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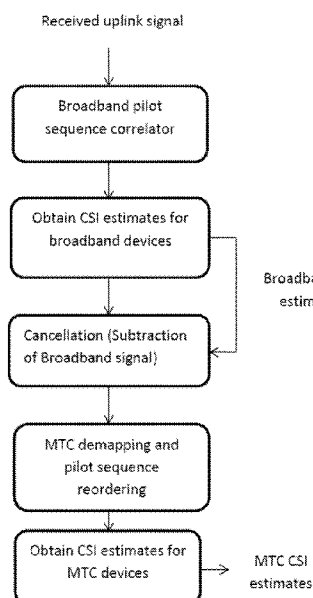


Figure 4

(57) Abstract: A method of obtaining channel state information estimates in a wireless communications network which supports wireless communications between UEs and multi input multi output base stations and wireless machine type communications between machine type communication devices and multi input multi output base stations, the method comprising each of or at least some of the machine type communication devices, applying a device-specific interleaving pattern to training signals of the machine type communication device, applying a device-specific sparse mapping pattern to the training signals of the machine type communication device, sending an uplink transmission from the machine type communication device comprising the training signals of the machine type communication device and data signals of the machine type communication device, each of or at least some of the UEs, sending an uplink transmission from the UE comprising training signals of the UE and data signals of the UE, and at least one multi input multi output base station, receiving an uplink signal comprising an uplink transmission from each of or at least some of the machine type communication devices and an uplink transmission from each of or at least some of the UEs, using the device-specific interleaving pattern and the device-specific mapping pattern of each of the machine type communication devices to distinguish the training signals of each machine type communication device from remaining machine type communication devices and from the training signals of each UE, and using the training signals of each of or at least some of the UEs to obtain channel state information estimates for each of or at least some of the UEs and using the training signals of each of or at least some of the machine type communication devices to obtain channel state information estimates for each of or at least some of the machine type communication devices.

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Non-Orthogonal Multiple Access for Machine Type Communications in a Wireless Communications Network

Technical Field

[1] The following disclosure relates to non-orthogonal multiple access for Machine Type Communications (MTC) in a wireless communications network and particularly the transmission of MTC data on the same resources used for other types of mobile communications, such as evolved Mobile Broadband (eMBB).

Background

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

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

[4] The 3GPP 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] 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) which is 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.

[6] Future generation networks are expected to provide access technology for a broad range of vertical services with heterogeneous requirements. 5G NR, for example, is expected to support services such as enhanced mobile broadband (eMBB), massive machine type communication (mMTC) and URLLC in a single technical framework. Each of these usage scenarios is subject to a wide range of key performance indicators that can be significantly different and even conflicting. Nevertheless, the same wireless communications networks need to provide access with high efficiency to both conventional wireless communication and other communications, such as MTCs.

[7] mMTC services are intended to support a large number of MTC 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 wireless communications cell

may be expected to support many thousands of MTC devices. For MTC, low UE complexity is one key requirement. In fact MTC devices are expected to support “low capability” applications with low volume of non-delay-sensitive data. High density connectivity and energy efficiency are also key requirements for MTC in order to enable network support of a large number of connected devices.

[8] In order to enable the simultaneous transmission of a large number of MTC devices with low volume of non-delay-sensitive data, novel multiple access schemes have been proposed. One of the most promising candidates are non-orthogonal multiple access (NOMA) schemes and uplink NOMA schemes have been considered for MTC in the upcoming 5G standard.

[9] When combined with the considerable spatial multiplexing gain of large scale Multi Input Multi Output (MIMO) systems, NOMA schemes can lead to considerable performance gains. Indeed, massive MIMO beamforming techniques are expected to be a key component of future Radio Access Technology (RAT) owing to their ability to distinguish users in the spatial domain. MIMO and massive MIMO technologies have made it possible to spatially multiplex a large number of connected devices on the same time-frequency resources.

[10] Exploiting the spatial multiplexing gain of massive MIMO with the use of NOMA is not a trivial task. Massive MIMO receiver systems require accurate Channel State Information (CSI) estimates for all active users in order to create the needed power difference for decoding the received signals. Obtaining such estimates requires a signalling overhead. In large MIMO antenna systems, the connection density, with power-domain NOMA, will be limited by the CSI estimation overhead since this scales with the number of connected devices. If intelligent CSI estimation schemes can be developed for MTC then the spatial multiplexing gain of massive MIMO can be leveraged in addition to power and code domain multi-user multiplexing in order to enable more efficient NOMA schemes.

Summary

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

[12] According to the invention there is provided a method of obtaining channel state information estimates in a wireless communications network which supports wireless communications between UEs and multi input multi output base stations and wireless machine type communications between machine type communication devices and multi input multi output base stations, the method comprising each of or at least some of the machine type communication devices, applying a device-specific interleaving pattern to training signals of the machine type communication device, applying a device-specific sparse mapping pattern to the training signals of the machine type communication device, sending an uplink transmission from the machine type communication device comprising the training signals of the machine type communication device and data signals of the machine type communication device, each of or at least some of the UEs, sending an uplink transmission from the UE comprising training signals of the UE and data signals of the UE, and at least one multi input multi output base station, receiving an uplink signal comprising an uplink transmission from each of or at least some of the machine type communication devices and an uplink transmission from each of or at least some of the UEs, using the device-specific interleaving pattern and the device-specific mapping pattern of each of the machine type communication devices to distinguish the training signals of each machine type communication device from remaining machine type communication devices and from the training

signals of each UE, and using the training signals of each of or at least some of the UEs to obtain channel state information estimates for each of or at least some of the UEs and using the training signals of each of or at least some of the machine type communication devices to obtain channel state information estimates for each of or at least some of the machine type communication devices.

[13] The device-specific interleaving pattern and the device-specific sparse mapping pattern may be applied to the training signals within each coherence slot of each of or at least some of the machine type communication devices.

[14] The training signals of each of or at least some of the machine type communication devices may comprise a set of known orthogonal training sequences particularly, a set of short orthogonal training sequences.

[15] The device-specific interleaving pattern may be a device-specific sequence-level interleaving pattern. The device-specific sequence-level interleaving pattern may be mathematically formulated as a permutation matrix:

$$[16] \quad \gamma_k (\gamma_k \in C^{\tau^2 \times \tau^2})$$

[17] where τ is the number of sequences.

[18] The device-specific sparse mapping pattern may be a device-specific sparse mapping pattern of time and frequency domain transmission resources of each of the at least some machine type communication devices. The pattern of time and frequency domain transmission resources may have a physical resource block granularity or a resource element granularity.

