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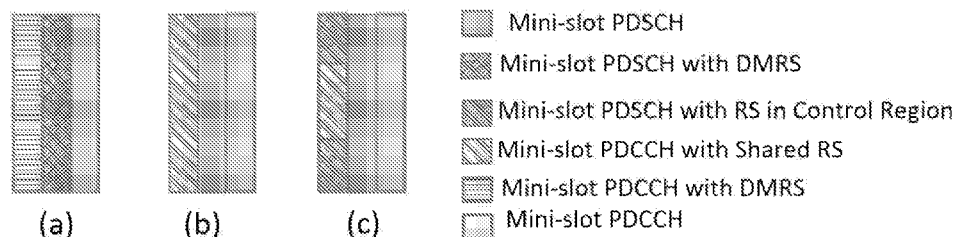
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Figure 4



(57) Abstract: Methods and systems for the transmission of reference symbols in an OFDM transmission system. Reference symbols may be located flexibly with a mini-slot to improve the overhead assigned to the transmission of reference symbols. Reference symbols may be shared between control and data portions of a mini-slot.



Shared Pilot Signals

Technical Field

[0001] The current disclosure relates to pilot signals in OFDM transmission systems, and in particular to shared pilot signals.

5 Background

[0002] 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
10 support macro-cell mobile phone communications. Communication systems and networks have developed towards a broadband and mobile system.

[0003] 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
15 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.

[0004] NR proposes an OFDM transmission format for the wireless link of the system.
20 OFDM systems utilise a number of sub-carriers spaced in frequency, each of which is modulated independently. Demodulation of the set of the sub-carriers allows recovery of the signals. Time slots are defined for the scheduling of transmissions, which each slot comprising a number of OFDM symbols. NR has proposed 7 or 14 OFDM symbols per slot. The sub-carriers, or frequency resources, within each slot may be utilised to
25 carry one or more channel over the link. Also, each slot may contain all uplink, all downlink, or a mixture of directions.

[0005] NR also proposes mini-slots (TR 38.912) which may comprise from 1 to (slot-length-1) OFDM symbols to improve scheduling flexibility. Each mini-slot may start at any OFDM symbol within a slot. gNBs are allowed to schedule mini-slots on some
30 pre-allocated resources, thus over-ruling their prior scheduling decision to satisfy latency constraints of some latency critical services. Some configurations may be limited to systems over 6GHz, or to a minimum mini-slot length of 2 OFDM symbols.

gNB can schedule mini-slots with the same numerology as of the slot or with a different numerology.

[0006] 5G proposes a range of services to be provided, including Enhanced Mobile Broadband (eMBB) for high data rate transmission, Ultra-Reliable Low Latency Communication (URLLC) for devices requiring low latency and high link reliability, and Massive Machine-Type Communication (mMTC) to support a large number of low-power devices for a long life-time requiring highly energy efficient communication.

[0007] TR 38.913 defines latency as *“The time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink.”* For URLLC, the target for user plane latency is 0.5ms for uplink (UL), and 0.5ms for downlink (DL).

[0008] TR 38.913 defines Reliability as *“Reliability can be evaluated by the success probability of transmitting X bytes within a certain delay, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface, at a certain channel quality (e.g., coverage-edge).”* For URLLC, a reliability requirement for one transmission of a packet is defined as 1×10^{-5} for 32 bytes with a user plane latency of 1ms.

[0009] Many legacy radio systems utilised cell-specific pilot reference symbols (RS) to allow coherent reception of data. In contrast, NR proposes the use of a specific RS for each physical channel, and no cell-specific RSs are provided. RS sequences and densities are being defined for slot-based communications in NR.

[0010] Two configurations are currently proposed for a single OFDM symbol with DMRS. Figure 1 shows a representation of configuration 1 in which two antenna ports are multiplexed in a comb structure in the frequency design. Figure 2 shows a representation of configuration 2 which is based on Frequency-Domain (FD) orthogonal covers codes (OCC) of adjacent Resource Elements (RE), which can support up to 6 antenna ports.

[0011] In both configurations all resources of the OFDM symbol are utilised for the DMRS with the maximum number of supported antenna ports. For 2 antenna ports all resources are used for configuration 1, 1/3 of the resources are used for type 2 (which

uses 2/3 of the resources for 4 antenna ports). Such resource consumption may be appropriate when the DMRS is for a slot, but is a large portion of resources for a mini-slot which can be as short as 1 OFDM symbol. The RS overhead is thus very large due to the current intention of an RS per physical channel.

5 [0012] Configuration types 1 and 2 have been defined to accommodate up to 8 and 12 antenna ports respectively over two symbols, by using OCC in time domain.

[0013] Figure 3 shows a specific examples mini-slots demonstrating the DMRS overhead. Mini-slot 1 comprises four OFDM symbols, two comprising control data (PDCCH) with DMRS, and two comprising data. The first data OFDM symbol also
10 comprises the DMRS for the PDSCH data channel in the mini-slot.

[0014] Mini-slot 2 comprises two OFDM symbols, one being control information and one being data, each with their own DMRS. In this mini-slot the DMRS does not use all resources in each OFDM symbol such that some resources are available for control and data information.

15 [0015] Mini-slot 302 has a first symbol comprising control information with DMRS, and data on a PDSCH. The subsequent two symbols comprise data with DMRS transmitted in the first of those symbols.

