiating base station may also share other relevant parameters, for example the Contention Window Size (CWS) used by the initiating base station, the MCOT, and how much time is remaining in the current transmission opportunity (TxOP). This latter value may be important since if the receiving base station decides to also utilise the resources secured by the initiating base station, those resources should be only utilised until the end of the MCOT as per the regulations from when the initiating base station obtained access. Both the initiating and receiving base stations must stop transmitting at the end of that period and perform a new LBT process with a proper gap and back-off as per the regulations to access the unlicensed resources. If each receiving base station started a new MCOT when it starts to transmit very long occupancy times could be created in continuity among the base stations of the same operator barring other devices from accessing the transmission resources. However, the initiating base station may have obtained access prior to the receiving base station receiving the indication and hence the receiving base station is not aware of when the TxOP ends, within the MCOT value of the initiating base station. Each receiving base station sharing the TxOP obtained by the initiating base station must therefore be made aware of when the current TxOP ends.

[63] For the case when the initiating base station plans to use the resources for a time shorter than its MCOT, from regulatory perspective, the neighbouring base stations sharing the resources may continue their utilisation up to the expiry of initiating base station MCOT, considering them part of a single group. In this case, mechanisms must be ensured for correct updating of the sensing related parameters following the TxOP and the initiating base station should not have the right to do another LBT while its initiated TxOP is still active by its neighbours for fairness reasons. So overall from the perspective of system control, signalling and fairness, neighbouring base stations should stop using the resources no later than the initiating base station, even if that is prior to the end of the TxOP.

[64] As set out above the transmission access details may be shared with neighbouring base stations. Which base stations qualify as neighbouring may be defined flexibly depending on the particular network configuration. For example, in some circumstances, possibly with densely packed small cells, information may be shared across a wider range of receiving base stations, whereas in other situations neighbouring base stations may be only those which share a boundary with the initiating base station. In another example, neighbouring base stations may be those which have hand-over relations with the initiating base station.

[65] In addition to defining neighbouring base stations more broadly, a receiving base station may also re-transmit the utilisation information to further base stations to enable wide sharing of resources. This may be particularly useful for small cells with dense deployments. However, the spread of the information should be limited to only those base stations expected to detect the initiating base stations transmissions to ensure transmissions detected during LBT are those in

the indication and not other transmissions which coincidentally appear the same. For example, a receiving base station may only be permitted to share the information if it has been received from the initiating base station directly (i.e. limit the spread to two “hops” between base stations). To facilitate this an initiating base station may include its identity in the message, or each base station may indicate if the message is an original or a re-transmission. For example, a flag may be included to indicate if the message is from the initiating base station. Additional flexibility may be possible by limiting the number of possible re-transmissions to a particular number and tracking the number of re-transmission in each message.

[66] If a base station re-transmits a message, that base station should ensure the details are kept up to date. For example, if the message includes the time remaining in the TxOP this should be updated to ensure all receiving base stations are aware of the absolute expiry time.

[67] To avoid the need to update the time remaining, the end of the TxOP may be specified as an absolute time, provided all relevant base stations have an equal reference time (for example, the actual absolute time, or a common reference time). This is likely since in the primary example all base stations belong to the same cellular network.

[68] As set out above, when receiving the utilisation information a receiving base station should perform an LBT process. In certain situations it could be possible for a receiving base station to proceed directly to commencing transmissions without performing an LBT process. However, this assumes that no other devices are using the same resources within the range of the receiving base station. As shown in Figure 4 it is not necessarily the case that because a first base station has access to resources, a second base station also has access.

[69] As with Figure 2, base station 40 provides coverage over region 42 and base station 41 provides coverage over region 43. Base station 41 can detect base station 40's transmissions, which extend to area 44. In an example situation UE 45 is connected to base station 40 using unlicensed resources and base station 40 transmits an indication of its use to base station 41, as set out above.

[70] A further device 46, for example a Wi-Fi device with coverage area 47, is positioned within the coverage area of base station 41, but out of range of base station 40. If base station 41 acted only on the indication from base station 40 its transmission would conflict with those of device 46. In contrast, base station 48 does not have any other devices in its coverage area 49 and so would be free to transmit based on the information from the initiating base station 40, without any further checks. However, it is not possible to know that until performing a check.

[71] A basic LBT process performed by base station 41 does not help resolve whether the base station 41 is free to transmit since it would not distinguish signals of the base station 40 from device 46.

[72] This difficulty may be overcome, as noted above, if the indication from base station 40 includes details of the resources being utilised which can be correlated against signals sensed by base station 41. The base station 41 must also perform a detailed sensing process to identify the distribution of power in the band of interest, or in the relevant channels. For example, the indication may include details of channels being utilised, and the sensing process may sense power on each channel. Correlation between the two then indicates the sensed signals are from base station 40, whereas a lack of correlation indicates the signals may be from a different device.

[73] The information sent by the initiating base station may include details of PRBs being utilised. For example, a bitmap may be utilised whereby each bit indicates the status of one PRB. Many different sub-carrier spacings (SCS) are likely to be possible, and the number of PRBs

changes for a given bandwidth as a function of SCS. The message must thus include sufficient information for the receiving base stations to decode and understand the information. To reduce the number of bits required for large bandwidth carriers with large number of PRBs, PRBs could be grouped for the indication. Typically, resource utilisation can be indicated for the duration of a slot, but more or less granular information could be transmitted if desired, for example at sub-slot or symbol level.

[74] Effectively, the base station 41 is applying a comparison to determine if the sensed signals are those from the initiating base station, or another device. Any appropriate data for that comparison may be used, and any appropriate comparison may be performed.

[75] There are situations where the signals from the initiating base station occupy the same or very similar frequencies to signals from another device. For example, the base station and device 46 may be using all available resources. In another situation, there could be a partial overlap of resources between the base station 40 and the device 46. Further information may be provided by the initiating base station to assist the receiving base stations in identifying the source of sensed signals. For example, the provided information may include the transmit power of the signals from the initiating base station. Power received at the receiving base stations from the transmissions of the initiating base station will vary due to channel variations, but due to the fixed locations of the base stations good estimates of path loss and statistical variation should be able to be acquired. The receiving base stations can then more accurately identify whether a sensed signal is from the initiating base station (if the sensed power is what would be expected due to the indicated transmission power and estimated path loss). Base stations can improve the accuracy of sensed powers using Discovery Reference Signals (DRS), Synchronization Sequence Blocks (SSBs), or any preamble/initial/reservation signal which is known to be there. These signals allow the receiving base stations make estimates of instantaneous realizations of the channel fading process linking them with the initiating base stations, hence allowing them to make a very precise estimate of the received power from the initiating base station.

