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(54) Title: SYNCHRONISATION SIGNALS IN SHARED SPECTRUM FOR CELLULAR NETWORKS

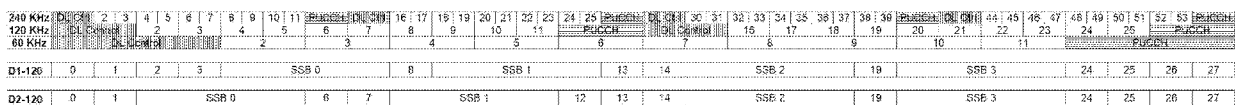


Figure 2

(57) Abstract: Transmission patterns are provided for the transmission of synchronisation signals in OFDM cellular communication systems which utilise beam sweeping. Patterns are provided with at least one OFDM symbol gap between each synchronisation signal burst to allow switching between beams.

Synchronisation Signals in Shared Spectrum for Cellular Networks

Technical Field

[1] The following disclosure relates to the transmission of synchronisation signals, and in particular to transmitting such signals when operating in shared transmission spectrum with a beam-sweeping base station.

Background

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

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

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

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

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

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

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

Summary

[9] The invention is defined in the claims, in which there is provided a method of transmitting an SS/PBCH burst in an OFDM transmission system operating in Frequency Range 2 and utilising beam sweeping, the method comprising the steps of selecting a plurality of starting locations for the transmission of SS/PBCH bursts, wherein the starting locations are selected such that there is a gap of at least one OFDM symbol between adjacent SS/PBCH bursts; and transmitting a plurality of SS/PBCH bursts, wherein each SS/PBCH bursts starts at one of the selected starting locations.

[10] The system may utilise a sub carrier spacing of 120 kHz.

[11] The starting locations may be at OFDM symbol numbers $\{4, 9, 15, 20\} + 28*n$, where $n = 0, 1, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[12] The starting locations may be at OFDM symbol numbers $\{2, 8, 15, 20\} + 28*n$, where $n = 0, 1, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[13] The starting locations may be at OFDM symbol numbers $\{4, 9, 15, 20\} + 28*n$, where $n = 0, 1, 2, \dots, 19$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[14] The system may utilise a sub carrier spacing of 240 kHz.

[15] The starting locations may be at OFDM symbol numbers $\{8, 14, 20, 32, 38, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 10$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[16] The starting locations may be at OFDM symbol numbers $\{8, 14, 20, 32, 38, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 19$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[17] The starting locations may be at OFDM symbol numbers $\{8, 16, 32, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[18] The starting locations may be at OFDM symbol numbers $\{8, 16, 32, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 19$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[19] The system may utilise a sub carrier spacing of 480 kHz.

[20] The starting locations may be at OFDM symbol numbers $\{4, 12, 20\} + 28*n$, where $n = 0, 1, 2, \dots, 21$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[21] The starting locations may be at OFDM symbol numbers $\{16, 32, 40, 64, 72, 88\} + 112*n$, where $n = 0, 1, 2, \dots, 10$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

[22] The system may utilise a sub carrier spacing of 960 kHz.

[23] The starting locations may be at OFDM symbol numbers $\{8, 20, 32, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

- [24] The starting locations may be at OFDM symbol numbers $\{32, 44, 64, 76, 88, 128, 144, 156, 176, 188\} + 224 \cdot n$, where $n = 0, 1, 2, \dots, 6$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
- [25] The method may further comprise the step of transmitting an indication of the starting locations.
- [26] The starting locations may be transmitted in the payload of the PBCH.
- [27] A reserved bit of the MIB payload may be utilised as part of the indication of the starting locations.
- [28] The number of starting locations may be no more than 128.
- [29] The PBCH DMRS may indicate at least part of the starting locations.
- [30] The starting locations may be indicated by SS/PBCH candidate index.

Brief description of the drawings

- [31] 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.
- [32] Figure 1 shows selected elements of a cellular communication system; and
- [33] Figures 2 to 5 show example transmission patterns.

Detailed description of the preferred embodiments

- [34] 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.
- [35] Figure 1 shows a schematic diagram of three base stations (for example, eNB or gNBs depending on the particular cellular standard and terminology) forming a cellular network. Typically, each of the base stations will be deployed by one cellular network operator to provide geographic coverage for UEs in the area. The base stations form a Radio Area Network (RAN). Each base station provides wireless coverage for UEs in its area or cell. The base stations are interconnected via the X2 interface and are connected to the core network via the S1 interface. As will be appreciated only basic details are shown for the purposes of exemplifying the key features of a cellular network. A PC5 interface is provided between UEs for SideLink (SL) communications. The interface and component names mentioned in relation to Figure 1 are used for example only and different systems, operating to the same principles, may use different nomenclature.
- [36] 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.
- [37] Set out below are various techniques for the transmission of synchronisation signals in cellular networks, which may be particularly appropriate for use with large sub-carrier spacings in shared transmission spectrum.

[38] A UE acquires time and frequency synchronisation with a cell using a cell search procedure which also detects the physical layer cell identify of the cell. Synchronisation is based on reception of a Primary Synchronisation Signal (PSS) and a Secondary Synchronisation Signal (SSS) transmitted by the base station of the cell. The base station transmits the Physical Broadcast Channel (PBCH), PSS and SSS in consecutive symbols in an SS/PBCH block. The PSS and SSS allow the UE to synchronise with the base station/cell, and PBCH is decoded to provide basic system information to allow the UE to complete configuration and initiate communications. The SS/PBCH block format is specified in TS 38.211. The SS/PBCH block burst spans 5 ms, during which the base station may transmit SS/PBCH blocks for active beams. SS/PBCH blocks for active beams will always be confined within this 5ms burst window. The SS/PBCH block transmission patterns are defined in TS 38.213.

[39] Base stations may operate in a beam-based mode in which transmissions are made on beams in certain directions, rather than using omnidirectional transmission. In Frequency Range 1 (FR1) it is proposed to support up to 8 beams, and in Frequency Range 2 (FR2) up to 64 beams. Due to equipment limitations (particularly in FR2) a base station may not be able to transmit on all beams simultaneously and so beam-sweeping operation may be utilised in which transmissions are made sequentially on each beam (or subset of beams). When operating with beam-sweeping each beam may transmit its own SS/PBCH block to ensure UEs receive the signals and can synchronise.

[40] The standards specify that a UE determines system timing by determining the system frame number (SFN), half radio frame flag and the beam index. Beam index corresponds to the position of a given SS/PBCH block in the SS/PBCH burst in a given half-frame. The following disclosure uses the terms beam index and SS/PBCH block candidate position index synonymously. SFN, half-frame flag and beam index become available at a UE after a successful PBCH decoding which is part of the SS/PBCH block transmitted by the base station. PBCH is used to transmit the master information block (MIB) received from higher layers to which the physical layer adds some additional information in the form of the PBCH payload. Radio frame identification, indicated as a 10-bit SFN (denoted as bits s_0 to s_9), is ensured by transmitting the 6 most significant bits (MSBs) s_4 to s_9 in the MIB payload. MIB payload is the transport block provided to the physical layer from the medium access control (MAC) layer. Four least significant bits (LSBs) of the SFN, s_0 to s_3 , and half-frame flag bit are transmitted as part of the PBCH payload. The physical layer adds the PBCH payload to the MIB payload and transmits the combined MIB payload and PBCH payload over PBCH after physical layer processing.