[0016] The examples of Figure 3 highlight the overhead incurred by requiring a DMRS for each channel. There is therefore a requirement for an improved RS structure.

20 [0017] The present invention is seeking to solve at least some of the outstanding problems in this domain.

Summary

[0018] 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
25 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.

[0019] There is provided a method of downlink data transmission from a base station to a UE in a cellular communication system utilising an OFDM modulation format, the
30 method comprising the steps of defining a mini-slot comprising at least one control OFDM symbol and at least one data OFDM symbol, wherein DMRSs are encoded on

the control and/or data OFDM symbols and are shared between the control and data OFDM symbols; and transmitting the mini-slot from the base station to the UE.

[0020] The DMRSs may be all encoded on one of the control OFDM symbols or on one of the data OFDM symbols.

5 [0021] A sub-set of the DMRSs may be encoded on one of the control OFDM symbols, and a sub-set of the DMRSs may be encoded on one of the data OFDM symbols.

[0022] Only one DMRS may be encoded on each sub-carrier in the mini-slot.

[0023] Control information may only occupy a sub-set of carriers of the at least one control OFDM symbol, the remaining carriers of the at least one control OFDM symbol
10 being utilised to carry data.

[0024] The at least one control OFDM symbol may occupy fewer frequency resources than the at least one data OFDM symbol, and wherein DMRSs for frequency resources used by the at least one control OFDM symbol may be encoded on a control OFDM symbol, and DMRSs for frequency resources used only by the at least one data OFDM
15 symbol are encoded on a data OFDM symbol.

[0025] The control and data OFDM symbols may be transmitted using the same at least one antenna port.

[0026] The mini-slot may be transmitted using a plurality of antenna ports.

[0027] The at least one data OFDM symbol may be transmitted using more antenna
20 ports than the at least one control OFDM symbol.

[0028] The DMRS may be transmitted for all antenna ports used by the at least one OFDM data symbol, and the at least one control OFDM symbol is transmitted using a subset of those ports.

[0029] The subset of ports may be a single port.

25 [0030] Additional ports may be used during the at least one control OFDM symbol for further data OFDM symbols.

[0031] The single port may be the first port used for transmission of the OFDM data symbol.

[0032] The transmission mode of the data part in the at least one control OFDM symbol
30 may be the same as the transmission mode of the data OFDM symbols.

[0033] The DMRS may be a single DMRS sequence.

[0034] The DMRS may comprise a set of two sequences, wherein a first of the sequences spans the at least one control OFDM symbol, and a second of the sequences spans the at least one data OFDM symbol for frequency resources not covered by the first sequence.

[0035] The DMRS may be non-user specific.

[0036] There is also provided a method of receiving downlink data transmission at a UE from a base station in a cellular communication system utilising an OFDM modulation format, the method comprising the steps of receiving an OFDM signal comprising at least one mini-slot, the mini-slot comprising at least one control OFDM symbol, and at least one data OFDM symbol, wherein DMRSs are received on at least one of the control OFDM symbol and data OFDM symbol, decoding the mini-slot utilising the DMRSs for both the at least one control OFDM symbol and the at least one data OFDM symbol.

[0037] The DMRSs may be all encoded on one of the control OFDM symbols or on one of the data OFDM symbols.

[0038] A sub-set of the DMRSs may be encoded on one of the control OFDM symbols, and a sub-set of the DMRSs are encoded on one of the data OFDM symbols.

[0039] Only one DMRS may be encoded on each sub-carrier in the mini-slot.

[0040] Control information may only occupy a sub-set of carriers of the at least one control OFDM symbol, the remaining carriers of the at least one control OFDM symbol being utilised to carry data.

[0041] The at least one control OFDM symbol may occupy fewer frequency resources than the at least one data OFDM symbol, and wherein DMRSs for frequency resources used by the at least one control OFDM symbol may be encoded on a control OFDM symbol, and DMRSs for frequency resources used only by the at least one data OFDM symbol are encoded on a data OFDM symbol.

[0042] The DMRS may be a single DMRS sequence.

[0043] The DMRS may comprise a set of two sequences, wherein a first of the sequences spans the at least one control OFDM symbol, and a second of the

sequences spans the at least one data OFDM symbol for frequency resources not covered by the first sequence.

[0044] 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

[0045] 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.

Figures 1 and 2 show example DMRSs for multiple ports;

Figure 3 shows example of mini-slots;

Figure 4 shows examples of shared DMRSs transmitted in the control portion;

Figure 5 shows examples of mini-slots with sub-sets of DMRSs transmitted in the control and data portions; and

Figure 6 shows examples of DMRS being transmitted in the data portion.

Detailed description of the preferred embodiments

[0046] 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.

[0047] The following disclosure provides a means to improve the spectral efficiency of DMRS transmission in mini-slots by sharing DMRS for control and data channels in a mini-slot.

[0048] The following description is given in the context of a cellular communication system, comprising land-based network components and remote User Equipment (UE). In particular reference is made to a wireless channel between a base station of the land-based network and the UE. Transmissions from the base station to the UE

are in the downlink direction, and transmissions from the UE to the base station are in the uplink direction. The base station may comprise, or be connected to, a gNB which performs network management and control functions.