[76] If the sensed resource occupancy is a subset of the utilisation indicated by the initiating base station it may be decided that only the initiating base station is utilising the transmission resources and the receiving base station can transmit. In the example of Figure 4, base station 41 will detect more resources being utilised than indicated by base station 40 and accordingly determines it cannot transmit. However, base station 48 would detect the same or fewer resources (if some are attenuated and cannot be detected) than indicated and hence that base station can transmit. The subset technique may be applied to frequency channels, PRBs, or other appropriate parameters.

[77] The sensing process for the receiving base stations may estimate the power spectral density across the spectrum. This implies that the receiving base station may measure the power in each narrow-channel over the bandwidth. This allows a more accurate estimate of transmission power and comparison to the utilisation information from the initiating base station. A granularity of PRB or a group of PRBs may be utilised. Such estimates may be compared to an indication from the indicating base station of which channels the base station is utilising to determine if the sensed signals are from the initiating base station.

[78] Although the estimated power spectral density analysis at the neighbouring base stations after receiving the ownership indication along with indicated resource occupancy can provide some indication regarding which resource blocks may be in use by other incumbent devices, this procedure may not be sufficient to start using the unlicensed resources without disturbing some other incumbent transmissions and for a fair utilization of the unlicensed resources. A more robust approach would be to apply an energy detection based channel sensing mechanism, with the knowledge of frequency resources used by the initiating base station. The receiving base stations

may apply energy detection thresholds to two sets of frequency resources. A first set comprises those indicated to be in use by the initiating base station, and the second set comprises those not indicated to be in use. The energy received in each of these sets can then be estimated and each value compared to different energy detection (ED) thresholds. The time to measure the energy can be the same as used in energy detection for conventional LBT procedures. The ED threshold for the first set (used by the initiating base station) may be higher than the ED threshold for the second set (not used). The ED threshold applied to the second set may be the threshold used for individual channel sensing or a threshold specified by local regulatory bodies to access the unlicensed resources. The ED threshold applied to the first set of resources can be calculated from the individual thresholds by combining it with the received power from the initiating base station. The simplest way would be to add the received power of the initiating base station in the individual ED threshold, although some offset can be applied to control the level of sharing among the neighbouring base stations.

[79] In summary, the energy in the frequency resources indicated as utilised by the initiating base station is compared to a first ED threshold, and the energy in the frequency resources not indicated as being used is compared to a second threshold. The first threshold may be higher than the second threshold, and the first ED threshold may be determined from the transmission power indicated by the initiating base station and estimated path losses.

[80] The aforementioned technique of applying two different energy detection thresholds to two complementary frequency resources can be implemented through energy subtraction and applying a single ED threshold. The receiving base stations can subtract the estimated received energy from an initiating base station from the sum of energy of the resource set indicated to be occupied in the received indication. It can combine this subtracted energy with the energy of the complementary frequency resource set not indicated to be occupied. Thus, effectively it has made an estimate of the received energy over the whole channel bandwidth minus the energy received from the initiating base station who sent the indication. Then it can apply a single conventional energy detection threshold to this energy value to decide clear channel assessment for the unlicensed resources.

[81] The technique of applying two different ED thresholds to the unlicensed channel resources enables identification of potential devices who might be using a fraction of the channel bandwidth. This technique also provides a finer control to what level of interference situations are allowed among the sharing base stations. Currently in LAA based schemes, the energy computation does not consider any possibility of resource ownership by other base stations of the same operator. A single ED threshold is applied which is selected as a function of if presence/absence of other RATs (Wi-Fi) can be established or not. A higher ED threshold is selected and applied if the absence of other devices can be established, for example by regulations. Thus, the current schemes facilitate frequency reuse only in cases when other devices are not there by regulations. Contrary to such schemes, the proposed scheme facilitates frequency reuse among the neighbouring base stations even when there are contenders from other RATs or different operators from the same RAT. The enhanced channel sensing based upon estimation and received ownership indication ensures the shared channel access when primarily the base station of the same operator is transmitting in the proximity and the fairness is ensured by leaving the resources as per the access right of the initiating base station.

[82] When a base station obtains access to transmission resources the base station can use the resources for downlink (DL), uplink (UL) or both DL and UL transmissions. The intended use of the resource can also be indicated to receiving base stations to further assist in determining whether the receiving base stations can share the resources. The method of indicating utilisation may vary between UL and DL. For example, for UL a bitmap representing interlace utilisation

may be used to provide a compact representation. Similarly, the same interlace representation could be used for DL.

[83] The duration of the TxOP, which could be up to MCOT duration, obtained for resources by the initiating base station may be longer than the transmissions that can be scheduled when channel access is first obtained. A base station may therefore transmit an initial indication of the resources to be utilise, and then transmit further indications as further resources are scheduled. For example, a new indication could be scheduled at the start of each slot, or when there is a change in scheduling.

[84] In order to constrain the variables available when sharing resources, sharing may only be allowed to commence at pre-defined times such as the start of a slot or sub-frame. Such limitations also allow time for propagation of messages from base stations wishing to share resources such that transmission details can be sent to other base stations for the remaining intervals during the TxOP.

[85] In the example of Figure 4, base station 48 may commence sharing the resources with base station 40 in response to the indication of resource utilisation. Subsequently base station 41 will sense transmissions from both base station 40 and 41. Even if device 46 has ceased transmissions it will thus still appear that base station 41 cannot transmit as it will detect more active resources and more received energy than indicated by base station 40 in its initial indication. However, as both base stations 40 and 48 are part of the same cellular network as of 41 it may be able to share those resources.