[41] For beam index identification, 6 bits b_0 - b_5 are required to indicate up to 64 beams (or SS/PBCH positions in the burst) which are permitted in FR2. 3 LSBs b_0 - b_2 are transmitted using the PBCH demodulation reference symbols (DMRS) by modulating the initialization sequence used to generate the DMRS. 3 MSBs b_3 to b_5 are transmitted as part of the PBCH payload which the physical layer adds to the MIB. More than 6 bits could be utilised to allow an increased number of beams or SS/PBCH candidate positions.

[42] In order to utilise beam-sweeping and allow transmission of SS/PBCH blocks suitable transmission patterns are required, particularly for operation in FR2 unlicensed spectrum which requires an appropriate channel access procedure for sharing the transmission resources.

[43] The following disclosure provides SS/PBCH burst designs which enable synchronisation of UEs when operating in shared FR2 spectrum with beam-sweeping. Also, specific transmission patterns are disclosed to avoid overlaps with scheduled transmissions, and also increased SS/PBCH candidate positions may be provided to address channel uncertainty in shared spectrum.

[44] For operation over 6 GHz unlicensed spectrum, the channel access procedure for transmission of the SS/PBCH block uses a deterministic duration under the conditions that (i) there is no unicast data, (ii) transmission duration is at most 1 millisecond and (iii) the discovery burst duty cycle is at most 1/20. For 6 GHz spectrum, 3GPP TS37.213 has specified the use of a Type 2A DL channel access procedure for the SS/PBCH block transmission along with non-unicast information where the base station will perform sensing over an interval of at least 25 micro-seconds.

[45] The 25 micro-second duration is split into a period of 16 micro-seconds (with sensing performed in the beginning), followed by one sensing slot of 9 micro-seconds. These parameters are intended to ensure fair co-existence with Wi-Fi devices, which use a Short Interframe Space (SIFS) of 16 micro-seconds and a basic sensing slot of 9 micro-seconds for the frequencies around 6 GHz. SIFS is the period that is used by Wi-Fi systems to indicate the delay during which a receiving device processes a received frame and responds back to indicate the correct reception of a packet as part of a hybrid-automatic repeat request (HARQ) mechanism. The SIFS duration is also used when the receiving device contributes to the channel access procedure in a request-to-send and clear-to-send procedure.

[46] To avoid interrupting an ongoing communication with SIFS gaps, Wi-Fi systems allow a prioritized channel access procedure which comprises of the SIFS period and at least one sensing slot. Thus, even prioritized transmissions, for example from Wi-Fi access points, may only start after SIFS plus one sensing slot, ensuring no harm to ongoing communication between a pair of devices which may have a SIFS gap.

[47] For 802.11ad enhancements targeting operation in the 60 GHz region, the SIFS period has been updated to be 3 micro-seconds and the sensing slot duration to be 5 micro-seconds. As defined in Section 21.12.4 of Part 11 of the relevant Wi-Fi standards.

[48] The adjusted timings for 802.11ad may be applied in a cellular channel access procedure to ensure fair coexistence. Accordingly, a UE may use a channel sensing period of at least 8 micro-seconds prior to an SS/PBCH transmission. The 8 micro-second period is a combination of the 3 micro-second SIFS period, and the 5 micro-second sensing slot.

[49] The 8 micro-seconds interval is divided into two intervals, one of 3 micro-seconds followed by an interval of 5 micro-seconds. The base station can transmit SS/PBCH without unicast data only if both intervals are found to be idle (i.e. the energy detected over the channel in both intervals is below the specified energy detection threshold). Additional conditions, such as duty cycle and maximum channel occupancy time may be utilised if required by relevant regulations. The sensing may be performed either omni-directionally, or directionally.

[50] The new reference timings for 802.11ad may also be used in relation to deterministic channel access for cellular operation. When channel access has been acquired in shared spectrum by a base station or a UE, and there is a gap (either because a device starts transmitting over a channel acquired by another device or the same device transmits after a gap) of at least 3 micro-seconds, the device is required to perform channel sensing for 3 micro-seconds. This channel sensing is the equivalent of Type 2B channel sensing suitable for 60 GHz operation.

[51] Similarly, if channel access has been acquired, and there is a gap of less than 3 micro-seconds, the transmission can be resumed without any channel sensing. This behaviour is permissible since no device should acquire the channel without a sensing duration of at least 3 micro-seconds, so no transmissions should have started during a gap of less than 3 micro-seconds. This channel sensing is the equivalent of Type 2C channel sensing suitable for 60 GHz operation, in view of the co-existence with 802.11ad devices.

[52] As noted above, when beam-sweeping is utilised a base station will not transmit on all beams simultaneously, meaning there are gaps of varying duration in each beam direction while another beam is in use. During the gaps in transmission other devices may have acquired the channel commenced transmissions, hence a channel access procedure of at least 8 micro-seconds, as set out above, should be performed before starting transmission on a new beam, even where channel access has previously been acquired. As discussed above, the sensing may be in an omni-directional or directional manner. This applies to the transmission of SS/PBCH blocks for a given beam.

[53] The standards permit the use of sub-carrier spacing of 60KHz and larger for high frequency operation. Rel-15 has standardized the SS/PBCH block patterns for SCS of 120 kHz and 240 kHz, where 240 kHz is only used for SS/PBCH block transmission and not for data. For further higher frequency operation, where the carrier bandwidths may be extremely large (GHz) even larger SCS may be required to help solve the problem of large FFT size which may be a bottleneck when the number of sub-carriers becomes very large. In this regard, for FR2, it may be advantageous to choose very large SCS going to 960 kHz or even 1920 kHz. This will require the design of new SS/PBCH block patterns to accommodate SS/PBCH blocks transmissions in different beam directions and potentially allow the usage of different SCS for SS/PBCH blocks and other control and data transmissions.

[54] For operation in unlicensed spectrum, Wi-Fi and its high frequency counterpart WiGig (which includes 802.11 ad standard) adhere to channel access procedures in the form of listen before talk. In order to co-exist in shared unlicensed spectrum cellular base stations may apply equivalent procedures. Current SS/PBCH block transmission designs for 120 kHz SCS and 240 kHz have SS/PBCH blocks transmitted from different beams contiguously. This is attractive for operation in licensed spectrum to compress the SS/PBCH blocks into a shorter span of time to have maximum flexibility in scheduling/control in the remaining time. However, when operating in unlicensed spectrum, as noted above, a channel access procedure may be required before starting transmissions on a new beam, thus preventing contiguous transmission between beams. The channel access procedures discussed above may be appropriate prior to commencing transmission on a beam, where there has been a gap in transmission on that beam.