[0049] Figure 4 shows a schematic diagram of sharing DMRS within a mini-slot. Figure 4(a) shows the conventional individual control and data DMRS case for a mini-slot which is three OFDM symbols in length. The first OFDM symbol carries the PDCCH for the mini-slot, and DMRS for that control channel. The second OFDM symbol carries the PDSCH data channel for the mini-slot, and DMRS. As explained above there is therefore a large DMRS overhead for the small amount of data transmitted.

[0050] In Figure 4(b) one DMRS transmission is shared between the control and data channels. The first OFDM symbol thus comprises the PDCCH and shared DMRS for both the PDCCH and subsequent PDSCH in the mini-slot. The overhead is thus reduced for the same mini-slot length. To allow the same DMRS to be utilised for both PDCCH and PDSCH the channels would normally be transmitted from the same antenna port.

[0051] Figure 4(c) shows a configuration in which the PDCCH does not occupy the whole of an OFDM symbol. It is then possible to multiplex data into unused parts of the first OFDM symbol of the mini-slot, thus further increasing data capacity. In such a case, the shared DMRS sequence should be expanded beyond the control part such as to cover all the frequency resources allocated to the mini-slot.

[0052] The particular arrangement of channels within each OFDM symbol is variable and subject to the particular configuration and channel usage of each system.

[0053] Figure 5(a) shows a conventional example in which the control part (in the first OFDM symbol) uses fewer frequency resources (sub-carriers) than the data parts of the mini-slot. This does not affect the system performance because DMRS is transmitted in both the control and data parts on the respective sub-carriers.

[0054] Figure 5(b) shows a transmission system which avoids repetition of the DMRS. The shared DMRS for the control part is transmitted in the first OFDM symbol on the respective sub-carriers. In the first data OFDM symbol DMRS is transmitted on the sub-carriers that were not included in the control part of the mini-slot, but DMRS is not transmitted on sub-carriers that were utilised in the control part of the mini-slot. The sub-carriers common to the control and data parts rely on shared DMRS placed in the

control region, the 1st OFDM symbol of the mini-slot. Thus these DMRS from the control part are used to decode respective sub-carriers across the whole mini-slot. The additional frequency sub-carriers allocated to the mini-slot data would need their dedicated DMRS to demodulate data over these frequency carriers. These are the data DMRS placed in the first data symbol, 2nd symbol of the mini-slot, over the additional sub-carriers which were not part of the control region.

[0055] In the foregoing disclosure, DMRS are transmitted in the first symbol of each channel which may minimise latency as the DMRS is then available at the start of the transmission of each channel. However, the DRMS may be transmitted in different OFDM symbols in a mini-slot.

[0056] Typically, when DMRS is sent in the first symbol, the UE can receive the DMRS and decode the PDCCH. The PDCCH contains details of the allocation of data frequency carriers, thus allowing decode of the data OFDM symbols. If DMRS is only sent in the data symbols, the UE must decode received signals in a different order, and restrictions are placed on the use of sub-carriers in the control and data parts. In particular all sub-carriers used for the PDCCH of a mini-slot must be used for the PDSCH in the OFDM symbols of the mini-slot. The UE thus receives shared DMRS on all relevant sub-carriers to decode the PDCCH, and then decode the PDSCH. More sub-carriers can be used for the PDSCH, provided all PDCH sub-carriers are included.

[0057] Figure 6(a) shows a conventional example in which both the control (PDCCH) and data (PDSCH) parts of the mini-slot carry a DMRS in the first relevant OFDM symbol.

[0058] In Figure 6(b) the same mini-slot is shown which uses the same frequency resources for both the control and data parts of the mini-slot. The DMRS is transmitted in the first OFDM symbol of the data part only and this shared DMRS is used to demodulate first the control information and then data. Once the UE has received the DMRS both the control and data parts can be decoded.

[0059] In Figure 6(c) in which only a sub-set of the sub-carriers used for data are used for the control part of the mini-slot. The remainder of the mini-slot is used for data. As seen in Figure 6(c) the DMRS is transmitted across all data sub-carriers, and hence the UE can decode both control and data parts of the mini-slot. Frequency carriers configured and used for the control region, would be assigned shared DMRS in the

first symbol of the data. Additional frequency carriers which are used for data would have dedicated DMRS.

[0060] In order to share DMRS between control and data OFDM symbols those symbols must all be transmitted via the same antenna port.

5 [0061] In the case where data transmission is using multiple antenna ports, the control portion may use the same set, or only a subset, of the antenna ports used to transmit the data. A specific port, for example the first, may be selected for the control portion. Shared DMRS for all the antenna ports used for data can be embedded either in the control region or in the data region. Thus demodulation of both control information and
10 data information can be facilitated through these shared pilots. One additional technique could be to embed shared pilots either in control or data region for the common antenna port (used to transmit both control and data) and the additional antenna ports which are used for data transmission can have dedicated DMRS in the data region.

15 [0062] If precoding vectors are optimized for multi-layer data transmission, this precoding vector may not be optimal for single port control transmission. One possibility to compensate this could be through applying a power offset in the control region. Another technique is to make the precoding design choice such that the first precoding vector is selected which is optimized for multi-layer data and single layer
20 control information transmission. In a first scheme, if the control region has some REs beyond CORESET or inside CORESET, these can be used for data multiplexing. In this scheme, although control information can be transmitted through a single antenna port or through single antenna transmit diversity, the data REs in the data region or multiplexed in the control region can be transmitted through multi-antenna port
25 transmission.