[19] The device-specific sparse mapping pattern may be characterized by a matrix:

$$[20] \quad \varphi_k \in C^{\tau^2 \times (\tau T)}$$

[21] where τ is the number of sequences.

[22] The device-specific sequence-level interleaving pattern permutation matrix and the device-specific sparse mapping pattern matrix may be part of a pre-designed codebook, which may be obtained using a same seed state to initialize a pseudorandom number generator at both the multi input multi output base station and the machine type communication devices. The seed may be based on a machine type communication device identification.

[23] Using the training signals of each of or at least some of the UEs to obtain the channel state information estimates for each of or at least some of the UEs may comprise correlating the training signals of the UE with known training signals for the UE to produce correlated training signals and using the correlated training signals to provide the channel state information estimates of the UE.

[24] Using the training signals of each of or at least some of the machine type communication devices to obtain the channel state information estimates for each of or at least some of the machine type communication devices may comprise applying a reciprocal device-specific interleaving pattern and a reciprocal device-specific mapping pattern to the training signals of the machine type communication device to produce reciprocated training signals, correlating the reciprocated training signals of the machine type communication device with known training signals for the machine type communication device to produce correlated training signals and using the correlated training signals to provide the channel state information estimates of the machine type communication device.

[25] The channel state information estimates may be used to acquire an estimate of uplink signal to interference plus noise ratio for each of or at least some of the machine type

communication devices. Interference cancellation between the uplink training signals of the or each of the machine type communication devices and the uplink training signals of the or each of the UEs may be performed.

[26] The wireless communications network may support non-orthogonal multiple access of the wireless communications between UEs and multi input multi output base stations and the wireless machine type communications between machine type communication devices and multi input multi output base stations.

[27] According to the invention there is provided a base station configured to perform the method of the invention. According to the invention there is provided a receiver of a base station configured to perform the method of the invention. According to the invention there is provided a UE configured to perform the method of the invention.

Brief description of the drawings

[28] 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.

[29] Figure 1 shows a schematic diagram of a cellular network;

[30] Figure 2 shows sparse mapping of training signals at a PRB level for MTC devices;

[31] Figure 3 shows sparse mapping of training signals at a RE level for MTC devices;

[32] Figure 4 shows a flow chart of an algorithm performed by the receiver of the invention;

[33] Figure 5 shows the cumulative distribution functions (CDFs) of achieved spectral efficiency for the MTC devices using the method of the invention;

[34] Figure 6 shows the CDFs for achieved total spectral efficiency of the MTC devices using the method of the invention, and

[35] Figure 7 shows the spectral efficiency gain of the method of the invention.

Detailed description of the preferred embodiments

[36] 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.

[37] 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.

[38] 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.

[39] In wireless communications, CSI is known channel properties of a communications link, which describe signal propagation from a transmitter to a receiver. In uplink transmission of multi-user, massive MIMO communications networks, estimation of CSI parameters, such as channel gains and receiving filter coefficients, are needed to be able to efficiently perform decoding of uplink signals from UEs to base stations and precoding of downlink signals from base stations to UEs to adapt these transmissions to current channel conditions. This is crucial for achieving reliable communication with high data rates in multiantenna systems. When massive MIMO systems are additionally used for MTCs from MTC devices, estimation of CSI parameters are needed to be able to efficiently perform decoding of uplink signals from UEs and MTC devices to base stations and precoding of downlink signals from base stations to UEs and MTC devices.

[40] The CSI parameter estimation task usually relies on transmission of known training, or pilot, sequences and estimating channel responses from the received signals to estimate the CSI. In TDD systems, CSI estimates can be acquired using uplink reference signal transmission. In FDD systems, explicit or implicit feedback is used. This raises the issue of training and feedback overhead. In TDD systems, the number of scheduled users for uplink training is restricted on each slice of the spectrum due to the limited coherence slot length and training overhead. In FDD systems, CSI feedback overhead grows very rapidly with the number of system antennas which limits the number of scheduled users.

[41] A method is provided of obtaining channel state information estimates in a wireless communications network which supports wireless communications between UEs and MIMO base stations and wireless MTCs between MTC devices and MIMO base stations.

[42] The method comprises each of or at least some of the MTC devices, applying a device-specific interleaving pattern to training signals of the MTC device, applying a device-specific sparse mapping pattern to the training signals of the MTC device and sending an uplink transmission from the MTC device comprising the training signals of the MTC device and data signals of the MTC device, each of or at least some of the UEs, sending an uplink transmission from the UE comprising training signals of the UE and data signals of the UE, and at least one MIMO base station, receiving an uplink signal comprising an uplink transmission from each of or at least some of the MTC devices and an uplink transmission from each of or at least some of the UEs, using the device-specific interleaving pattern and the device-specific mapping pattern of each of the MTC devices to distinguish the training signals of each MTC device from remaining MTC devices and from the training signals of each UE and using the training signals of each of or at least some of the UEs to obtain CSI estimates for each of or at least some of the UEs and using the training signals of each of or at least some of the MTC devices to obtain CSI estimates for each of or at least some of the MTC devices.

[43] The wireless communications network supports non-orthogonal multiple access of the wireless communications between UEs and multi input multi output base stations and the wireless machine type communications between machine type communication devices and multi input multi output base stations.

[44] In the method, the low volume, non-delay-sensitive characteristic of MTCs is exploited to enable the estimation of instantaneous CSI in a high density connectivity scenario with both UE communication and MTC device communication, while improving the achievable performance of both communication types.

[45] The device-specific interleaving pattern and the device-specific sparse mapping pattern are applied to the training signals within each coherence slot of each of the MTC devices.

[46] In this embodiment, the training signals of each of the MTC devices comprise a set of known short orthogonal training sequences:

$$[Q_1, \dots, Q_\tau]$$

containing τ sequences of size τ each.

[47] These sequences have same correlation properties as broadband sequences.

[48] The device-specific interleaving pattern is a device-specific sequence-level interleaving pattern and is mathematically formulated as a process by permutation matrix:

$$\gamma_k \ (\gamma_k \in \mathbb{C}^{\tau^2 \times \tau^2})$$

[49] The sequence-level of the device-specific interleaving pattern enables exploitation of the mutual orthogonality of the set of training sequences.

[50] In this embodiment, the device-specific sparse mapping pattern is a device-specific sparse mapping pattern of time and frequency domains of transmission resources of each of the MTC devices. The device-specific sparse mapping pattern of time and frequency domains of transmission resources may have a PRB granularity or RE granularity or both.