[55] Set out below are designs for SS/PBCH block transmission in beam-based transmission systems. The designs are independent of the specific type of channel access procedure when switching beams. The proposed designs provide tolerance to beam switching delays and associated transients which may affect the detection probability of SS/PBCH blocks transmitted without adequate gap to a beam switch. The techniques disclosed utilize SS/PBCH block bursts with time gaps between consecutive SS/PBCH blocks. There is therefore provided a method of transmitting synchronization signals from a base station on a plurality of a beams, wherein the signals are arranged in a burst with a time gap between signals transmitted on each beam.

[56] When operating at 120 kHz SCS each OFDM symbol is approximately 8.9 micro-seconds. The noted 8 micro-second sensing duration can thus be accommodated in a gap of 1 OFDM symbol (at 120 kHz). At 240kHz each OFDM symbol is approximately 4.5 micro-seconds and hence 2 OFDM symbols are required to allow an 8 micro-second sensing period. Similarly, for SCS of 480 kHz and 960 kHz, 4 and 8 OFDM symbols are required respectively to perform the channel sensing over a duration of at least 8 micro-seconds.

[57] Set out below are designs for SS/PBCH block bursts for SCS ranging from 120 kHz to 960 kHz. All of the proposed designs ensure a minimum gap to enable channel sensing prior to beam switching. In addition, as the SCS of SS/PBCH block can be different from the control/data SCS, the designs seek to maximise DL and UL control opportunities for different numerologies

(SCSs). DL control, typically sent in the initial few symbols of a slot in the numerology of control (data), help the base station schedule the resources for DL and UL transmissions. UL control, typically scheduled in the last few symbols of a slot, help the base station receive HARQ feedback and UL control information.

[58] Figure 2 shows two proposed designs (D1-120 and D2-120) for SS/PBCH block pattern for sub-carrier spacings of 120 kHz. This design targets harmonious operation of SS/PBCH blocks transmitted using 120 kHz, with allowing maximum possibility for the DL/UL control transmission opportunities for SCS starting from 60 kHz. The choice of 60 kHz is taken as the lower SCS of 15 kHz and 30 kHz are only allowed in lower frequency range FR1 in 3GPP. Figure 2 shows one slot (14 symbols) of 60 kHz SCS, which spans 28 and 56 symbols of 120 kHz and 240 kHz SCSs respectively. The first 3 rows show the symbols from 60 kHz to 120 kHz SCS, with the applicable SCS noted in the first column. For each SCS in its corresponding row, the first two symbols have been highlighted to show the potential downlink control transmission, and the last two symbols have been highlighted to show the potential uplink control transmission. The bottom two rows provide the proposed designs (D1-120 and D2-120) of SS/PBCH block patterns for 120 kHz SCS.

[59] The candidate positions for the D1-120 design of Figure 2 are:-

- $D1_120 = \{4, 9, 15, 20\} + 28*n$
- $n = 0, 1, 2, \dots, 15$

[60] The design D1-120 of Figure 2 is that it has at least one OFDM symbol gap between consecutive SS/PBCH blocks, providing more than 8 micro-seconds for channel sensing to be performed after beam switching. This design avoids any overlap with the 60 kHz SCS DL and UL control. For the two slots of 120 kHz SCS, it provides 1 overlap free DL and UL control. It also provides a gap at symbols 13 and 14, which can enable a single symbol UL control and a single symbol DL control respectively. For 240 kHz SCS, it provides half of the DL and UL control opportunities.

[61] The candidate positions for the D2-120 design of Figure 2 are:-

- $D2_120 = \{2, 8, 15, 20\} + 28*n$
- $n = 0, 1, 2, \dots, 15$

[62] This design (D2-120) also has at least one OFDM symbol gap between each SS/PBCH block, thus providing at least 8 micro-seconds to perform channel sensing between consecutive beams. In addition to the gap introduction similar to D1_120, D2_120 has a different trade-off for the overlap with control positions. As control resource sets of only a single symbol are allowed, the DL control can be transmitted within a single symbol. On the contrary, for UL control, there needs to be a switching gap, time advance and then uplink control transmission over at least one symbol. Exploiting this difference of UL and DL control, D2_120 slightly displaces the first two SS/PBCH candidates earlier with partial overlap with 60 KHz DL control. The 60kHz DL control transmission at the beginning of the slot is only overlap-free for the first symbol, but more overlap-free DL and UL control transmission opportunities for 120 & 240 kHz SCSs, as can be seen in Figure 2.

[63] The designs of Figure 2 provide 4 SS/PBCH blocks in each slot of 60 kHz SCS (0.25 micro-seconds). Thus, in 5 ms(SS/PBCH burst duration) there are 80 candidate SS/PBCH block positions.

[64] When the transmission carrier is part of licensed spectrum, the first 64 SS/PBCH block candidate positions may be used. When the transmission carrier is part of shared unlicensed

spectrum, the position of an SS/PBCH block may not be available due to channel access uncertainty (i.e. channel sensing when switching to a new beam detects a transmission). Additional SS/PBCH candidate positions may be provided within the burst span for utilisation if some positions are not available due to lack of channel access. Each SS/PBCH block will be identifiable with its beam index, thus providing the UE necessary information to be able to determine the complete system timing information.

[65] The designs make all SS/PBCH candidate positions available for transmission within the 5 ms window. 5 ms is kept as it is already defined as the SS/PBCH burst duration. If the burst duration is modified, the same approach of making additional positions available for SS/PBCH can be adopted by utilising all the positions which fit within the updated burst duration.

[66] For the proposed designs, each design provides 2 SS/PBCH block candidate positions in one slot of 120 KHz. As there are 40 slots of 120 kHz SCS in 5 ms, the designs will provide overall 80 SS/PBCH candidate positions. Thus, candidate positions for Design D1-120 for 120 kHz SCS are:-

- $D1_120 = \{4, 9, 15, 20\} + 28*n$
- $n = 0, 1, 2, \dots, 19$

[67] The only change is for the possible values of n, which now range from 0 to 19. The same change is applicable to the second design, D2-120, of Figure 2. With 80 positions, the beam index (or more precisely the SS/PBCH candidate position index) will need 7 bits. In the legacy design, there are 6 bits to transmit an index for one of the 64 beams, where 3 bits are transmitted using PBCH DMRS, and 3 bits are transmitted as PBCH payload. With the proposed designs of Figure 2 for 120 kHz SCS, one additional bit needs to be transmitted to enable the UEs determine the system timing information. Techniques to transmit the beam index (or SS/PBCH candidate position index) are disclosed below.

[68] Figure 3 shows proposed designs for SS/PBCH block pattern for sub-carrier spacings of 240 KHz. These designs aim to provide co-existence with SS/PBCH blocks transmitted using 120 kHz to allow maximum possibility for the DL/UL control transmission opportunities for SCS starting from 60 KHz. Figure 3 shows one slot (14 symbols) of 60kHz SCS, which is equivalent in time to 28 and 56 symbols of 120 kHz and 240 kHz SCS respectively. The first 3 rows show the symbols from 60 kHz to 120 kHz SCS, with the relevant SCS noted in the first column. For each SCS in its corresponding row, the first two symbols have been highlighted to show the potential downlink control transmission, and the last two symbols have been highlighted to show the potential uplink control transmission. The bottom two rows provide the proposed designs of SS/PBCH block patterns for 240 kHz SCS (D1-240 and D2-240).