[86] This issue is mitigated if base station 48 also transmits its resource utilisation (i.e. it is also an initiating base station as far as its transmissions are concerned) and base station 41 compiles both indications. This could though increase the signalling load and generate some issues in the sharing region as the neighbours of base station 48 may be different from the neighbours of initiating base station 40. Alternatively, base station 48 may transmit an indication back to base station 40 that it intends to share the resources, which updates its own indications in a subsequent transmission. This indication may include its resource occupancy, the transmit power and the duration over which it intends to share the resources. This allows the initiating base station 40 to send the accurate indication of the resource occupancy and transmission power for the unlicensed resources to its neighbouring base stations in the next intervals. Base station 40 may include detailed information about base station 48, or include a flag indicating that at least one other base station is sharing the resources. This indication is helpful as it may allow better application of received power thresholds as the channels linking the receiving base stations with the base stations 40 and 48 may be different. Base station 41 thus receives improved data for comparison with the sensed situation.

[87] Figure 5 shows a more detailed process for sharing transmission resources, applying the principles described above. At step 50 the base station desires access to transmission resources and initiates an LBT process at step 51. If at step 51 the base station acquires access to the transmission resources, it starts utilising those resources at step 52 and transmits an indication of its utilisation to neighbouring base stations at step 53. The base station continues to transmit until it reaches the MCOT for the resources, or has no more use for the channel, and reverts to standard behaviour.

[88] If the base station does not successfully acquire access to the transmission resources, it may attempt to share resources with an initiating base station. At step 54 the base station checks if it has received information from a neighbouring base station winning the transmission rights and indicating utilisation of the transmission resources.

[89] If there are resources that may be available for sharing, the base station may check, at step 55, the time remaining in the TxOP to ensure the opportunity is suitable. For example, if there is only a very short time available, or less time than required for the intended transmission, it may be inefficient to start transmissions, stop, and try later to access the resources with the conventional LBT process. It may be more efficient to wait and attempt to obtain access later.

[90] If there is sufficient time remaining, at step 55, the base station performs an appropriate form of LBT at step 56. For example, as set out above, the power in two sets of channels may be calculated and compared to two different thresholds. Alternatively, any of the processes described above may be utilised. If the LBT process shows the resources are utilised by a different device then the base station cannot share the resources and seeks other options for transmission.

[91] The LBT process of step 51 is conventional energy detection over the channel bandwidth without paying any attention to over which parts of resources the energy is spread, and which devices may potentially be using those resources. As will be appreciated the LBT of step 56 is more complex than that of step 51 as it intends to ascertain which parts of the transmission resources may be available for transmission, even if a conventional LBT process suggests transmission is not possible.

[92] If access is available, the base station shares the resources until the end of the TXoP (or its transmission is complete) at step 57 before returning to idle for subsequent operation. The process therefore allows transmission resources to be shared and used more efficiently in situations where conventional LBT processes would not allow the base station to transmit.

[93] Simulations have been utilised to show possible advantages of the techniques described above. A cell arrangement shown in Figure 6 was utilised. A configuration with gNB1 surrounded by M neighbouring base stations of the same network is considered, and it is assumed that there are N devices (for example, Wi-Fi or other cellular devices) in proximity competing for the same transmission resources.

[94] In the situation where there is no coordination, from the point of view of the base station gNB1, there are N contending devices plus the neighbouring base stations of the same network. This also assumes that the neighbouring base stations transmissions are detectable at gNB1. For most urban deployments and with the spectrum going to higher frequencies with larger path-loss, this is a valid assumption. gNB1 will contend against N devices (Wi-Fi or other operators) plus M of its neighbouring base stations.

[95] If full buffer traffic is assumed at each device so that each device always has traffic to transmit, the target base station gNB1 and all M+N other nodes will try to gain access to the transmission resources. Due to contention window and random draw-based channel sensing procedures (for example, LBT of LAA/eLAA in 3GPP), in the long term all the devices will have equal opportunity of channel access. Thus, for the target base station gNB1 the resource access is $1/(M+N)$.

[96] In the situation of a base station sharing utilisation information, with the legacy channel sensing mechanisms are still in place, the probability of channel access by the target (initiating) base station gNB1 is still $1/(M+N)$. However, as soon as it gains access to the resources, it indicates the utilisation information to its neighbouring base stations. This information also includes the remaining time within the COT, channel resource occupancy and the transmit power which helps others to find the remaining time of the COT and to establish that there are no other users transmitting over the same unlicensed resources. If the other base stations identify other devices transmitting, the other base stations do not transmit.

[97] Assuming gNB1 only shares resources with its direct neighbours, gNB1 shares some of the neighbouring base stations out of M with each of its direct neighbours which must not be transmitting when gNB1 was able to gain resource access. This number is exactly $M/2=3$ for this hexagonal layout. Thus, each neighbouring base station receiving a resource utilisation indication from gNB1 may still have $M/2$ of its neighbours who might be potentially transmitting as they are not in the proximity of gNB1. For the other "N" contenders, if we assume that the density such devices is same for each base station, each neighbouring base station will have half of them $N/2$ silent which are shared neighbours of gNB1 and other half $N/2$ may potentially transmit. Thus, the success probability that each neighbouring base station sees no device active other than gNB1 is

$$[98] \quad p_s = 1/(M/2 + N/2) = 2/(M+N)$$

[99] and the failure probability would be the case that it sees at least one active device active other than gNB1

$$[100] \quad p_f = 1 - p_s = (M+N-2)/(M+N)$$

[101] Considering the probabilities random at each neighbouring base stations, the sharing will be possible when one, two or M neighbours have the success probability. Thus, the overall probability of sharing the unlicensed resources is given by:

$$[102] \quad P = p_s^1 \times p_f^{M-1} + p_s^2 \times p_f^{M-2} + p_s^3 \times p_f^{M-3} + \dots + p_s^M$$

[103] Results are shown in Figure 7 where the channel access per base station has been plotted against different numbers of contending devices (N). The solid (lower) curve shows the legacy channel usage mechanism where the base station does not share the resources with its neighbours. The dashed (upper) curve shows the effective channel access per base station when the base station gaining the channel access indicates to its neighbouring base stations of the same operator and under suitable conditions, these neighbouring base stations can share the resources.

[104] With an increase in the number of neighbouring devices, both schemes show reduction in channel access which is normal due to fair usage principle enforced by channel sensing mechanisms. One would observe a spectral efficiency advantage of the proposed scheme ranging between 200% to 300% for different number of contenders trying to access the same resource. The results show the clear advantage of sharing the unlicensed resource access with neighbouring base stations.

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

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

[107] 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.