[51] Sparse mapping means that, in any given RE, only a portion of connected MTC devices are active. This is advantageous as it enables control of the level of interference between UE communications and MTS communications, in each RE, and saves energy for the MTC devices.

[52] The sparse mapping in the transmission resources is performed based on an assigned device-specific mapping pattern which is characterized by a unique matrix:

$$\varphi_k \in \mathbb{C}^{\tau^2 \times (\tau T)}$$

[53] Note that φ_k contains at maximum τN entries that are set to 1.

[54] When the MTC devices are permitted to perform uplink training using τT REs, then the device-specific sparse mapping pattern will be characterized by a density:

$$\rho = N/T$$

where τN is the number of occupied training REs.

[55] Note that the density ρ is a design parameter that can be tuned according to MTC device density and the level of permitted interference between UE communications and MTC communications.

[56] The uplink training signal of a MTC device k is given by:

$$P_k = [Q_1, \dots, Q_\tau] \cdot \gamma_k \cdot \varphi_k$$

[57] The sequence-level interleaving pattern permutation matrix and the device-specific sparse mapping pattern matrix may be part of a pre-designed codebook or may be obtained using a same seed state to initialize a pseudorandom number generator at both the MIMO base station and the MTC devices. The seed may be based on a MTC device ID. This further reduces the need for pre-allocate interleaving and mapping patterns.

[58] A depiction of the sparse mapping of the training signal in the time-frequency transmission resource grid is given in the Figure 2. The figure represents Demodulation Reference Signal (DMRS) location on the transmission resource grid with a PRB granularity. Sparse mapping is performed at a PRB level in both time and frequency domains of the transmission resource grid.

[59] Sparse mapping at the PRB level may be a limitation. It exploits many PRBs for training signals which must be expanded in frequency, time or both and the ability to do sparse mapping is quickly limited by channel coherence slot bandwidth and coherence slot time.

[60] A characteristic of a 5G NR transmission resource grid may be used to overcome this issue. This consists of exploiting an existing sparsity of 5G NR DMRS within a PRB. As shown in Figure 3, DMRSs occupy typically one quarter of the Resource Elements within a DMRS PRB. A higher number of REs within a PRB can therefore be used. The sparse mapping can be applied at an RE level, alone or in conjunction with sparse mapping at a PRB level.

[61] One advantage of applying a sparse mapping pattern to MTC device training signals is that, at any given time and frequency, only a portion of the MTC devices are interfering with broadband uplink signals from UEs. This means that the estimation of the CSI of a large number of MTC devices does not result in a substantial degradation of UE broadband communication quality.

[62] Only the MTC training signals are modified, as described above. The MTC data signals are not modified, they retain the conventional mapping in the transmission resource. This results in a new frame structure for uplink transmissions of the MTC devices. The frame structure of the UE transmissions is not changed, as this has already been specified in network standards. No orthogonal division between the MTC device transmissions and the UE transmissions is enacted.

[63] When the training signals of the UEs and the MTC devices are received, these are then used to obtain CSI estimates for the UEs and the MTC devices.

[64] For the UEs, this comprises correlating the training signals of each UE with known training signals for the UE to produce correlated training signals and using the correlated training signals to provide the CSI estimates of the UE.

[65] For the MTC devices, this comprises applying a reciprocal device-specific interleaving pattern and a reciprocal device-specific mapping pattern to the training signals of each MTC device to produce reciprocated training signals, correlating the reciprocated training signals of the MTC device with known training signals for the MTC device to produce correlated training signals and using the correlated training signals to provide the CSI estimates of the MTC device.

[66] In more detail, upon receiving the uplink signal from the UEs and the MTC devices the MIMO base station correlates the uplink signal with known training sequences of the training signals for each UE to produce a UE correlated uplink signal and uses the UE correlated uplink signal to provide the CSI estimates of each UE. The UE correlated uplink signal is then multiplied with the known training sequences of the training signals for each UE and the resultant signal subtracted from the original uplink signal to produce a MTC device uplink signal. A reciprocal device-specific interleaving pattern and a reciprocal device-specific mapping pattern is applied to the MTC device uplink signal, to produce a reciprocated MTC device uplink signal. The reciprocated MTC device uplink signal is correlated with known training sequences of the training

signals for each MTC device to produce a MTC device correlated uplink signal. The MTC device correlated uplink signal is then used to provide the CSI estimates of each MTC device.

[67] Using the described method, contamination between the MTC device training signals and the UE training signals is minimized enabling sufficiently accurate CSI estimates to be obtained.

[68] The CSI estimates can be used to acquire an estimate of uplink signal to interference plus noise ratio (SINR) for each of the MTC devices.

[69] There is further provided a MTC device, a UE and a base station each configured to perform the method described above.

[70] There is also provided a receiver of a base station configured to perform the method described above.

[71] The receiver of the base station receives the uplink transmissions of the UEs and the uplink transmissions of the MTC devices and performs successive interference cancellation between the transmissions. The interference cancellation will be required between devices (UE or MTC) having correlated channels, i.e. spatially close channels, in order to be able to correctly decode multiple layers of multiplexed data on the same transmission resources. Using the interference cancellation allows the receiver to enable coexistence of MTC device signals and UE signals on the same time-frequency transmission resources. Cancellation of interference between the MTC device signals and the UE signals is particularly important when using NOMA for the transmission resource elements.

[72] The receiver of the base station exploits the acquired CSI estimates to perform interference cancellation only when needed, i.e. when a device SNR is not sufficient to perform correct detection of the signals of the device. This reduces the number of interference cancellations that are required to interference cancellation for only a subset of devices. The receiver exploits the correlation properties of the UE and MTC device training signals to cancel cross tier interference. The special structure of the training signals is leveraged.

[73] Reducing the number of interference cancellation iterations decreases the complexity of the receiver and, consequently, the impact of error propagation.

[74] The receiver of the base station comprises an algorithm, as illustrated in Figure 4, which carries out the following steps.

- (i) receiving the uplink signal from the UEs and the MTC devices,
- (ii) correlating the broadband uplink signal with known training, or pilot, sequences of the training signals for each UE to produce a UE correlated uplink signal,
- (iii) using the broadband UE correlated uplink signal to provide the CSI estimates of each UE,
- (iv) multiplying the UE correlated uplink signal with the known training sequences of the training signals for each UE and subtracting the resultant signal from the original broadband uplink signal to produce a MTC device uplink signal,
- (v) applying a reciprocal device-specific interleaving pattern (reordering) and a reciprocal device-specific mapping pattern (demapping) to the MTC device uplink signal to produce a reciprocated MTC device uplink signal,
- (vi) correlating the reciprocated MTC device uplink signal with known training sequences of the training signals for each MTC device to produce a MTC device correlated uplink signal,
- (vii) using the MTC device correlated uplink signal to provide the CSI estimates of each MTC device.