[0063] Mini-Slot data can be further multiplexed in the control region by the following mechanism. If data transmission is through N ports, the DMRS for N antenna ports are transmitted in the control or data portions. The gNB multiplexes multi-antenna port
30 transmitted data in the control portion where there is not CORESET or there are no CCEs.

[0064] Additional multiplexing may also be obtained on the resource elements which carry control information. The first of the data antenna ports is used to transmit control

information and the rest of the antenna ports (spatial layers additional to the first) are used for data transmission. The UE may see some interference due to this control information or the UE may not know the antenna ports are in use but if some multi-antenna transmission modes are agreed to be used from a fixed subset, the UE can
5 try to demodulate reference symbols from this subset. Relative comparison of estimated channel powers corresponding to different transmission modes (different antenna ports) can let the UE identify the active transmission mode.

[0065] In an example a conventional mini-slot may be 10 PRBs for 2 OFDM symbols; the first symbol is for control and the second symbol for data. If the control region has
10 an RS density of 1/3 (single antenna – configuration 2), out of $10 \times 12 = 120$ REs, there are 40 RS and 80 REs for control information. In the data part, using Configuration Type 2 (1/3 RS), there are so 40 RS and 80 data REs. So overall there are $80 + 80 = 160$ REs available for control and data.

[0066] If shared pilots are used with transmission of the DMRS in the control portion,
15 with the same RS density, in the control portion there are 40 RS and 80 control information RS available. In the data part the whole OFDM symbol is available, providing 120 REs. The mini-slot with shared DMRS thus provides 200 REs compared to 160 in the conventional approach, without any loss of channel estimation quality.

[0067]

[0068] In another example, a mini-slot is configured such that control information is
20 using a single antenna port and the data part is being transmitted through two antenna ports. With individual DMRS for control and data the control symbol has the same split for DMRS and control information resource elements as the previous example. If for the same resources (10 PRB = 120 REs), the data part is using 2 antenna ports, the
25 DMRS part in the data region is the same as the DMRS occupies the same number of resource elements for one or two antenna ports in Configuration Type 2. However, the 80 data REs become effectively $80 \times 2 = 160$ REs. Thus overall control and data REs available are $80 + 160 = 240$ when both have their dedicated DMRS.

[0069] For the shared DMRS case with DMRS for the two ports embedded in the
30 control region and control information being transmitted through one of these antenna ports, the control portion resource usage remains the same (40 RS and 80 REs), but all of the resource elements in the data portion are now available for information data

using two ports, offering 240 REs, giving a total of 320 REs for control and data compared to 240 in the conventional case.

[0070] The proposed DMRS sharing structures thus reduce the overhead as expected.

[0071] NR intends to support multi-user (MU) MIMO for PDCCH. Reference symbols
5 may be shared between control and data in such a situation providing the reduced overhead discussed above. Reference Symbols may be embedded in control portions of mini-slots such that UEs can estimate their channels and attempt to decode the control information. Data transmission for each user can then be performed using the antenna port through which they received reference symbols and their respective
10 control information.

[0072] For each user scheduled in a MU-MIMO system, reference sequences can be orthogonal or non-orthogonal. The reference sequence for each user can be a function of user RNTI, or it can be pre-informed to relevant users through higher layer (MAC or RRC) signalling. Each scheduled UE would consider that it is the only UE scheduled
15 on the physical resources. Thus, the reference symbols (sequences) appear to each UE as transmitted from a single antenna port which is used both for control and data transmission.

[0073] One example of orthogonal sequences can be Zadoff-Chu sequences of a certain length with different cyclic shifts which are inherently orthogonal to each other.
20 If PN sequences are used, they are not perfectly orthogonal to each other but have good auto- and cross-correlation properties. Another technique could be to apply orthogonal cover codes to reference symbols of different users in time, frequency or time-frequency, although that should be known to user to be able to do channel estimation and demodulation of control information. Regarding the density of the
25 reference sequences, it can follow any of the configurations, like Configuration Type 1 or Configuration Type 2 or a variation of these.

[0074] MU-MIMO operation can be achieved through the multiplexing techniques similar to LTE TM5 (MU-MIMO) or through multi-layer beamforming similar to LTE TM7 when dual layer beamforming is used to do the transmission to two users
30 simultaneously on the same time-frequency resources, as described below.

[0075] Users which are being transmitted can be scheduled for single layer and single port transmission. They don't necessarily need to know the existence of other users to

be able to decode their data. One method to improve the demodulation performance is to convey some limited information to these users through which they can apply some interference rejection or cancellation strategies.

[0076] Although there is common understanding that the typical use of mini-slots would be for a single user but the standard does not restrict the use of mini-slots to single users. Thus, the network is free to schedule multiple users in a single mini-slot. For the mini-slots with single user scheduled, the DMRS should be user specific.

[0077] A scenario presents with multiple users scheduled on orthogonal time-frequency resources, thus excluding MU-MIMO or multi-layer beamforming destined to multiple users on the same resource. For such mini-slots with multiple users, DMRS sharing will be possible only if these users are being transmitted with the same antenna port(s), and includes the port through which control information is being transmitted. In such scenarios, sharing of DMRS between control and data of these users can be facilitated by the use of common (common to mini-slot users) DMRS (sort of LTE cell specific reference symbols).

[0078] The current disclosure shows various methods for sharing DMRS between control and data for mini-slots, including single and multi-port transmission and for single user or multiple users scheduled in mini-slots.