[69] The candidate positions for the first design of Figure 3 (D1-240) for 240 kHz SCS are:

- $D1_240 = \{8, 14, 20, 32, 38, 44\} + 56*n$
- $n = 0, 1, 2, \dots, 10$

[70] where to achieve 64 beams, only the first 4 candidate SS/PBCH positions are used for n=10.

[71] This design (D1-240 of Figure 4) has a gap of at least two OFDM symbols between consecutive SS/PBCH blocks, providing more than 8 micro-seconds for the channel sensing between the transmissions from consecutive beams. This design avoids overlap with 60 kHz and 120 kHz SCSs DL and UL control opportunities. For the 4 slots of 240 kHz SCS shown in Figure 3, it provides 3 out of 4 DL and 3 out of 4 UL control opportunities free of overlap. An advantage of this design is that it provides 6 SS/PBCH candidate positions in 250 micro-seconds, thus it

provides 64 SS/PBCH candidate positions within a duration of less than 2.75 ms. Fitting all of the SS/PBCH candidate positions in a shorter time improves the flexibility of data/control transmission in the beams where users are present, thus increasing system efficiency.

[72] For unlicensed spectrum, the possibility of SS/PBCH positions being unavailable due to channel uncertainty can be compensated by making all the candidate positions within the SS/PBCH burst duration available for utilization. For the design D1-240 of Figure 4, that will result in 120 positions within 5 ms. These candidate positions are as in the following:

- $D1_240 = \{8, 14, 20, 32, 38, 44\} + 56*n$
- $n = 0, 1, 2, \dots, 19$

[73] To convey the beam index (or SS/PBCH candidate position index) for 120 candidate positions, 7 bits are needed. This implies one bit in addition to the legacy design for 64 beam positions in 3GPP Rel-15/Rel-16.

[74] Candidate positions for the second design in Figure 4, D2-240, for 240kHz SCS are:-

- $D2_240 = \{8, 16, 32, 44\} + 56*n$
- $n = 0, 1, 2, \dots, 15$

[75] A first advantage of this (D2-240) design is that the minimum distance between two consecutive SS/PBCH blocks is at least 4 OFDM symbols of 240 kHz SCS. This implies that this design can be used in other situations or frequencies of operation where channel sensing duration is larger. A minimum gap of 4 OFDM symbols of 240 kHz SCS means it can even accommodate a sensing duration of 16 micro-seconds. Another advantage of this design is that it has zero overlap with any DL/UL control opportunity from 60 kHz SCS numerology to 240 kHz SCS. This design, thus, provides no limitation to the DL/UL control, facilitating the system operation and providing no restriction for scheduling or HARQ feedback transmission in the uplink direction which can be very valuable for the services with strict latency constraints.

[76] For the unlicensed case, all possible SS/PBCH candidate positions fitting within the SS/PBCH burst window can be used. The candidate positions for this design in the unlicensed case are :-

- $D2_240 = \{8, 16, 32, 44\} + 56*n$
- $n = 0, 1, 2, \dots, 19$

[77] This provides 80 candidate positions for SS/PBCH transmission, requiring the indication of beam index (SS/PBCH candidate position index) requiring an indication comprising of 7 bits.

[78] Figure 4 shows a design for a SS/PBCH block burst for sub-carrier spacings of 480 kHz. This design enables transmission of SS/PBCH blocks using 480 kHz SCS while allowing fully the DL/UL control transmission opportunities for all SCS starting from 60 kHz. Figure 4 shows one slot (14 symbols) of 60 kHz SCS, which is equivalent to 4 slots of 240 kHz SCS. The figure comprises of four sub-figures stacked on top of each other, where each sub-figure shows one slot of 240 kHz SCS.

[79] For each sub-figure of Figure 4, the first 5 rows show the symbols from 60 kHz to 960 kHz SCS, with the relevant SCS noted in the first column. For each SCS in its corresponding row, the first two symbols of a slot have been highlighted to show the potential downlink control transmission, and the last two symbols have been highlighted to show the potential uplink control transmission. The bottom two rows provide two proposed designs (D1-480 and D2-480) for SS/PBCH block bursts for 480 kHz SCS.

[80] The designs of Figure 4 have a gap of at least 4 symbols between consecutive SS/PBCH blocks allowing a channel access duration of up to 8 micro-seconds. The first design (D1-480) is suitable when the data/control SCS will be 240 KHz or larger as its construction ignores the DL/UL control positions for 60 and 120 kHz SCSs. This design has no overlap with DL/UL control of 240 kHz SCS, and with half of all DL/UL control positions for 480 kHz SCS.

[81] Candidate positions for design D1-480 of Figure 4, for 480 kHz SCS, are:

- $D1_480 = \{4, 12, 20\} + 28*n$
- $n = 0, 1, 2, \dots, 21$

[82] only the first candidate position is used for $n=21$ to achieve 64 SS/PBCH candidate positions.

[83] For unlicensed case, all the SS/PBCH positions can be used within the burst span of 5 ms, thus n will range from 0 to 79 providing 240 SS/PBCH candidate positions. This will require an 8-bit indication for SS/PBCH candidate position.

[84] The second design of Figure 4 (D2-480) is more inclusive and ensures overlap free DL/control opportunities starting from control/data SCS of 60 kHz at the expense of reduced SS/PBCH density per unit time. This design has zero overlap with DL/UL control of 60, 120, 240 kHz SCS and only very limited overlap with DL/UL control occasions of 480 and 960 kHz SCSs.

[85] Candidate positions for the second design of Figure 4, D2-480, for 480 kHz SCS are:

- $D2_480 = \{16, 32, 40, 64, 72, 88\} + 112*n$
- $n = 0, 1, 2, \dots, 10$

[86] where first 4 candidate positions are used for $n=10$ to achieve 64 SS/PBCH positions.

[87] For the unlicensed case, n goes from 0 to 19 providing 120 SS/PBCH candidate positions. This will require 7-bit indication for SS/PBCH candidate position.

[88] The primary feature of design D2_480 is its smooth co-existence when any sub-carrier spacing starting from 60 KHz is allowed in the system for the transmission of DL/UL control and data. On the other hand, D1_480 design ignores the overlaps with 60 KHz and 120 KHz sub-carrier spacings. This allows D1_480 to have a higher SS/PBCH density in time and SS/PBCH burst will finish in a shorter time duration leading to system efficiency.

[89] The rationale behind the first design, D1_480, is that for example if a system is operating such that 480 KHz and 960 KHz sub-carrier spacings are only used for SS/PBCH when data and control are 240 KHz or above, then D1_480 can become quite an optimized design. On the other hand, if co-existence with all sub-carrier spacings of FR2 needs to be ensured starting from 60 KHz, then D2_480 is a much better candidate.

[90] Figure 5 shows the proposed design for SS/PBCH block burst for sub-carrier spacings of 960 kHz. Figure 5 shows one slot (14 symbols) of 60kHz SCS, which is equivalent to 4 slots of 240 kHz SCS. Figure 6 comprises four sub-figures stacked on top of each other, where each sub-figure shows one slot of 240 kHz SCS.