[108] 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.

[109] 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.

[110] 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.

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

[112] 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.

[113] 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.

[114] 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.

[115] 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.

[116] 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.

[117] 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.

[118] 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.

[119] 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 resource sharing in a cellular communication system, the method performed by a first base station and comprising the steps of
obtaining access to transmission resources for a defined transmission interval;
transmitting an indication to a second base station of the cellular communication system of the resources to which the first base station has obtained access.
2. A method according to claim 1, wherein the transmission resources are unlicensed spectrum resources.
3. A method according to claim 1 or claim 2, wherein access to the transmission resources by the first base station is obtained by a listen before talk process.
4. A method according to any preceding claim, wherein the indication includes scheduling of resources from the first base station.
5. A method according to any preceding claim, wherein the indication of resource is given per physical resource block.
6. A method according to claim 5, wherein the indication comprises a bitmap wherein each bit relates to a physical resource block.
7. A method according to any preceding claim, further comprising transmitting an indication of transmission power used by the first base station on the transmission resources.
8. A method according to any preceding claim, further comprising transmitting an indication of the defined transmission interval.
9. A method according to any preceding claim, further comprising transmitting an indication of the end of the defined transmission interval.
10. A method according to any preceding claim, further comprising transmitting an indication that the transmission resources were obtained by the first base station.
11. A method according to any preceding claim, wherein the indication of resources comprises an indication of the carrier index of those resources.
12. A method of resource sharing in a cellular communication system, the method performed by a second base station and comprising the steps of
receiving an indication of transmission resources obtained by a first base station;
sensing transmission power received at the second base station;
comparing the sensed transmission power to the indication of transmission resources; and
if the comparison indicates the sensed transmission power is only from the first base station, initiating transmission from the second base station.
13. A method according to claim 12, wherein the transmission resources are unlicensed spectrum resources.

14. A method according to claim 12 or claim 13, wherein the indication includes scheduling of resources from the first base station.
15. A method according to any of claims 12 to 14, wherein the indication of resources is given per physical resource block.
16. A method according to claim 15, wherein the indication comprises a bitmap wherein each bit relates to a physical resource block.
17. A method according to any of claims 12 to 16, further comprising receiving an indication of transmission power used by the first base station on the transmission resources.
18. A method according to claim 17, further comprising estimating the path loss between the first base station and the second base station.
19. A method according to any of claims 12 to 17, further comprising receiving an indication of the defined transmission interval.
20. A method according to any of claims 12 to 19, further comprising receiving an indication of the end of the defined transmission interval.
21. A method according to any of claims 12 to 20, further comprising receiving an indication that the transmission resources were obtained by the first base station.
22. A method according to any claims 12 to 21, wherein the indication of resources comprises an indication of the carrier index of those resources.
23. A method according to any of claims 12 to 22, further comprising the step of transmitting the received indication to a third base station.
24. A method according to claim 23, further comprising the step indicating the identity of the base station from which the indication was received.
25. A method according to any of claims 23 to 24, wherein the second base station ceases transmission on the indicated resources if the first base station ceases transmission on those resources.
26. A method according to any of claims 12 to 25, wherein the step of comparing comprises comparing energy received in resources indicated as being utilised by the first station to a first threshold, and energy received in resources not indicated as being utilised by the first station to a second threshold.
27. A method according to claim 26, wherein the first threshold is higher than the second threshold.
28. A method according to claim 12, wherein the comparison is between indicated physical resource blocks and sensed power in those resource blocks.

29. A method according to claim 28, wherein it is determined that the sensed transmission power is only from the first base station if the sensed physical resource blocks are a subset of the indicated physical resource blocks.
30. A base station configured to perform the method of any of claims 1 to 29.