[0079] The sharing may be achieved using a single sequence which spans the mini-slot time-frequency resource.

[0080] In an alternative, two sequences may be utilised, comprising a control DMRS sequence spanning the control region frequency carriers and a data DMRS sequence spanning the remaining frequency resources over which mini-slot data is scheduled, complementary to the control frequency carriers.

[0081] The use of a single sequence has the advantage that DMRS detection and channel estimation performance will be better. This is also helpful in case of multi-port transmission to single user or to multiple users. All the discussion in the previous subsections applies equally to this case where the shared DMRS is a single sequence.

[0082]

[0083] Usage of two different DMRS sequences, one control DMRS and the other data DMRS may limit the use of mini-slots to single antenna port transmission. To overcome

this limitation the DMRS for the additional ports may be added in the control region. These additional DMRS in the control region could either follow the DMRS configuration for data or they could be multiplexed on the same resources as of control region DMRS. Putting the DMRS of additional data ports in the control region can be
5 done in an orthogonal manner if these are using Zadoff-Chu sequences by selecting different cyclic shifts. In case of PN sequences used for DMRS, multiplexing on the same resource would result in some degradation in correlation properties.

[0084] The primary disclosure hereinbefore is of a front-loaded data DMRS (DMRS occupying one or two symbols at the start of data in mini-slots) on each frequency
10 resource in a mini-slot. However, for long mini-slots a further DMRS may be required within the mini-slot, for example in high Doppler scenarios.

[0085] 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
15 configured to perform the method of any aspect of the present invention. Further options and choices are described below.

[0086] 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
20 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
25 processing engine such as, for example, a microprocessor, microcontroller or other control module.

[0087] 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
30 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.

[0088] 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.

[0089] 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.

[0090] 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.

[0091] 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.

[0092] 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

[0093] 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.

[0094] 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.

[0095] 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.

[0096] 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. 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.

[0097] 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 recognize 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.

[0098] 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.

[0099] 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.

[0100] 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.

5 Claims

1. A method of downlink data transmission from a base station to a UE in a cellular communication system utilising an OFDM modulation format, the method comprising the steps of
 - 10 defining a mini-slot comprising at least one control OFDM symbol and at least one data OFDM symbol, wherein DMRSs are encoded on the control and/or data OFDM symbols and are shared between the control and data OFDM symbols; and transmitting the mini-slot from the base station to the UE.
2. A method according to claim 1, wherein the DMRSs are all encoded on
 - 15 one of the control OFDM symbols.
3. A method according to claim 1, wherein the DMRSs are all encoded on one of the data OFDM symbols.
4. A method according to claim 1, wherein a sub-set of the DMRSs are encoded on one of the control OFDM symbols, and a sub-set of the DMRSs are
 - 20 encoded on one of the data OFDM symbols.
5. A method according to any preceding claim, wherein only one DMRS is encoded on each sub-carrier in the mini-slot.
6. A method according to any preceding claim, wherein control information only occupies a sub-set of carriers of the at least one control OFDM symbol, the
 - 25 remaining carriers of the at least one control OFDM symbol being utilised to carry data.
7. A method according to claim 1, wherein the at least one control OFDM symbol occupies fewer frequency resources than the at least one data OFDM symbol, and wherein DMRSs for frequency resources used by the at least one
 - 30 control OFDM symbol are encoded on a control OFDM symbol, and DMRSs for frequency resources used only by the at least one data OFDM symbol are encoded on a data OFDM symbol.
8. A method according to any preceding claim, wherein the control and data OFDM symbols are transmitted using the same at least one antenna port.

- 5 9. A method according to any of claims 1 to 7 wherein the mini-slot is transmitted using a plurality of antenna ports.
10. A method according to claim 9, wherein the at least one data OFDM symbol is transmitted using more antenna ports than the at least one control OFDM symbol.
- 10 11. A method according to claim 10, wherein DMRS are transmitted for all antenna ports used by the at least one OFDM data symbol, and the at least one control OFDM symbol is transmitted using a subset of those ports.
12. A method according to claim 10, wherein the subset of ports is a single port.
- 15 13. A method according to claim 12, wherein additional ports are used during the at least one control OFDM symbol for further data OFDM symbols.
14. A method according to Claim 12, wherein the single port is the first port used for transmission of the OFDM data symbol.
15. A method according to claim 6, wherein the transmission mode of the data
20 part in the at least one control OFDM symbol is the same as the transmission mode of the data OFDM symbols.
16. A method according to any preceding claim, wherein the DMRS is a single DMRS sequence.
17. A method according to any of claims 1 to 15, wherein the DMRS
25 comprises a set of two sequences, wherein a first of the sequences spans the at least one control OFDM symbol, and a second of the sequences spans the at least one data OFDM symbol for frequency resources not covered by the first sequence.
18. A method according to any preceding claim, wherein the DMRS is non-user specific.
- 30 19. A method of receiving downlink data transmission at a UE from a base station in a cellular communication system utilising an OFDM modulation format, the method comprising the steps of
- receiving an OFDM signal comprising at least one mini-slot, the mini-slot comprising at least one control OFDM symbol, and at least one data OFDM symbol,

5 wherein DMRSSs are received on at least one of the control OFDM symbol and data OFDM symbol,

decoding the mini-slot utilising the DMRSSs for both the at least one control OFDM symbol and the at least one data OFDM symbol.