[91] For each sub-figure, the top 5 rows show the symbols from 60 kHz to 960 kHz SCS, with the relevant SCS noted in the first column. For each SCS in its corresponding row, the first two symbols of a slot have been highlighted to show the potential downlink control transmission, and the last two symbols have been highlighted to show the potential uplink control transmission. The bottom two rows provide the proposed designs of SS/PBCH block bursts for 960 kHz SCS.

[92] The designs (D1_960 and D2_960) of Figure 5 have a gap of at 8 symbols between consecutive SS/PBCH blocks allowing a channel access duration of up to 8 micro-seconds. The first design is suitable when the data/control SCS will be at least 240 kHz or larger as its construction ignores the DL/UL control positions for 60/120 kHz SCSs. This design has no overlap with DL/UL control of 240, 480 and 960 kHz SCSs. This is beneficial to allow this subset of SCSs (240, 480 and 960 kHz) for SS/PBCH and control/data without any overlap or limitation of DL/UL control opportunities due to SS/PBCH transmissions.

[93] Candidate positions for the first design of Figure 5, D1-960, for 960 kHz SCS are:

- $D1_960 = \{8, 20, 32, 44\} + 56*n$
- $n = 0, 1, 2, \dots, 15$ (to acquire 64 beams)

[94] For unlicensed case, n goes from 0 to 79 providing 320 SS/PBCH candidate positions. This will require 9-bit indication for SS/PBCH candidate position. To contain the overhead, only first 256 candidate positions can be allowed, which can be indicated with 8-bit signalling.

[95] The second design of Figure 5 (D2_960) ensures overlap free DL/control opportunities starting from control/data SCS of 60 kHz at the expense of reduced SS/PBCH density per unit time. This design has zero overlap with DL/UL control for all SCSs ranging from 60 kHz to 960 kHz. Thus, this can be a good candidate in case all SCSs are deemed necessary for DL/UL control.

[96] Candidate positions for the second design of Figure 5, D2-960, for 960 kHz SCS are:

- $D2_960 = \{32, 44, 64, 76, 88, 128, 144, 156, 176, 188\} + 224*n$
- $n = 0, 1, 2, \dots, 6$

[97] where first 4 candidate positions are used for n=6.

[98] For unlicensed case, n goes from 0 to 19 providing 200 SS/PBCH candidate positions. This will require 8-bit indication for SS/PBCH candidate position.

[99] The readers will appreciate that D1_480 and D1_960 designs have been optimally constructed when data/control SCS is 240 KHz or larger. These designs can suitably be used by restricting the system operation for control and data for SCS of 240 KHz or larger. The two other designs for these SCS D2_480 and D2_960 have reduced SS/PBCH density in time but allow operation for any SCS ranging from 60 KHz, allowing no restriction on the use of data/control SCS.

[100] As noted above, this disclosure uses the term beam index synonymously with SS/PBCH candidate position index. The objective in the following disclosure is to transmit the index of each SS/PBCH candidate position so that the UE decoding each SS/PBCH block can determine the SS/PBCH candidate position in the SS/PBCH burst. Based on this determined position the UE can determine the complete system timing information by combining the position with the SFN and half-frame flag. As set out above, various SS/PBCH burst block designs are proposed with an increased number of candidate positions to allow for channel access uncertainty. This may increase the size of the SS/PBCH candidate position index.

[101] For example, for the maximum number of beams at 64 (requiring 6-bit SS/PBCH candidate index indication), the designs proposed for 120 kHz SCS increasing the number of possible candidate positions to 80 will require a 7-bit indication. In all the SS/PBCH burst designs described above for 120 kHz SCS to 960 kHz SCS, 7-, 8-, or 9-bit indication is required. The legacy design for PBCH carries 3 LSBs in PBCH DMRS and 3 MSBs in PBCH payload, generated and added by physical layer. The following disclosure discusses methods to convey

SS/PBCH candidate positions which may be particularly appropriate for the burst designs discussed above.

[102] The indication of position may be provided by the payload of PBCH. As MSBs are added to the PBCH payload, additional bits of the SS/PBCH candidate index can be added to the PBCH payload. This will increase the size of physical layer generated PBCH payload from 8 bits to 9, 10 or 11 bits with an addition of 1, 2 or 3 bits respectively. Although the addition of extra bits is technically straightforward, physical layer processing must be modified. In the legacy design 8 bits of the PBCH payload is added to the 24 bit MIB payload, resulting in 32 bit combined payload to which the physical layer processing is applied. If the number of bits is increased above 32 many aspects of physical layer processing, such as scrambling, CRC addition, and interleaving, may need significant re-design which may be unattractive due to its higher complexity.

[103] To avoid increasing the size of the payload, a reserved bit of the MIB payload may be utilised to add a bit to the candidate position index indication. The size of the candidate position index can thus be increased by 1 bit (from 64 to 128 positions) without any increase in data to be conveyed, or re-design of physical layer processing. This can be exploited by limiting the use of upto 128 candidate positions for the designs which can actually accommodate more than 128 positions.

[104] In a further example, the PBCH DMRS may be utilised to indicate the SS/PBCH candidate index. In the legacy design 3 LSBs of the SS/PBCH candidate index are carried by the PBCH DMRS by selection from 8 possible DMRS sequences. The number of DMRS sequences can be increased to the desired number to convey additional bits of SS/PBCH candidate index. For example, 16 or 32 DMRS sequences can be used to accommodate 1 or 2 additional bits of SS/PBCH candidate index respectively. For this strategy, the number of DMRS sequences does not need to be increased to 32 for all SCSs. In fact, to avoid UE blind decoding for DMRS sequences becoming too complex, only SCSs where 8 bits are required for SS/PBCH candidate position indication use 32 sequences. The PBCH DMRS for the rest of the DMRS sequences may use only 16 DMRS sequences.

[105] In the SS/PBCH burst designs proposed in the last section, the designs for 120 kHz and 240 kHz need only 7 bits for SS/PBCH candidate position indication, whereas the designs for 480 kHz and 960 kHz SCS need more than 7 bits. Thus, the base stations transmitting SS/PBCH blocks at 120 kHz or 240 kHz SCSs will use only 16 PBCH DMRS sequences and will use more PBCH DMRS sequences for 480 kHz and 960 kHz SCS.

[106] A compromise may be achieved by restricting the maximum number of SS/PBCH candidate positions to the first 128 positions for designs which can accommodate more than 128 positions in an SS/PBCH burst. This allows unified use of a 7 bit indication of SS/PBCH block position, which can be achieved by increasing the number of possible DMRS sequences to 16. This can be a good trade-off of additional timing flexibility with limited increase in the DMRS decode complexity.