[75] A pseudo-code of the data receiver algorithm is:

Input: SINR threshold θ , Condition=1, $k=1$, Δ = set of MTC devices

While condition

$\Delta_k = [i \in \Delta, (SINR_i) > \theta]$

Decode the signal of users in Δ_k using simple linear receiver (MF)

If $\Delta_k = \Delta$

Condition=0

Else

Apply interference cancellation by removing the contribution of devices in Δ_k

$\Delta = \Delta / \Delta_k$

$k = k + 1$

End if

End while

[76] It can be seen that the receiver processes the uplink signal on a communication type basis, rather than on a device by device basis.

[77] The method and receiver described above allow the issue of CSI estimation and non-orthogonal multiple access in high density connectivity scenarios with both UE and MTC device communications to be addressed. The method and receiver enable access of MTC devices to the same transmission resources used for eMBB communication, i.e. the method and receiver are suitable for the multiservice case where QoS requirements and traffic volume are heterogeneous.

[78] The method used for obtaining CSI estimates for conventional cellular devices and a large number of MTC devices limits the required training signal overhead. This results in an improved spectral efficiency. This is achieved while improving the performance of both the cellular and the MTC devices owing to their ability to exploit the entire bandwidth.

[79] The performance of the method in a wireless communications network has been compared to that of a massive MIMO network using a conventional TDD protocol and orthogonal access between MTC device communications and broadband UE communications in the frequency domain. A coherence time of 1 ms and a coherence bandwidth of 210 KHz was used.

[80] In the reference setting, $(1 - \alpha)$ of the bandwidth is allocated to the broadband UE communications with $\alpha = 0.5$. The rest of the bandwidth is reserved for the MTC device communications. No frequency division between the MTC traffic and the broadband traffic is used. For the sake of fair comparison, the MTC devices are assumed to use all of the time-frequency resources that are not dedicated for uplink training in order to send data. A scenario with 7 cells in a 3GPP urban macro network is assumed. The base station in each cell is equipped with 100 antennas and serves 10 broadband devices and 20 MTC devices. The length of the MTC device training sequences is $\tau = 4$.

[81] Figure 5 shows a comparison of the cumulative distribution functions (CDFs) of the achievable spectral efficiency for MTC devices using the method and received described above. A considerable improvement of the achievable sum rate CDF can be seen. This gain results from the method enabling accurate CSI estimates to be acquired with reduced training signal overhead. The obtained CSI estimates allow the correct formation of the required signal beams for decoding with reduced training signal overhead, resulting in increased spectral efficiency.

[82] Figure 6 shows a comparison of the CDFs of the achievable spectral efficiency for all active devices which includes broadband and MTC devices. A considerable improvement of the achievable sum rate CDF can be seen. This is mainly due to the improvement in MTC spectral

efficiency that is enabled by the method, in addition to the resulting efficient coexistence of the two communication types on the same frequency resources. The sparse mapping of the MTC device training signals enables minimizing of the impact of interference on broadband device CSI estimation accuracy, which enables an increase of connection density with reduced training signal overhead and without degrading broadband device communication performance.

[83] Figure 7 shows the gain in spectral efficiency that the method achieves when compared to a conventional power domain NOMA scheme. The method enables considerable reduction of the required training signal resources to perform accurate CSI estimation. The achieved gain increases with the number of active MTC devices.

[84] 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.

[85] 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.

[86] 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.

[87] 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.

[88] 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.

[89] 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.

[90] 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.

[91] 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.

[92] 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.

[93] 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.

[94] 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.

[95] 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.

[96] 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.

[97] 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.

[98] 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 obtaining channel state information estimates in a wireless communications network which supports wireless communications between UEs and multi input multi output base stations and wireless machine type communications between machine type communication devices and multi input multi output base stations, the method comprising
each of or at least some of the machine type communication devices,
applying a device-specific interleaving pattern to training signals of the machine type communication device,
applying a device-specific sparse mapping pattern to the training signals of the machine type communication device,
sending an uplink transmission from the machine type communication device comprising the training signals of the machine type communication device and data signals of the machine type communication device,
each of or at least some of the UEs,
sending an uplink transmission from the UE comprising training signals of the UE and data signals of the UE, and
at least one multi input multi output base station,
receiving an uplink signal comprising an uplink transmission from each of or at least some of the machine type communication devices and an uplink transmission from each of or at least some of the UEs,
using the device-specific interleaving pattern and the device-specific mapping pattern of each of the machine type communication devices to distinguish the training signals of each machine type communication device from remaining machine type communication devices and from the training signals of each UE, and
using the training signals of each of or at least some of the UEs to obtain channel state information estimates for each of or at least some of the UEs and using the training signals of each of or at least some of the machine type communication devices to obtain channel state information estimates for each of or at least some of the machine type communication devices.
2. A method according to claim 1 wherein the device-specific interleaving pattern and the device-specific sparse mapping pattern are applied to the training signals within each coherence slot of each of or at least some of the machine type communication devices.
3. A method according to claim 1 or claim 2 wherein the training signals of each of or at least some of the machine type communication devices comprise a set of known orthogonal training sequences.
4. A method according to claim 3 wherein the set of orthogonal training sequences comprise a set of short orthogonal training sequences.
5. A method according to any one of the preceding claim wherein the device-specific interleaving pattern is a device-specific sequence-level interleaving pattern.

6. A method according to claim 5 wherein the device-specific sequence-level interleaving pattern is mathematically formulated as a permutation matrix:

$$\gamma_k (\gamma_k \in C^{\tau^2 \times \tau^2})$$

where τ is the number of sequences.

7. A method according to any one of the preceding claims wherein the device-specific sparse mapping pattern is a device-specific sparse mapping pattern of time and frequency domains transmission resources of each of the at least some machine type communication devices.

8. A method according to claim 7 wherein the device-specific sparse mapping pattern of time and frequency domains transmission resources has a physical resource block granularity.

9. A method according to claim 7 or claim 8 where the device-specific sparse mapping pattern of time and frequency domains transmission resources has a resource element granularity.