20. A method of receiving downlink data transmission according to claim 19,
10 wherein the DMRSSs are all encoded on one of the control OFDM symbols.

21. A method of receiving downlink data transmission according to claim 19, wherein the DMRSSs are all encoded on one of the data OFDM symbols.

22. A method of receiving downlink data transmission according to claim 19, wherein a sub-set of the DMRSSs are encoded on one of the control OFDM symbols,
15 and a sub-set of the DMRSSs are encoded on one of the data OFDM symbols.

23. A method of receiving downlink data transmission according to any of claims 19 to 22, wherein only one DMRS is encoded on each sub-carrier in the mini-slot.

24. A method of receiving downlink data transmission according to any of
20 claims 19 to 23, wherein control information only occupies a sub-set of carriers of the at least one control OFDM symbol, the remaining carriers of the at least one control OFDM symbol being utilised to carry data.

25. A method of receiving downlink data transmission according to any of
25 claims 19 to 24, wherein the at least one control OFDM symbol occupies fewer frequency resources than the at least one data OFDM symbol, and wherein DMRSSs for frequency resources used by the at least one control OFDM symbol are encoded on a control OFDM symbol, and DMRSSs for frequency resources used only by the at least one data OFDM symbol are encoded on a data OFDM symbol.

26. A method of receiving downlink data transmission according to any of
30 claims 19 to 25, wherein the DMRS is a single DMRS sequence.

27. A method of receiving downlink data transmission according to any of
claims 19 to 25, wherein the DMRS comprises a set of two sequences, wherein a first of the sequences spans the at least one control OFDM symbol, and a second of the sequences spans the at least one data OFDM symbol for frequency resources
35 not covered by the first sequence.