[107] For a 6-bit SS/PBCH candidate position indication denoted as b0 to b5, the legacy design conveys bits b0 to b2 in PBCH DMRS and b3 to b5 in the PBCH payload. For the case of 7-bit SS/PBCH candidate position indication, denoted as b0 to b6, an approach is to use the legacy bit mapping for the first 6 bits and add the MSB, b6 to the indication provided by the DMRS sequence. This means that DMRS will carry 4 bits (b0 to b2 and b6) and the PBCH payload will carry b3 to b5. A potential disadvantage of this design is that neighbouring SS/PBCH candidate positions will use the same PBCH DMRS, thereby compromising the detection quality. To overcome this, 4 LSB bits b0 to b3 are mapped on PBCH DMRS and may be conveyed through

16 possible sequences of PBCH DMRS and the 3 MSBs b4 to b6 may be added to the PBCH payload.

[108] If more than 1-bit needs to be added to the existing 6 bits of SS/PBCH candidate position indication, a hybrid of the two approaches described above can be used in which the number of transmitted bits is increased beyond 3 using both DMRS indication and payload indication. For example, if an 8-bit SS/PBCH position index needs to be supported, two additional bits need to be transmitted compared to legacy 6-bit design. 1 extra bit can be transmitted in the PBCH as payload (using the techniques described above) and 1 bit can be transmitted by increasing the number of DMRS sequences to 16 (using the techniques described above). Going beyond, the hybrid approach can be adapted to accommodate even larger number of SS/PBCH candidate positions.

[109] The discussion above for the proposed SS/PBCH block designs is mainly set in the context of the unlicensed spectrum for the reasons of channel sensing at beam switching instants but the readers will appreciate that the designs apply verbatim to the licensed spectrum. This can help unify the same SS/PBCH burst designs for licensed and unlicensed spectrum. Another advantage is that the designs proposed here help absorb better the transients which get generated at beam switching instants, otherwise they may degrade the quality of SS/PBCH blocks transmitted contiguously.

[110] The patterns discussed above may replace existing designs for use in licensed spectrum for 120 KHz and 240 KHz SCS, or the proposed patterns may only be used in unlicensed shared spectrum. Devices are aware if they are operating in licensed or unlicensed spectrum and so are able to utilise the appropriate patterns without any confusion.

[111] This disclosure has proposed various methods to indicate the increased number of SS/PBCH block candidate positions in the SS/PBCH burst. The problem of additional SS/PBCH candidate positions is mainly set in the context of unlicensed shared spectrum to accommodate more positions than the maximum number of beams to compensate the uncertainty of channel access. The design though applies verbatim if the number of beams is increased in licensed or unlicensed spectrum beyond 64, requiring SS/PBCH candidate position comprising of more than 6 bits.

[112] 3GPP NR Release-15 has restricted the burst length to duration of half-frame, i.e., 5 milliseconds. This basically means that all the candidate positions for a given frequency range always fit within this duration of 5 milliseconds. The proposed designs in this disclosure provide the symbols positions from a reference symbol 0. To keep up with the existing design, this reference symbol 0 is taken to be the first symbol of the half-frame. Nevertheless, for higher frequency operation, the symbol times will become very small with the use of very large SCS. This may lead to the change of burst length from 5 milliseconds to smaller time intervals. The proposed designs stay valid even if the burst length is changed to a different duration. The symbol 0, the reference point, in the proposed designs need to be mapped to the new reference symbol as a minor adaptation to achieve the designs for any new burst duration. The change in burst duration may also impact the total number of candidate positions for the unlicensed carrier.

[113] The proposed designs have provided 64 candidate positions where currently 3GPP has decided to support up to 64 beams in FR2 and FR2-extensions going up to 71 GHz. The readers will appreciate though that the proposed SS/PBCH burst designs can be easily adapted to achieve smaller or larger number of SS/PBCH candidate positions. To achieve smaller number of beam positions, say 32 or 16, first 32 or 16 candidate positions in the proposed design can be used. To achieve a design for larger than 64 beams and eventually more SS/PBCH block

positions, the additional positions can be replicating the proposed design so as to get the desirable number of candidate positions.

[114] As will be apparent, the above disclosure includes methods of transmitted the signals discussed herein by a base station on appropriate beams for reception by UEs. For example, the disclosure includes the steps of transmitting a synchronisation signal in a first candidate position on a first beam, switching to a second beam and performing a channel access procedure for that second beam, and subsequently transmitting a second synchronisation signal on the second beam in a second candidate position.

[115] 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.

[116] 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.

[117] 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.

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

[119] 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.

[120] 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.

[121] 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.

[122] 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.

[123] 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.

[124] 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.

[125] 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.

[126] 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.

[127] 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.

[128] 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.

[129] Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term 'comprising' or "including" does not exclude the presence of other elements.

Claims

1. A method of transmitting an SS/PBCH burst in an OFDM transmission system operating in Frequency Range 2 and utilising beam sweeping, the method comprising the steps of
selecting a plurality of starting locations for the transmission of SS/PBCH bursts, wherein the starting locations are selected such that there is a gap of at least one OFDM symbol between adjacent SS/PBCH bursts; and
transmitting a plurality of SS/PBCH bursts, wherein each SS/PBCH bursts starts at one of the selected starting locations.
2. The method of claim 1, wherein the system utilises a sub carrier spacing of 120 kHz.
3. The method of claim 2, wherein the starting locations are at OFDM symbol numbers $\{4, 9, 15, 20\} + 28*n$, where $n = 0, 1, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
4. The method of claim 2, wherein the starting locations are at OFDM symbol numbers $\{2, 8, 15, 20\} + 28*n$, where $n = 0, 1, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
5. The method of claim 2, wherein the starting locations are at OFDM symbol numbers $\{4, 9, 15, 20\} + 28*n$, where $n = 0, 1, 2, \dots, 19$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
6. The method of claim 1, wherein the system utilises a sub carrier spacing of 240 kHz.
7. The method of claim 6, wherein the starting locations are at OFDM symbol numbers $\{8, 14, 20, 32, 38, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 10$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
8. The method of claim 6, wherein the starting locations are at OFDM symbol numbers $\{8, 14, 20, 32, 38, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 19$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
9. The method of claim 6, wherein the starting locations are at OFDM symbol numbers $\{8, 16, 32, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
10. The method of claim 6, wherein the starting locations are at OFDM symbol numbers $\{8, 16, 32, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 19$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
11. The method of claim 1, wherein the system utilises a sub carrier spacing of 480 kHz.
12. The method of claim 11, wherein the starting locations are at OFDM symbol numbers $\{4, 12, 20\} + 28*n$, where $n = 0, 1, 2, \dots, 21$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
13. The method of claim 11, wherein the starting locations are at OFDM symbol numbers $\{16, 32, 40, 64, 72, 88\} + 112*n$, where $n = 0, 1, 2, \dots, 10$ and the reference symbol index 0

corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.