10. A method according to any one of claims 7 to 9 wherein the device-specific sparse mapping pattern is characterized by a matrix:

$$\phi_k \in C^{\tau^2 \times (\tau T)}$$

where τ is the number of sequences.

11. A method according to claim 10 as dependent from claim 6 wherein the device-specific sequence-level interleaving pattern permutation matrix and the device-specific sparse mapping pattern matrix are part of a pre-designed codebook.

12. A method according to claim 10 as dependent from claim 6 wherein the device-specific sequence-level interleaving pattern permutation matrix and the device-specific sparse mapping pattern matrix are obtained using a same seed state to initialize a pseudorandom number generator at both the multi input multi output base station and the machine type communication devices.

13. A method according to claim 12 wherein the seed is based on a machine type communication device identification.

14. A method according to any one of the preceding claims wherein using the training signals of each of or at least some of the UEs to obtain the channel state information estimates for each of or at least some of the UEs comprises correlating the training signals of the UE with known training signals for the UE to produce correlated training signals and using the correlated training signals to provide the channel state information estimates of the UE.

15. A method according to any one of the preceding claims wherein using the training signals of each of or at least some of the machine type communication devices to obtain the channel state information estimates for each of or at least some of the machine type communication devices comprises applying a reciprocal device-specific interleaving pattern and a reciprocal device-specific mapping pattern to the training signals of the machine type communication device

to produce reciprocated training signals, correlating the reciprocated training signals of the machine type communication device with known training signals for the machine type communication device to produce correlated training signals and using the correlated training signals to provide the channel state information estimates of the machine type communication device.

16. A method according to any one of the preceding claims further comprising using the channel state information estimates to acquire an estimate of uplink signal to interference plus noise ratio for each of or at least some of the machine type communication devices.

17. A method according to any one of the preceding claims wherein interference cancellation between the uplink training signals of the or each of the machine type communication devices and the uplink training signals of the or each of the UEs is performed.

18. A method according to any one of the preceding claims wherein the wireless communications network supports non-orthogonal multiple access of the wireless communications between UEs and multi input multi output base stations and the wireless machine type communications between machine type communication devices and multi input multi output base stations.