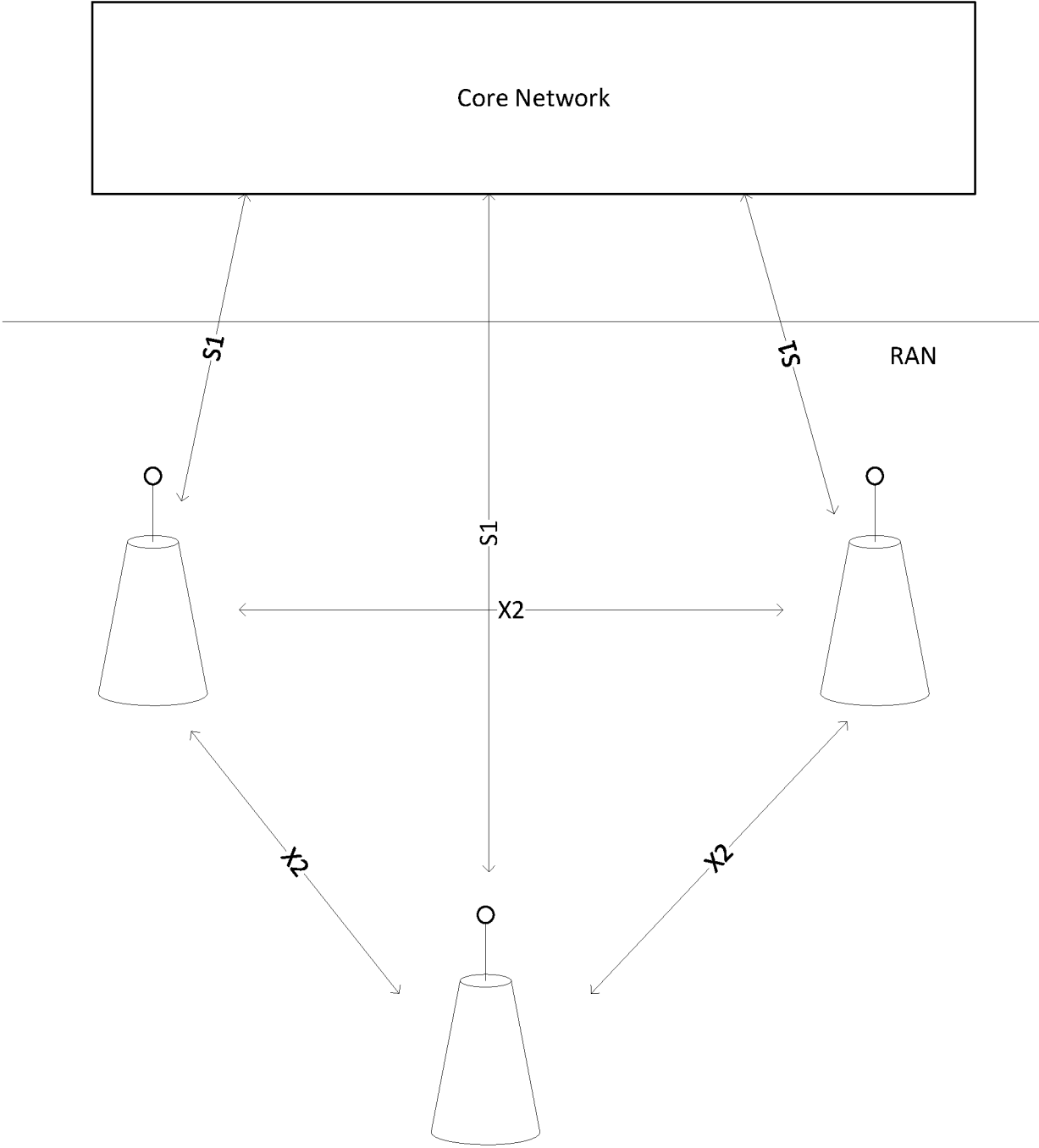


Figure 1

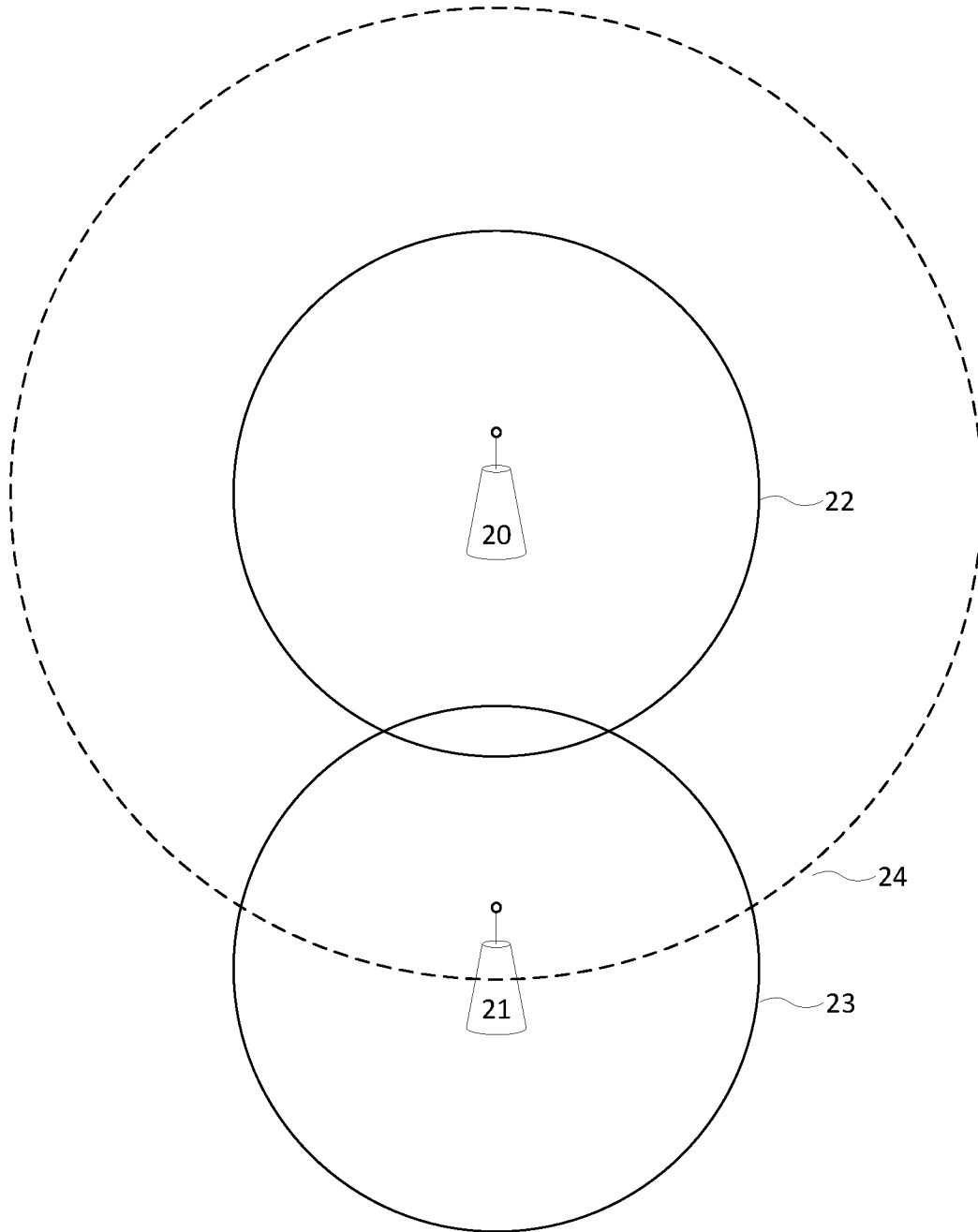


Figure 2

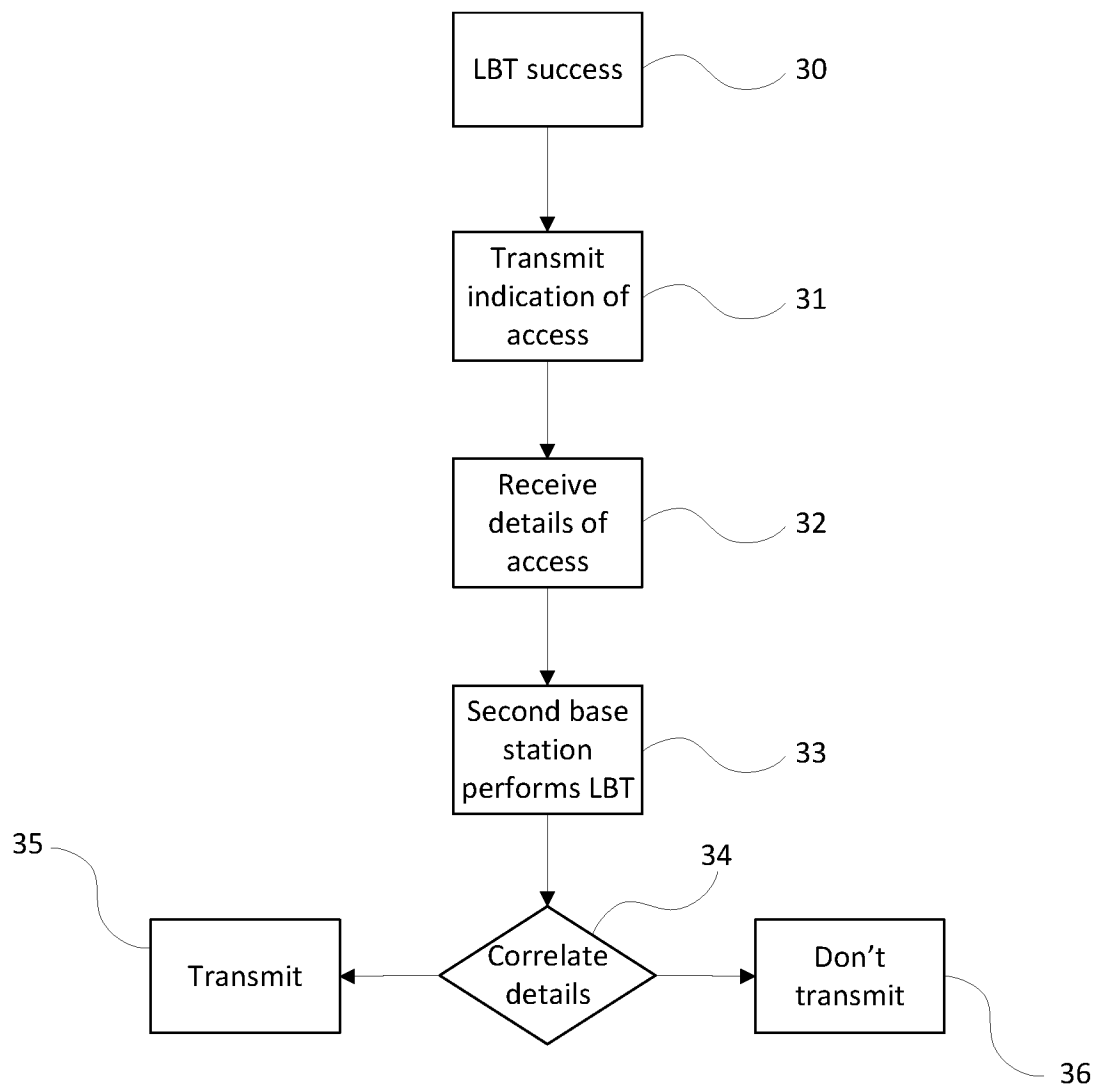


Figure 3

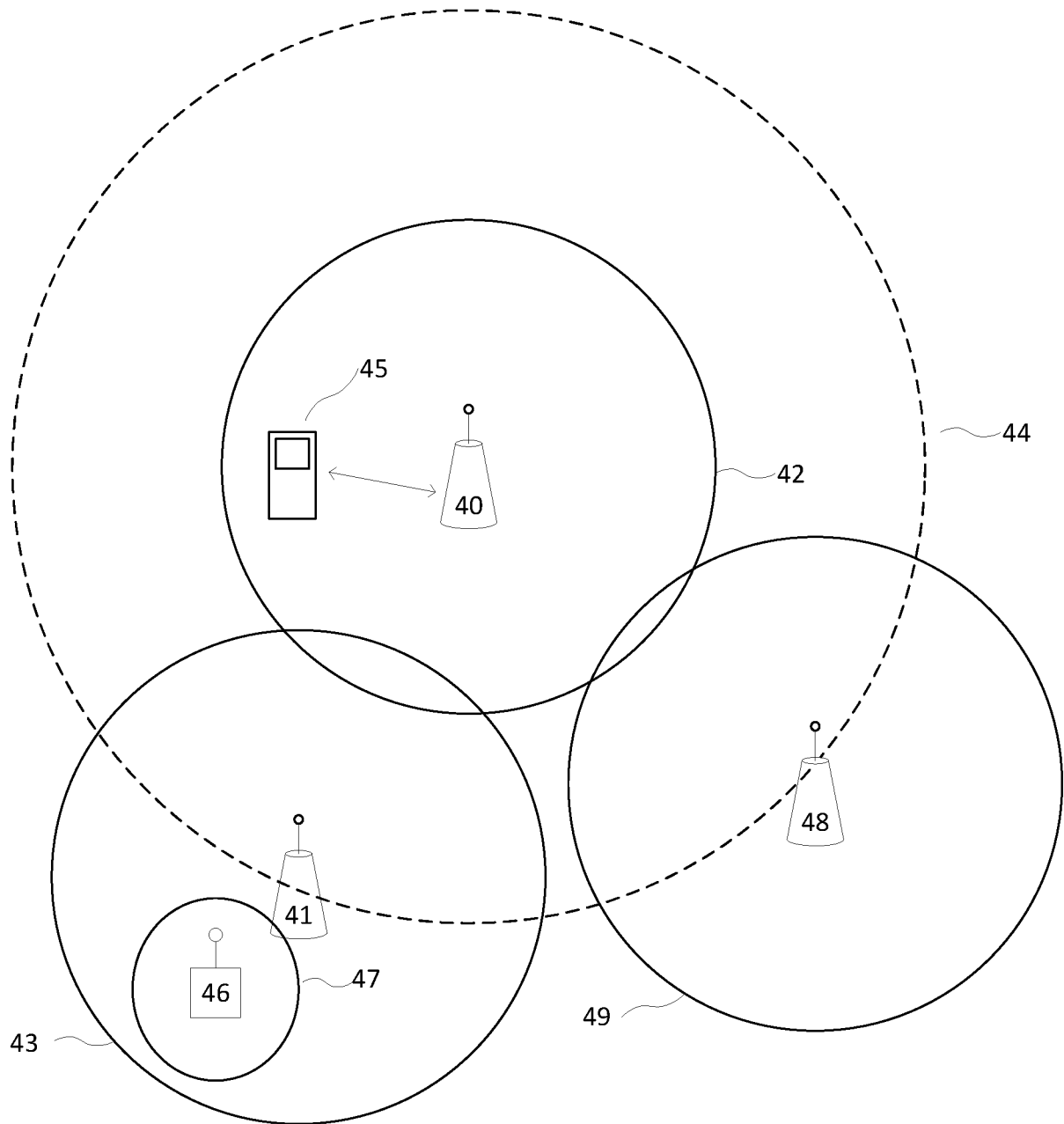


Figure 4

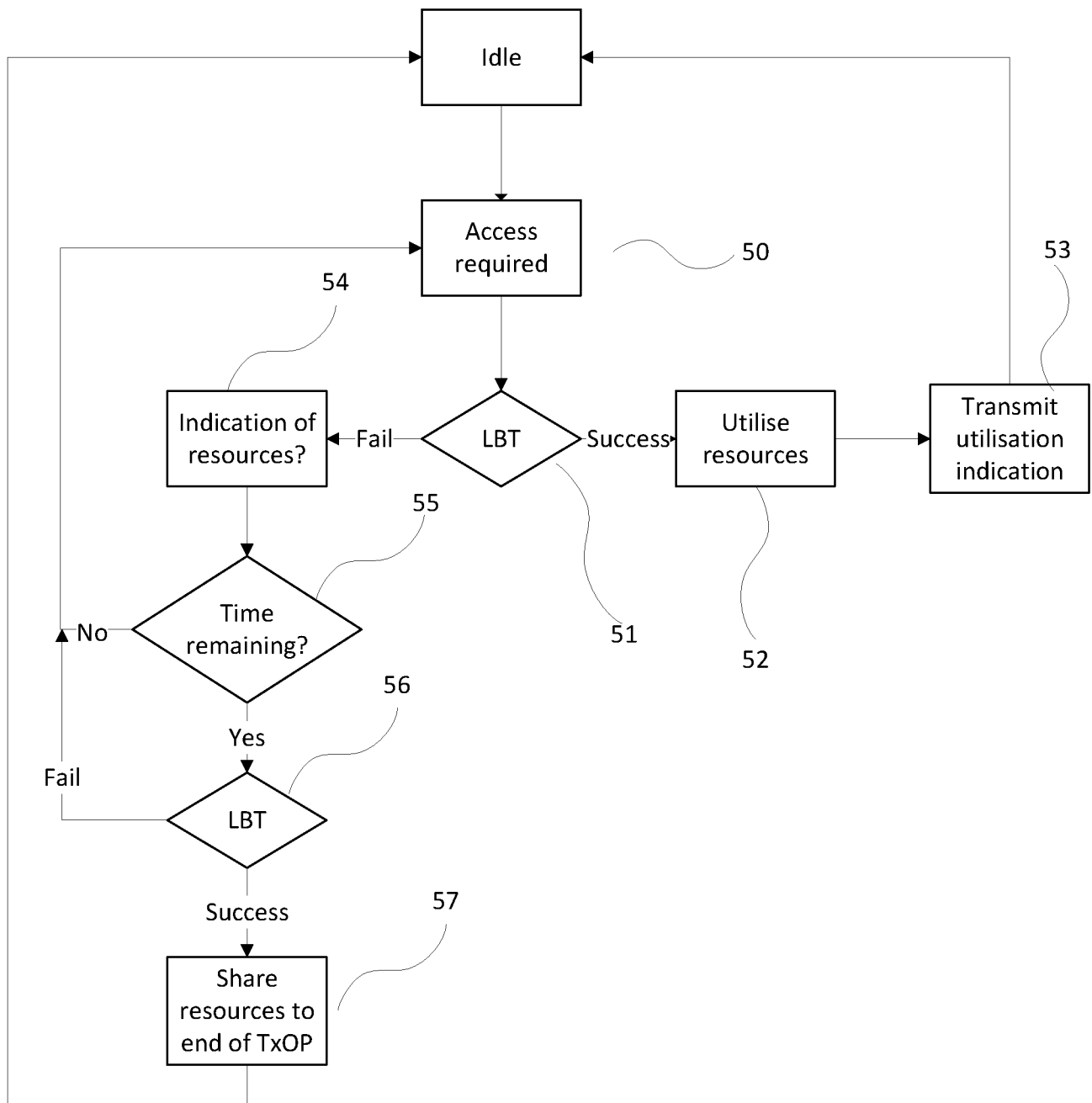


Figure 5

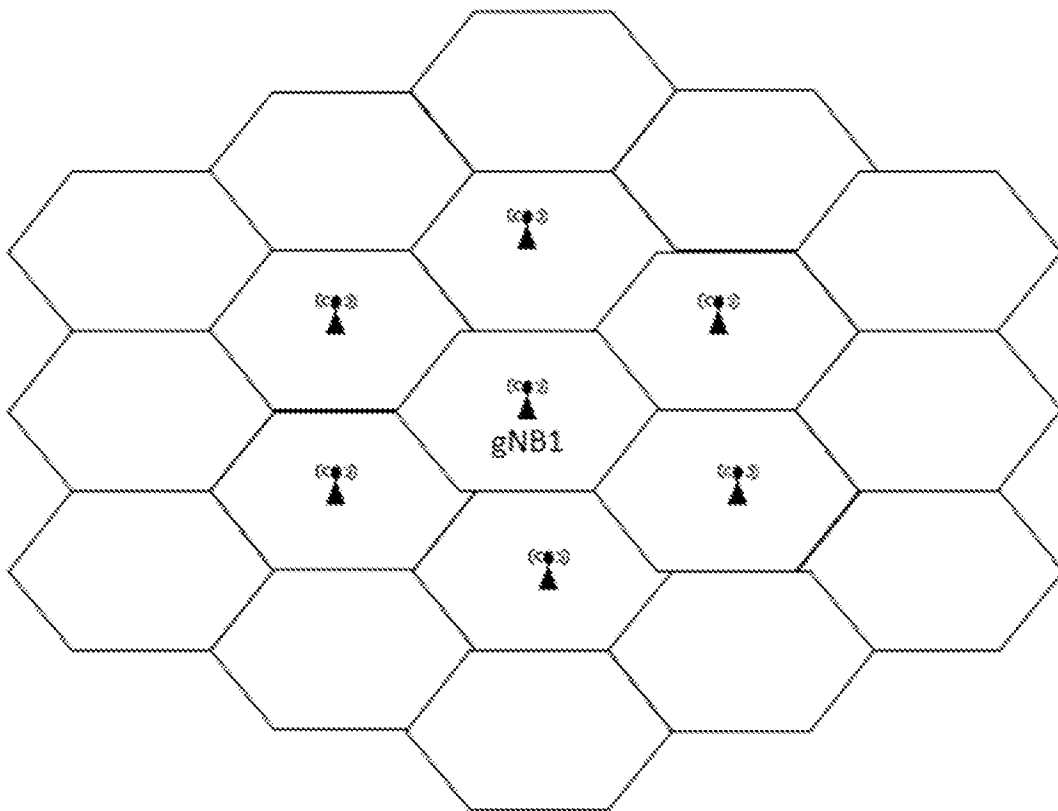


Figure 6

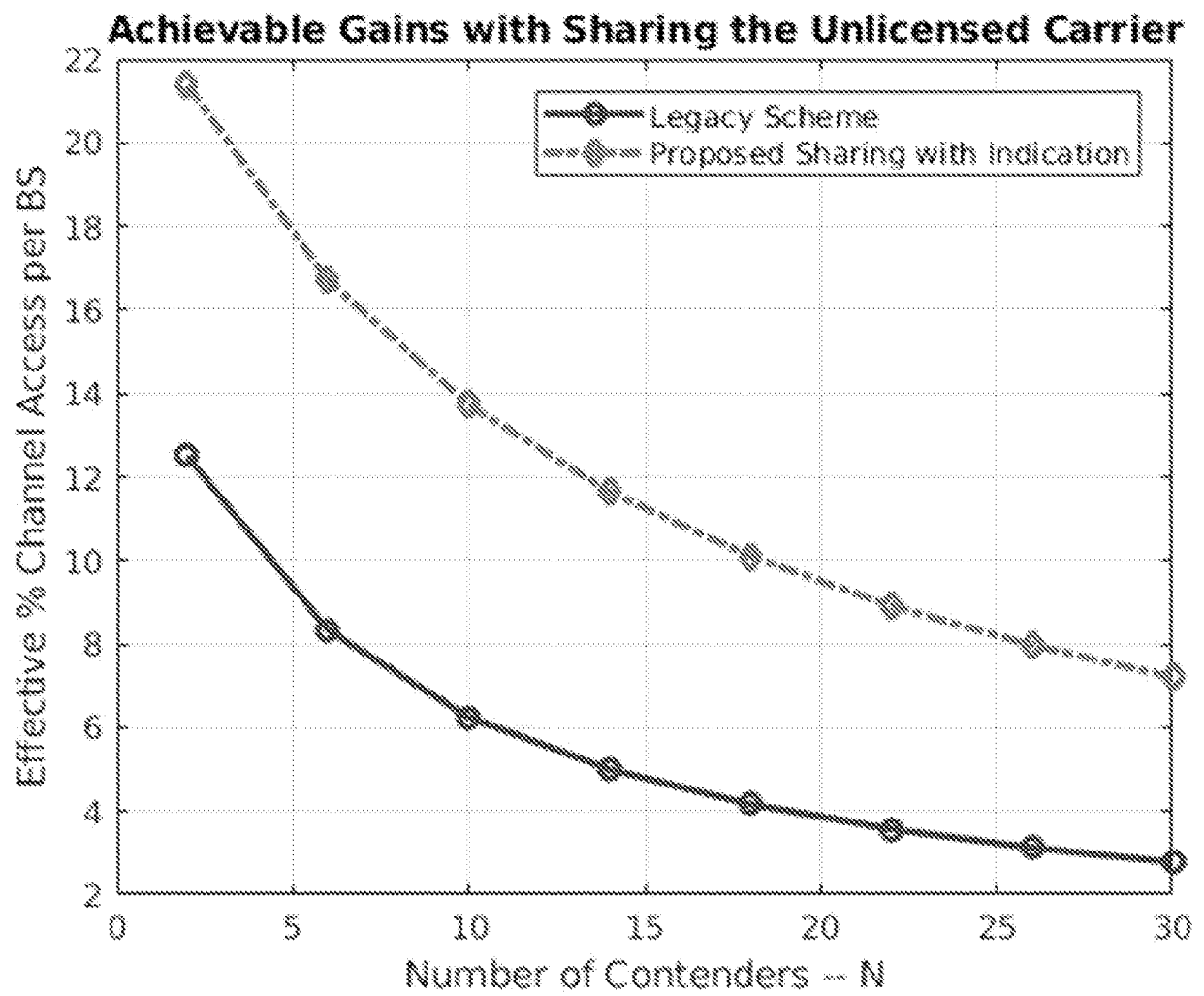


Figure 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2019/099513

A. CLASSIFICATION OF SUBJECT MATTER

H04W 74/08(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W; H04Q; H04L

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