14. The method of claim 1, wherein the system utilises a sub carrier spacing of 960 kHz.
15. The method of claim 14, wherein the starting locations are at OFDM symbol numbers $\{8, 20, 32, 44\} + 56*n$, where $n = 0, 1, 2, \dots, 15$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
16. The method of claim 14, wherein the starting locations are at OFDM symbol numbers $\{32, 44, 64, 76, 88, 128, 144, 156, 176, 188\} + 224*n$, where $n = 0, 1, 2, \dots, 6$ and the reference symbol index 0 corresponds to the first symbol of the first slot in a half-frame where SS/PBCH blocks are being transmitted.
17. The method of any preceding claim, further comprising the step of transmitting an indication of the starting locations.
18. The method of claim 17 wherein the starting locations are transmitted in the payload of the PBCH.
19. The method of claim 18, wherein a reserved bit of the MIB payload is utilised as part of the indication of the starting locations.
20. The method of any of claims 17 to 19, wherein the number of starting locations is no more than 128.
21. The method of any of claims 17 to 20, wherein the PBCH DMRS indicates at least part of the starting locations.
22. The method of any of claims 17 to 21, wherein the starting locations are indicated by SS/PBCH candidate index.

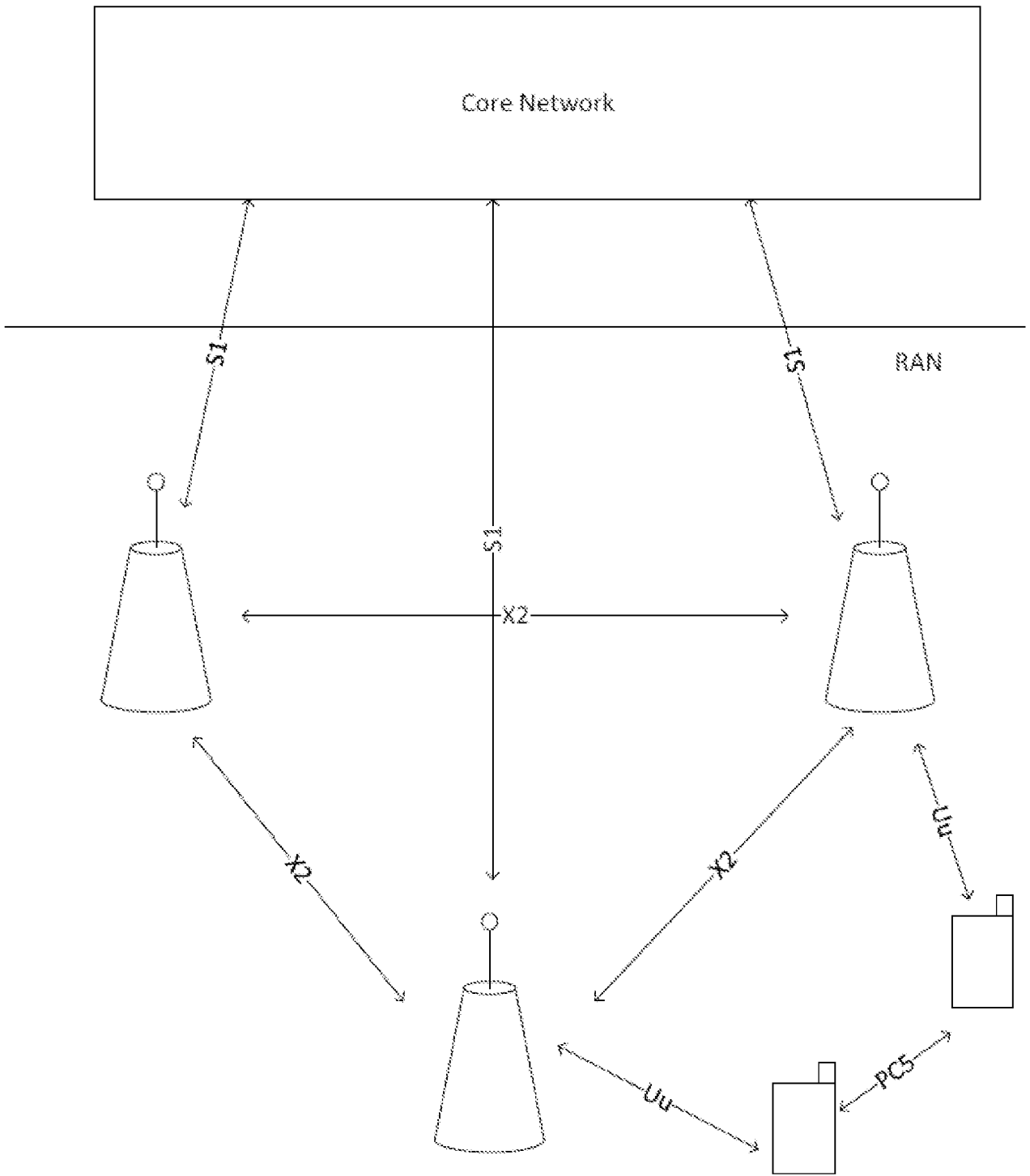