19. A base station configured to perform the method of any of claims 1 to 18.

20. A receiver of a base station configured to perform the method of any of claims 1 to 18.

21. A UE configured to perform the method of any of claims 1 to 18.

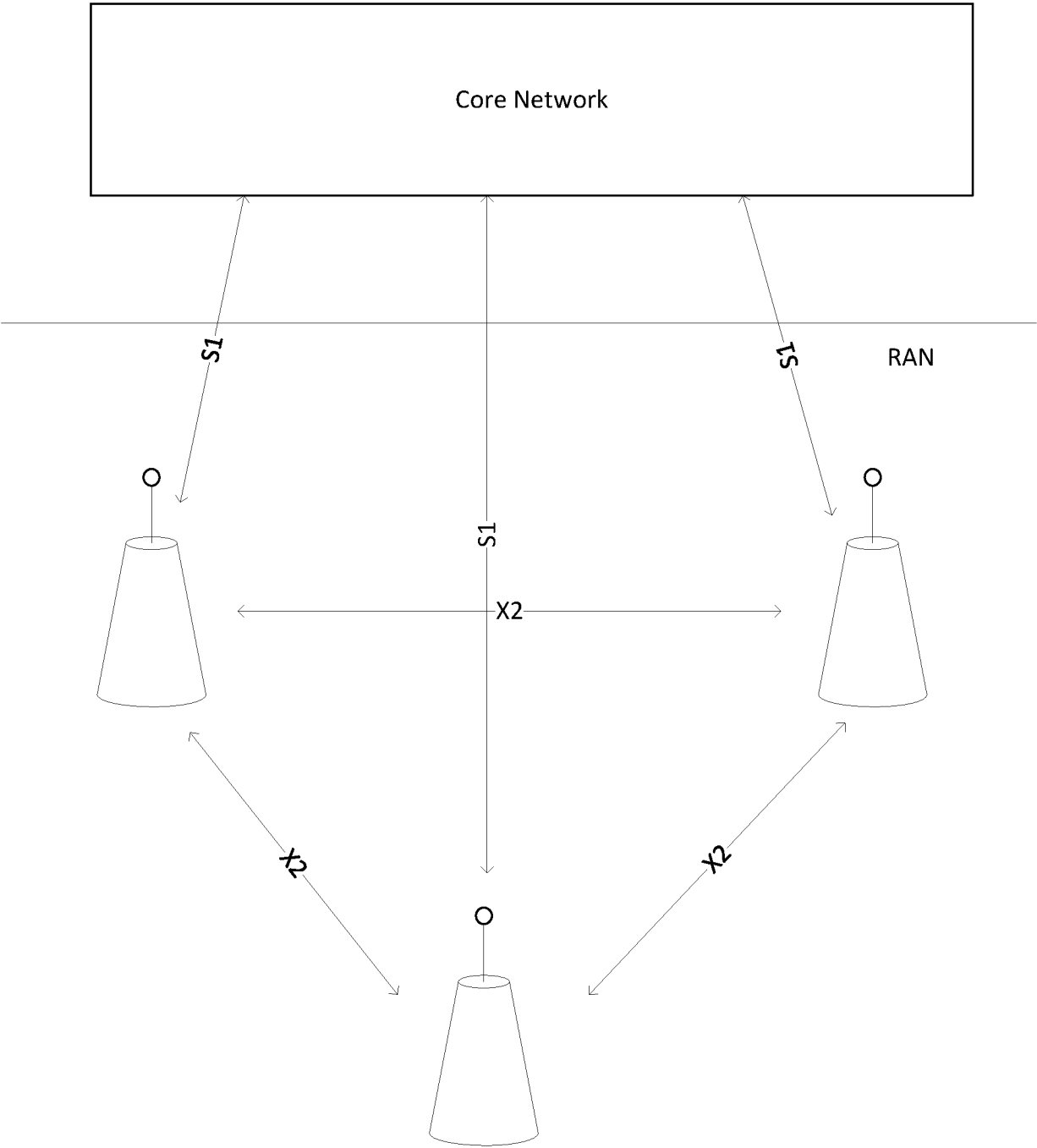


Figure 1

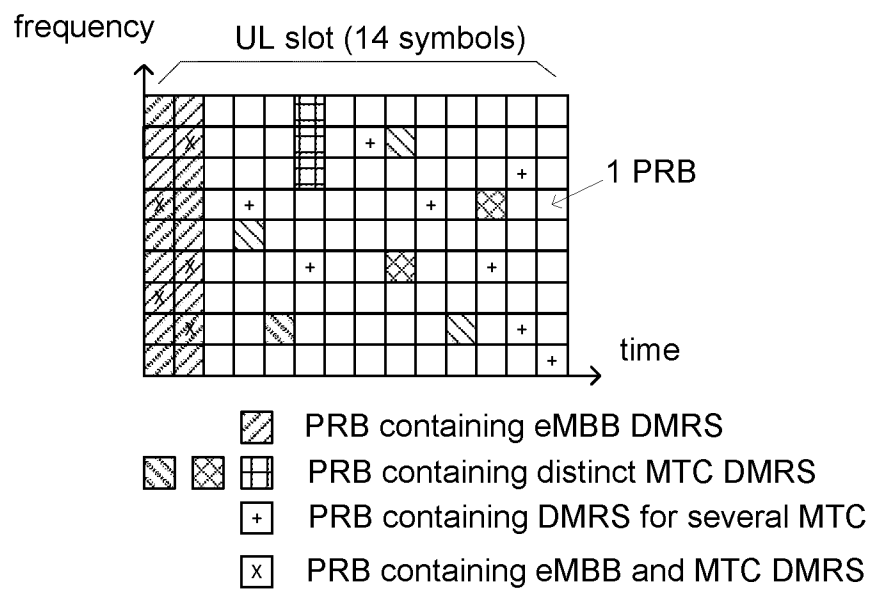


Figure 2

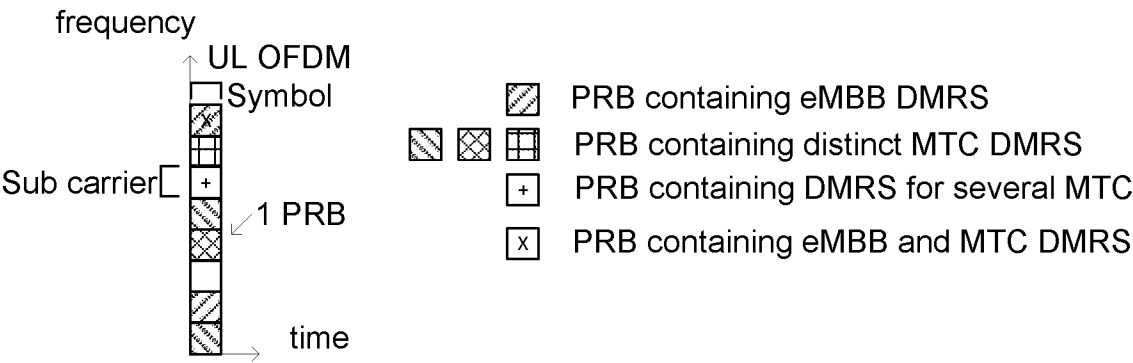


Figure 3

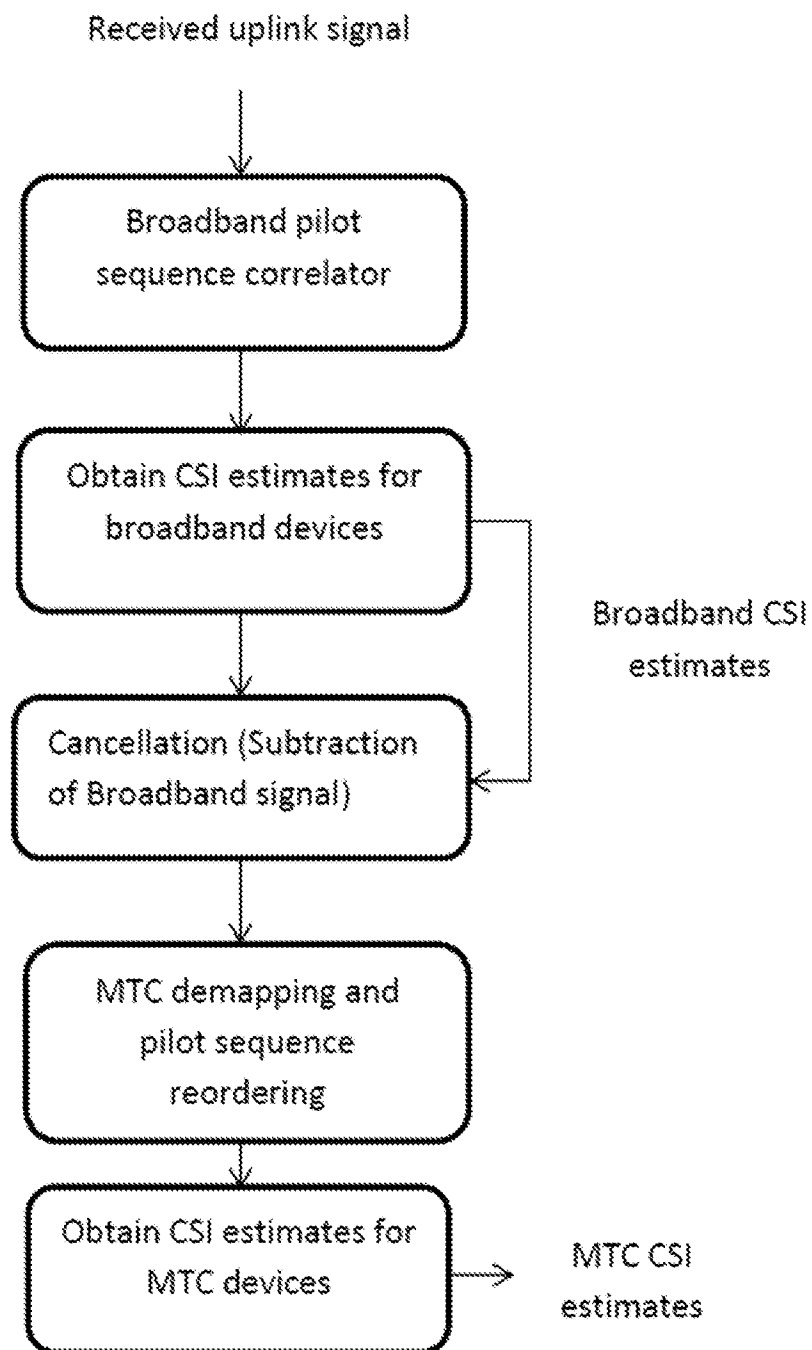


Figure 4

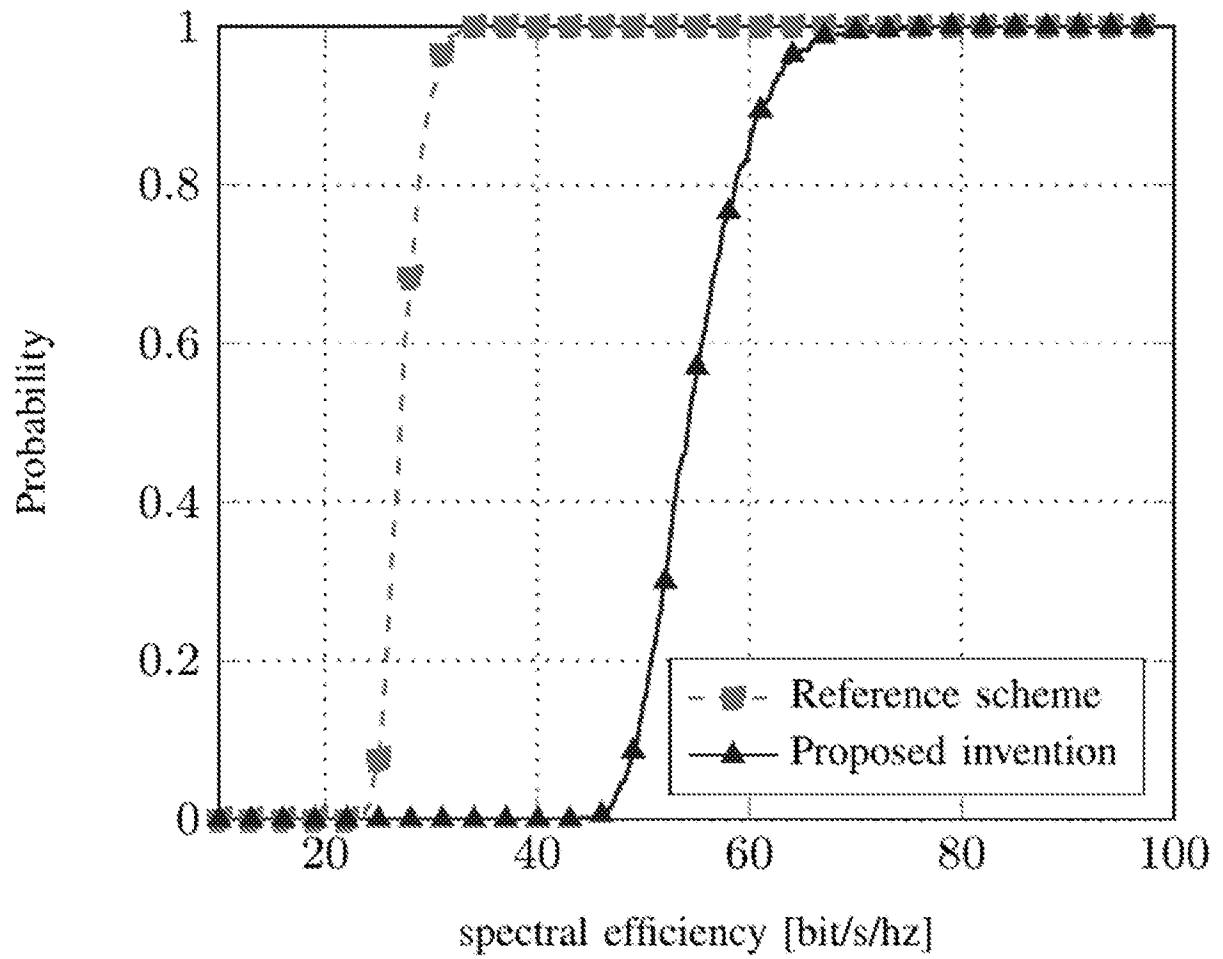


Figure 5

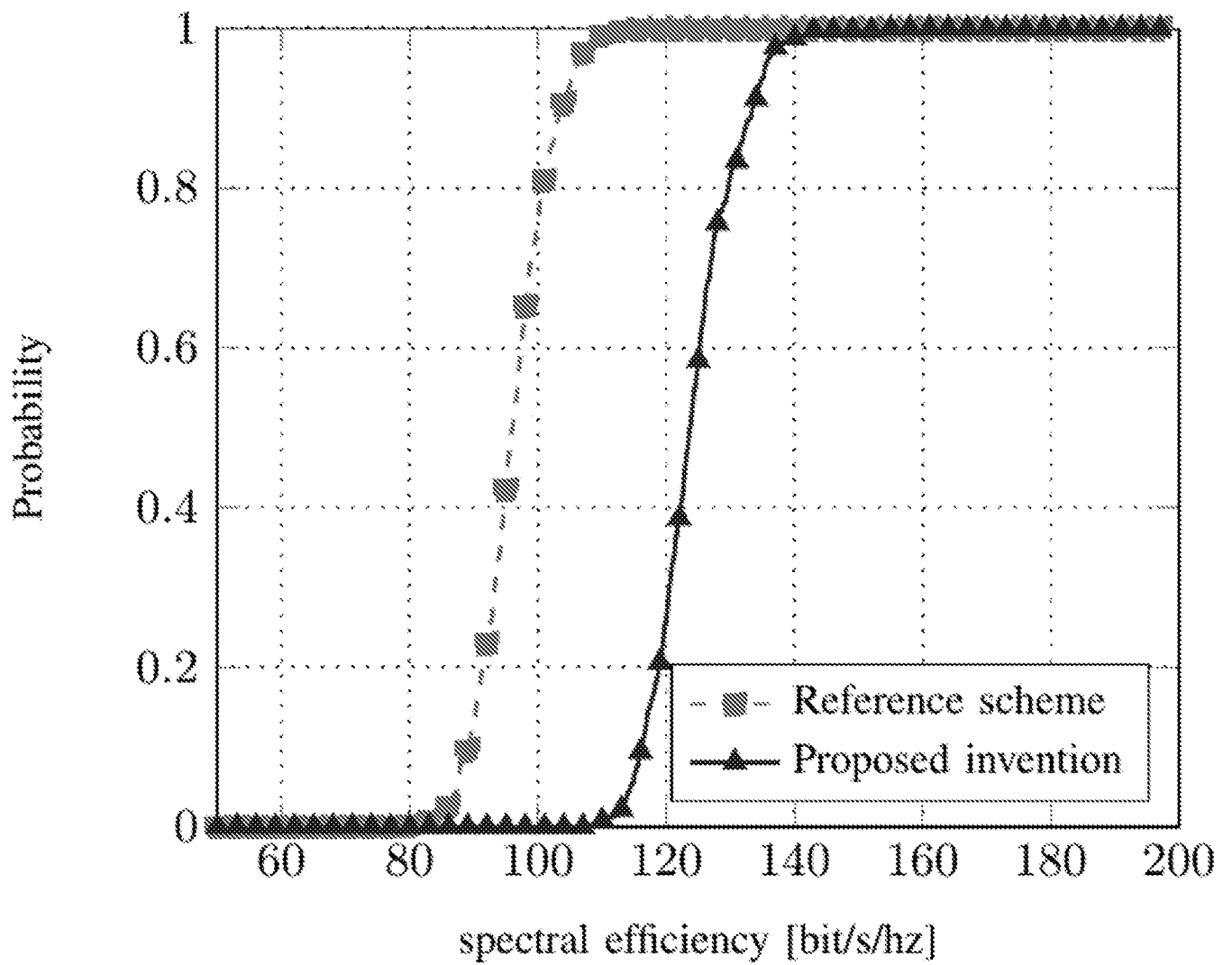


Figure 6

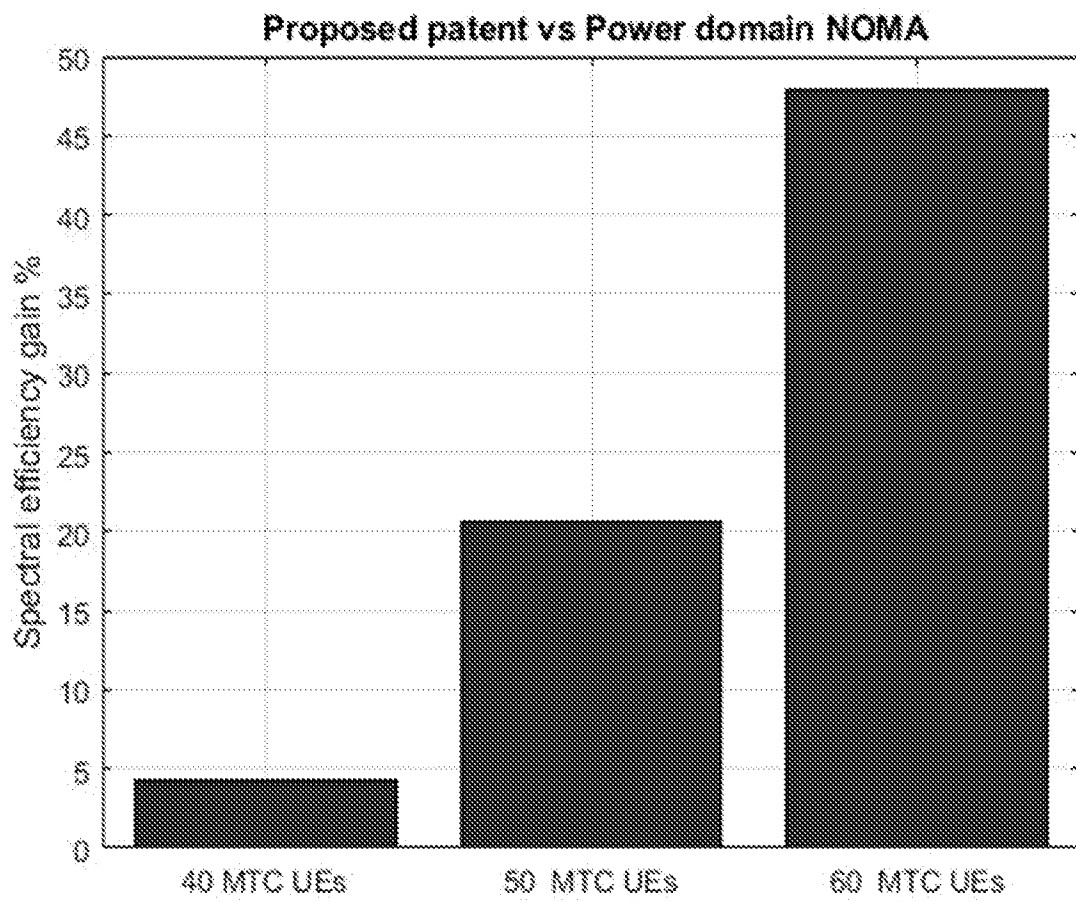


Figure 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2020/078574

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/06(2006.01)i; H04L 5/00(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)

H04B; H04L

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

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