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

CNKI,CNPAT,EPODOC,WPI:LBT,listen before talk,shar+, resources, unlicensed, transmission interval, time, indication, access, occupy, use, utilized, sense, transmission power

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2017114552 A1 (TELEFONAKTIEBOLAGET LM ERICSSON PUBL) 06 July 2017 (2017-07-06) description page 5 line 4 to page 6 line 5, page 7 line 17 to page 11 line 9, page 12 line 28 to page 15 line 5, page 17 lines 27-35; figures 1-8	1-30
A	WO 2016155480 A1 (ZTE CORPORATION) 06 October 2016 (2016-10-06) the whole document	1-30
A	WO 2015169359 A1 (NOKIA SOLUTIONS AND NETWORKS OY) 12 November 2015 (2015-11-12) the whole document	1-30
A	US 2015172950 A1 (QUALCOMM INCORPORATED) 18 June 2015 (2015-06-18) the whole document	1-30



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

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

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

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

“&” document member of the same patent family

Date of the actual completion of the international search

19 September 2019

Date of mailing of the international search report

08 October 2019

Name and mailing address of the ISA/CN

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XING,Chaoxia

Facsimile No. (86-10)62019451

Telephone No. 86-(10)-53961600

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2019/099513

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WO	2016155480	A1	06 October 2016	CN	106160967	A	23 November 2016
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				WO	2015169397	A1	12 November 2015
				EP	3140945	A1	15 March 2017
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				EP	3140944	A1	15 March 2017
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