Figure 1

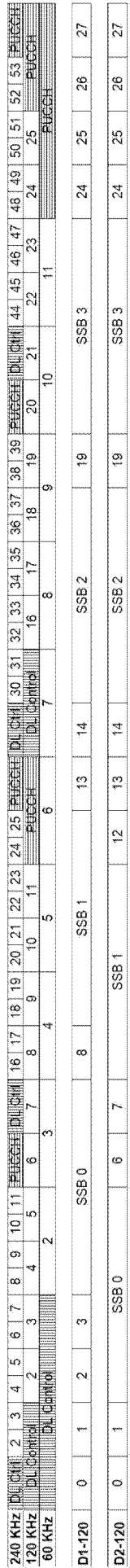


Figure 2

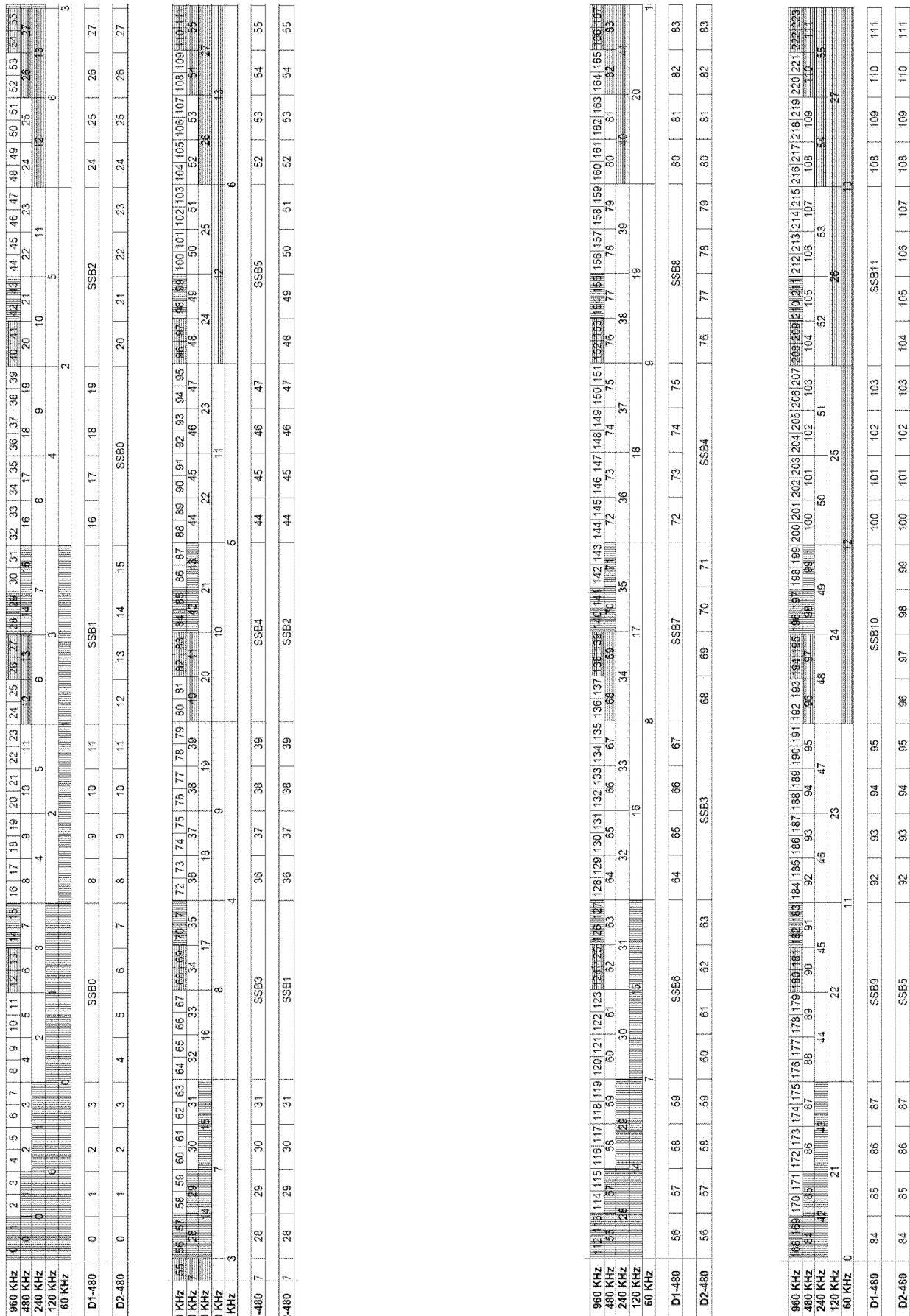


Figure 4

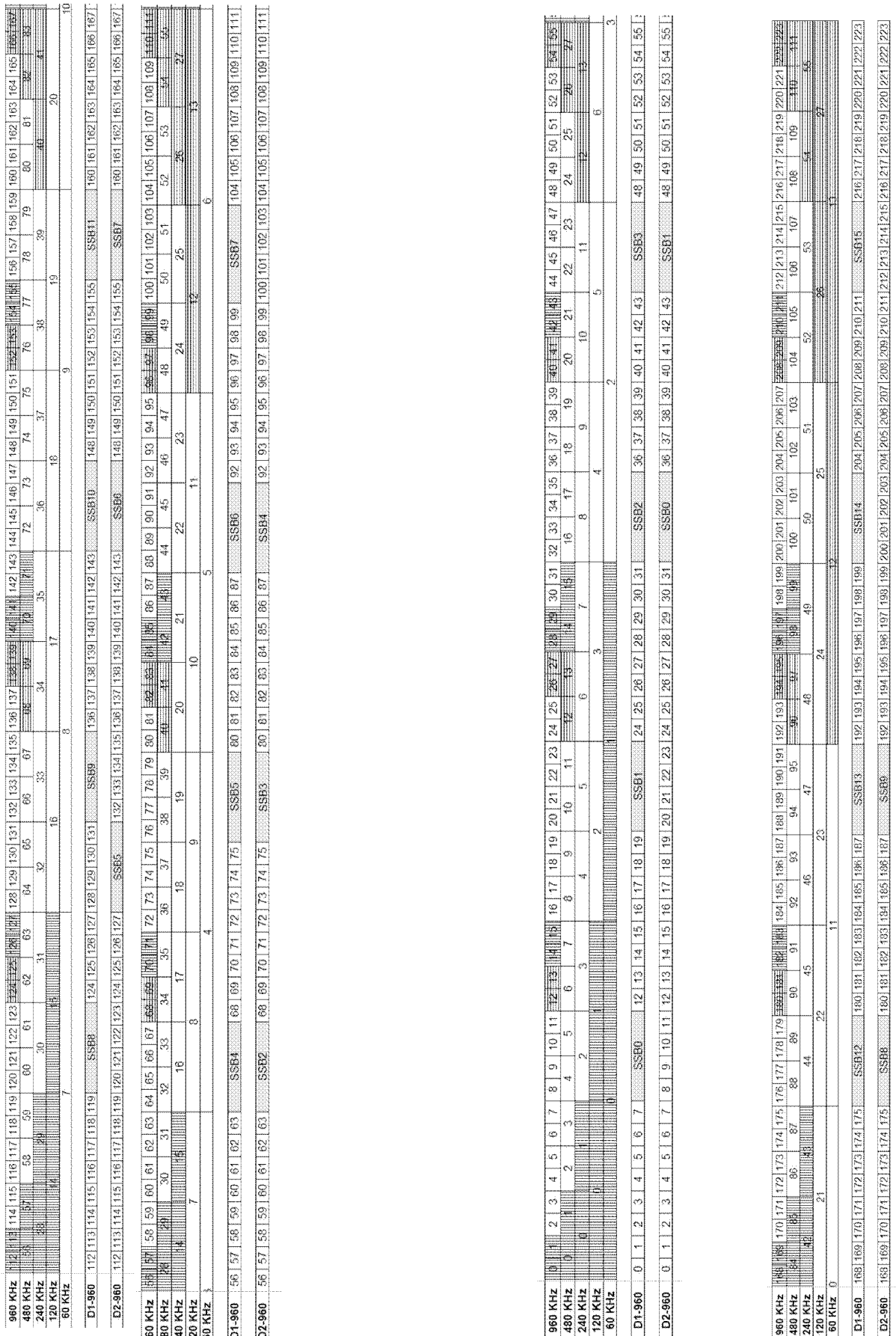


Figure 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2021/106594

| | | |
|--|---|---|
| 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; 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) WPI;EPODOC;CNPAT;CNKI;3GPP: SS+, PBCH, burst, OFDM, symbol, gap, distance, interval, start, distributed, beam, sweeping, consecutive, LBT, sens+ | | |
| C. DOCUMENTS CONSIDERED TO BE RELEVANT | | |
| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
| X | SAMSUNG. "R1-1702901 SS burst set composition and time index indication" 3GPP TSG RAN WG1 #88, 17 February 2017 (2017-02-17), sections 1-3 | 1-22 |
| X | ZTE et al. "R1-1704358 Composition of SS block, burst and burst set" 3GPP TSG RAN WG1 Meeting #88bis, 07 April 2017 (2017-04-07), sections 2-6 | 1-22 |
| A | AT&T. "R1-1719622 Remaining details on Remaining minimum system information" 3GPP TSG RAN WG1 Meeting 91, 01 December 2017 (2017-12-01), the whole document | 1-22 |
| A | WO 2020025060 A1 (MEDIATEK SINGAPORE PTE.LTD.) 06 February 2020 (2020-02-06) the whole document | 1-22 |
| <input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex. | | |
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