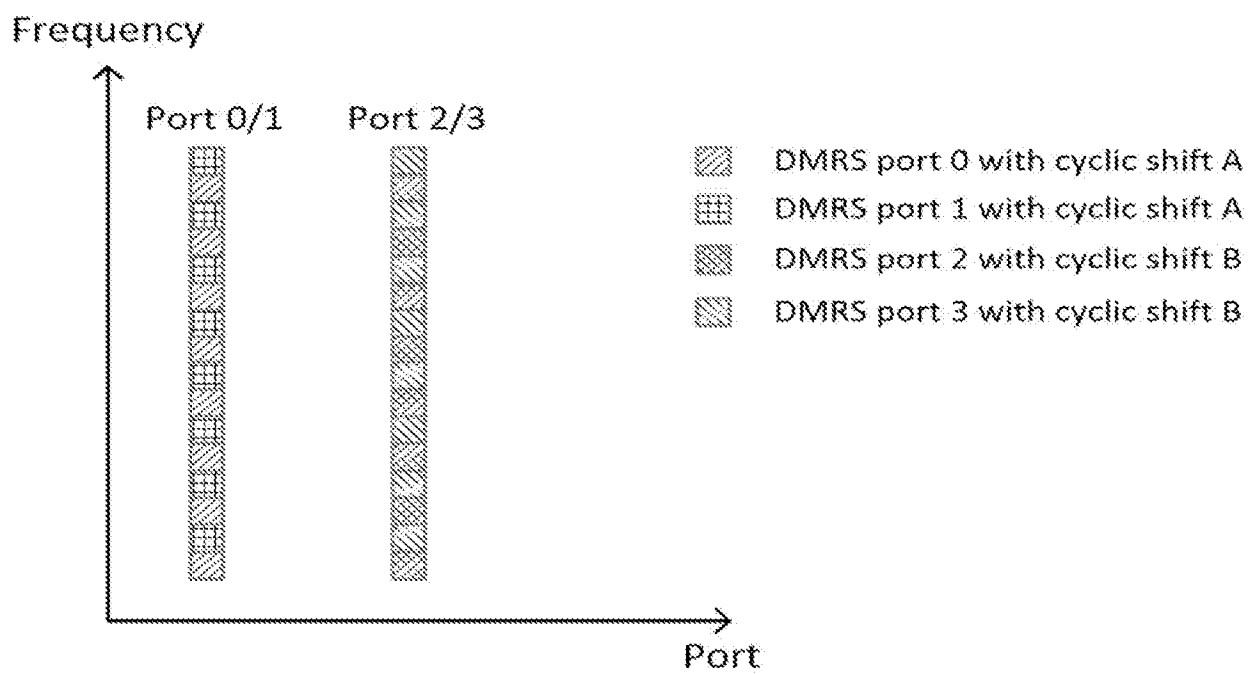


Figure 1

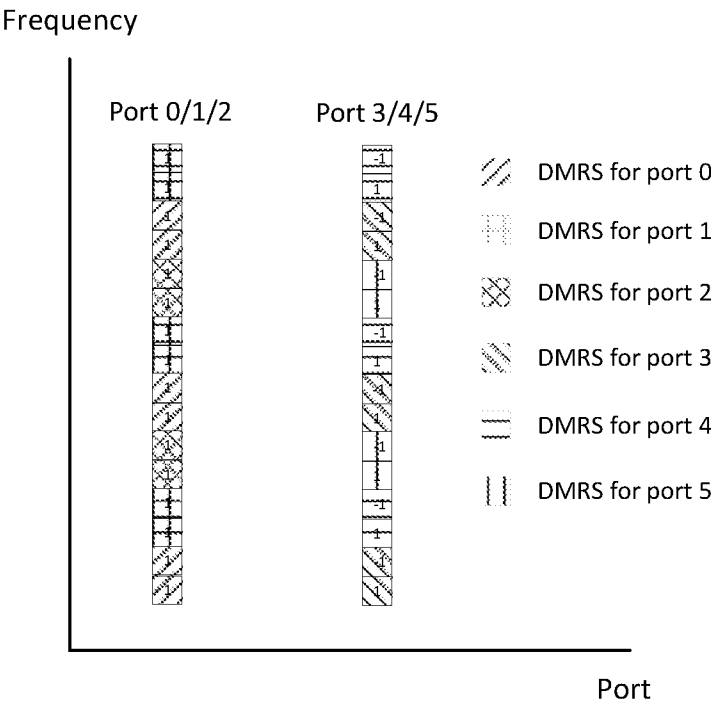


Figure 2

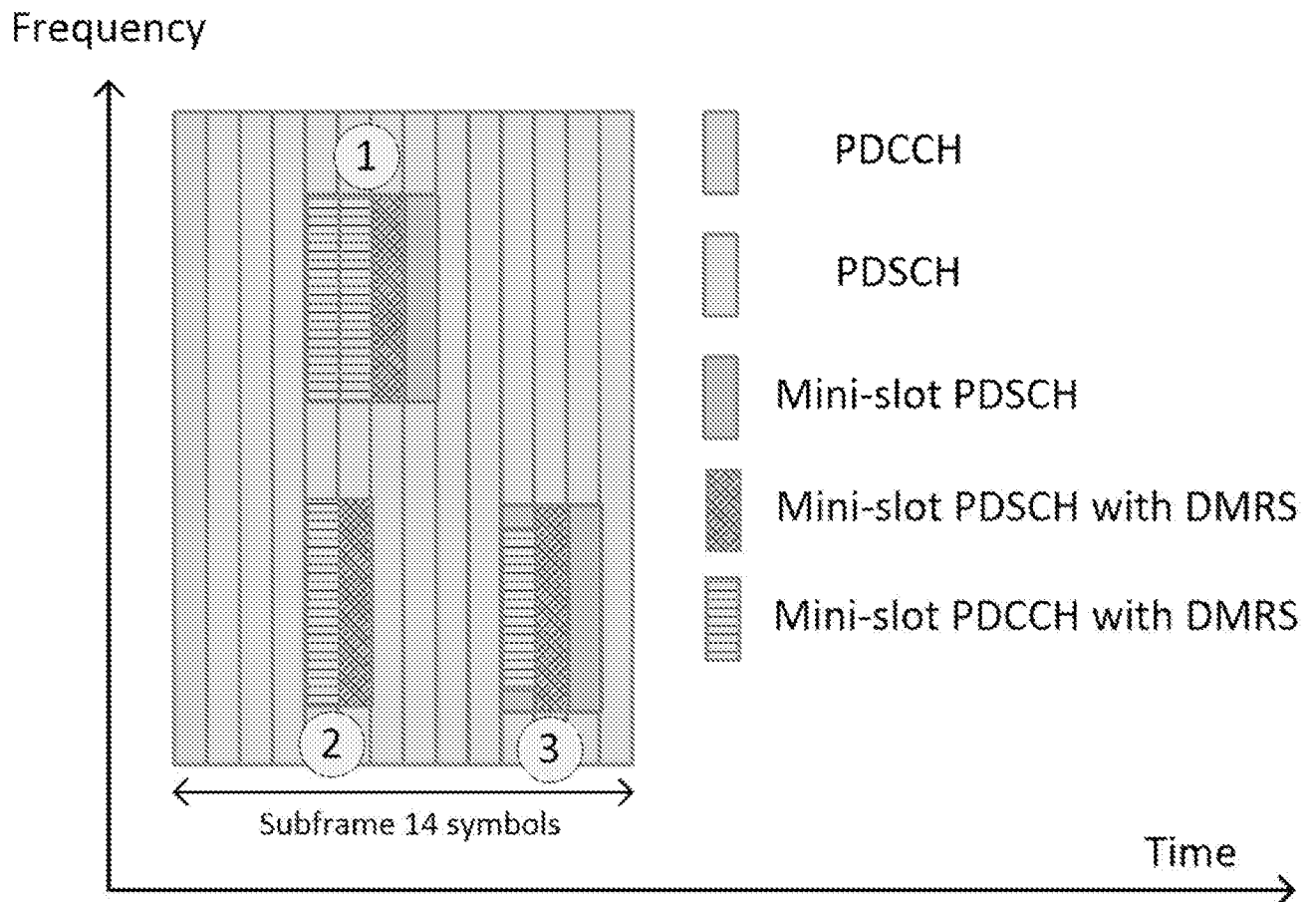


Figure 3

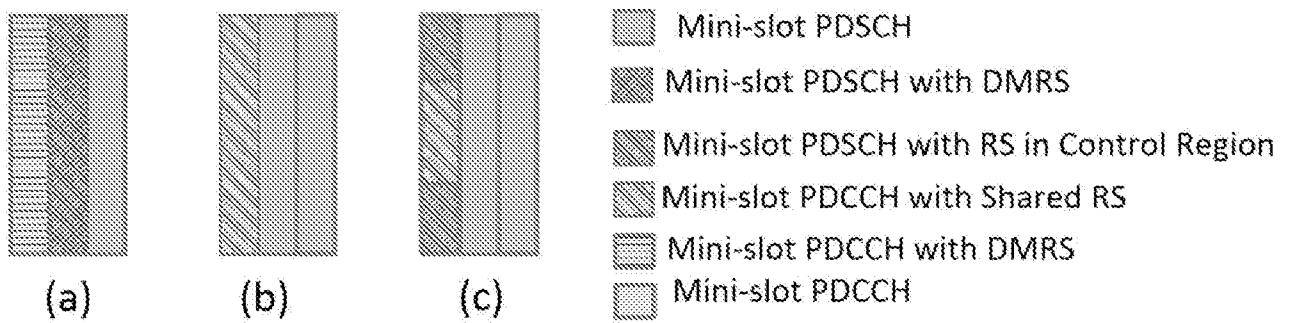


Figure 4

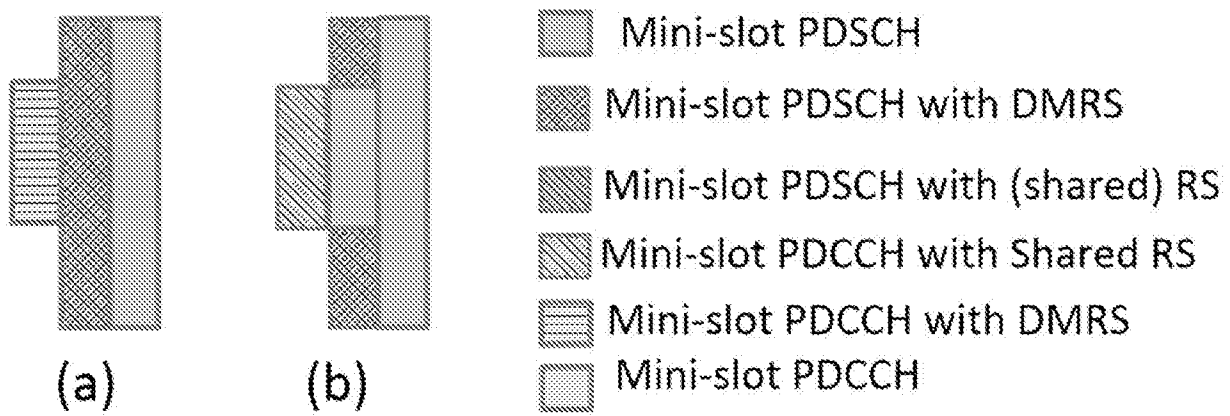


Figure 5

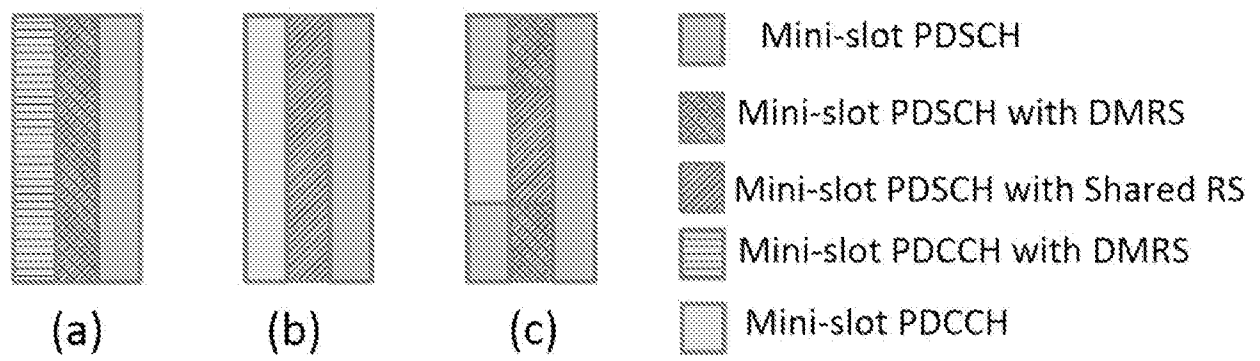


Figure 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2018/099516

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/04(2009.01)i; H04L 27/26(2006.01)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; H04B; H04J; H04Q

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)

CNPAT,CNKI,WPI,EPODOC,3GPP: OFDM, mini-slot, 5G, DMRS, PDSCH, PDCCH, control, data, channel, symbol

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	ETRI. "Views on DMRS for NR-PDCCH" <i>3GPP TSG RAN WG1 Meeting #90 R1-1713812</i> , 12 August 2017 (2017-08-12), section 2	1-27
X	HUAWEI et al. "PDCCH reliability for URLLC" <i>3GPP TSG RAN WG1 NR Ad Hoc Meeting R1-1709986</i> , 30 June 2017 (2017-06-30), section 3, 4.2	1-27
X	HUAWEI. "Email discussion [86b-23] on multi-steps DL control channel design" <i>3GPP TSG RAN WG1 Meeting #87 R1-1611656</i> , 18 November 2016 (2016-11-18), Appendix, Question 5, Intel	1-27
A	CN 103095631 A (ZTE CORPORATION) 08 May 2013 (2013-05-08) the whole document	1-27

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

* Special categories of cited documents:

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

"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

13 September 2018

Date of mailing of the international search report

29 October 2018

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2018/099516

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	103095631	A	08 May 2013	WO	2013064034	A1	10 May 2013