CNKI,CNPAT,EPODOC,WPI,3GPP:CSI estimate, CSI feedback, CSI measurement, CSI report, MTC, UEs, uplink signal, UL slot, UL OFDM, PRB, eMBB,distinct, distinguish, training signals, pattern, DM-RS,DMRS,interleaver,sparse,non-orthogonal, NOMA

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CMCC. "Considerations on NoMA related procedures" <i>3GPP TSG RAN WG1 Meeting #94, R1-1811033</i> , 12 October 2018 (2018-10-12), sections 1-2	1-21
Y	NEC. "Discussion on NOMA Schemes for NR" <i>3GPP TSG RAN WG1 Meeting #94, R1-1808563</i> , 24 August 2018 (2018-08-24), sections 1-2	1-21
Y	CMCC. "Discussion on NoMA related procedures" <i>3GPP TSG RAN WG1 Meeting #94, R1-1808835</i> , 24 August 2018 (2018-08-24), sections 1-2	1-21
Y	HUAWEI et al. "Discussion on the design of SCMA" <i>3GPP TSG RAN WG1 Meeting #92bis, R1-1803663</i> , 20 April 2018 (2018-04-20), sections 1-2	1-21
Y	INTERDIGITAL INC. "Aspects of IDMA NOMA Transmitter" <i>3GPP TSG RAN WG1 #94, R1-1809083</i> , 24 August 2018 (2018-08-24), sections 1-2	1-21



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

07 May 2020

Date of mailing of the international search report

28 May 2020

Name and mailing address of the ISA/CN

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Telephone No. 86-(10)-53961600

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2020/078574**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2018084578 A1 (SAMSUNG ELECTRONICS CO., LTD.) 11 May 2018 (2018-05-11) the whole document	1-21

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2020/078574

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)		Publication date (day/month/year)	
WO	2018084578	A1	11 May 2018	EP	3491749	A1	05 June 2019
				KR	20180047891	A	10 May 2018
				CN	109845131	A	04 June 2019
				US	2018123668	A1	03 May 2018