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(54) Title: SIGNALING OF SEQUENCE GENERATOR INITIALIZATION PARAMETERS FOR UPLINK REFERENCE SIGNAL GENERATION

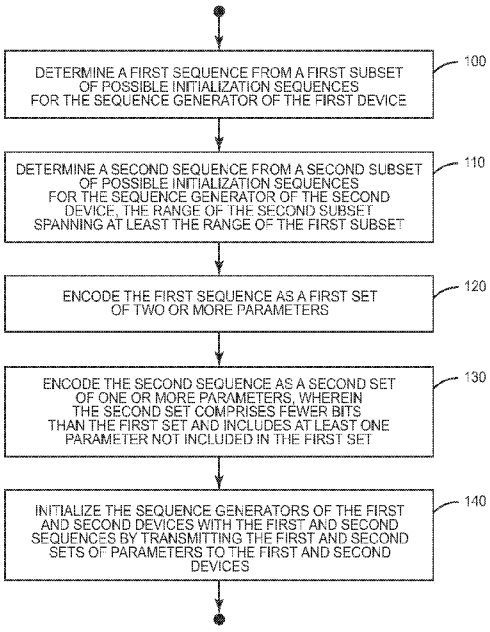

FIG. 2

(57) Abstract: A base station initializes pseudo-random sequence generators on which wireless devices base generation of uplink reference signals. The base station determines (100) a first sequence from a first subset of possible initialization sequences for a sequence generator of a first device, and determines (110) a second sequence from a second subset of possible initialization sequences for a sequence generator of a second device. The range of this second subset spans at least the range of the first subset. The base station further encode (120) the first sequence as a first set of two or more parameters, and encodes (130) the second sequence as a second set of one or more parameters. This second set includes at least one parameter not included in the first set, and comprises fewer bits than the first set. The base station initializes (140) the sequence generators by transmitting the first and second sets of parameters to the devices.

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SIGNALING OF SEQUENCE GENERATOR INITIALIZATION PARAMETERS FOR UPLINK REFERENCE SIGNAL GENERATION

TECHNICAL FIELD

[0001] The present invention generally relates to initialization of pseudo-random sequence generators on which wireless devices base generation of uplink reference signals, and more particularly relates to advantageous techniques for encoding and signaling parameters for such initialization.

BACKGROUND

[0002] A wireless device (also referred to as a user equipment, UE) transmits one or more uplink reference signals in a wireless communication system for any number of reasons, such as to permit the receiving base station to estimate the wireless channel. The wireless device typically generates a reference signal using one or more pseudo-random sequence generators. Accordingly, initialization of the sequence generator(s) with particular initialization sequence(s) dictates the uplink reference signal that the device transmits. The base station governs the initialization of the device's sequence generator(s) in this regard, meaning that signaling an initialization sequence to a wireless device presents challenges in terms of signaling overhead.

[0003] Consider, for instance, Long Term Evolution (LTE) networks. LTE networks are designed with the aim of enabling optional CoMP (Coordinated multipoint processing) techniques, where different sectors and/or cells operate in a coordinated way in terms of, e.g., scheduling and/or processing. An example is uplink (UL) CoMP where the signal originating from a single UE is typically received at multiple reception points and jointly processed in order to improve the link quality. UL joint processing (also referred to as UL CoMP) allows transformation of what is regarded as inter-cell interference in a traditional deployment into a useful signal. Therefore, LTE networks taking advantage of UL CoMP may be deployed with a smaller cell size compared to traditional deployments, in order to fully take advantage of the CoMP gains.

[0004] The LTE UL is designed assuming coherent processing, i.e., the receiver is assumed to be able to estimate the radio channel from the transmitting UE and to take advantage of such information in the detection phase. Therefore, each transmitting UE sends a reference signal

(RS) associated with each UL data or control channel (e.g., PUSCH and PUCCH). 3GPP TS 36.211 V10.4.0 (2011-12), "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 10)." In case of PUSCH, one demodulation reference signal (DMRS) per slot is transmitted on the same bandwidth as the uplink data channel. In case of PUCCH, multiple PUCCH-RSs are transmitted and time multiplexed by the UE within each subframe, spanning the PUCCH bandwidth assigned to the UE.

[0005] Additional RSs possibly transmitted by UEs consist of sounding reference signals (SRS). These reference signals are transmitted by a UE at predetermined time instances and over a predetermined bandwidth, in order to enable estimation of the UL channel properties at the network side.

[0006] RSs from different UEs within the same cell potentially interfere with each other and, assuming synchronized networks, even with RS originated by UEs in neighboring cells. In order to limit the level of interference between RSs, different techniques have been introduced in different LTE releases in order to allow orthogonal or semi-orthogonal RSs. The design principle of LTE assumes orthogonal RS within each cell and semi-orthogonal RS among different cells (even though orthogonal RSs can be achieved for aggregates of cells by so called "sequence planning"). However, orthogonality of DMRS transmitted by UEs belonging to different cell is currently under discussion in Rel-11 LTE standardization. A family of techniques for inter-cell DMRS orthogonality has been discussed. Some of these techniques rely on the possibility of coordinating the base-sequence index (BSI) employed for RS generation by different UEs in different cells, as described more fully later.

[0007] Another application in the UL of LTE is mutli-user, multiple-input multiple-output (MU-MIMO), where data transmissions on PUSCH from multiple UEs are coscheduled on at least partly overlapping bandwidth in the same subframe, within the same cell. The UEs are separated at the receiver side by exploiting multiantenna processing. In order to allow the receiver to resolve the signals from the coscheduled UEs, it is beneficial to assign the DMRS in an orthogonal fashion for such UEs. This may be achieved by assigning different orthogonal cover codes (OCCs) to the DMRS of the coscheduled UEs. If the coscheduled bandwidths are

fully overlapping, cyclic shift (CS) separation of the DMRS for the different UEs may also be exploited.

[0008] Each DMRS is characterized by a group-index and a sequence-index, which define the so called base-sequence index (BSI). BSIs are assigned in a cell-specific fashion in Rel-8/9/10 and they are a function of the cell-ID, where a cell-ID characterizes a cell in LTE and affects several cell-specific algorithms and procedures. Different base sequences are semi-orthogonal, which implies that some inter-sequence interference is present in the general case. The DMRS for a given UE is only transmitted on the same bandwidth of PUSCH and the base sequence is correspondingly generated so that the RS signal is a function of the PUSCH bandwidth. For each subframe, 2 RSs are transmitted, one per slot. In Rel-11 it is likely that UE-specific assignment of BSIs will be introduced.

[0009] Orthogonal DMRS can be achieved by use of cyclic shift (CS) in Rel-8/9 or by CS in conjunction with orthogonal OCC in Rel-10. CS is a method to achieve orthogonality based on cyclic time shifts, under certain propagation conditions, among RS generated from the same base sequence. Only 8 different CS values can be dynamically indexed in Rel-8/9/10, even though in practice less than 8 orthogonal DMRS can be achieved depending on channel propagation properties (without considering OCC in this example). Even though CS is effective in multiplexing DMRSs assigned to fully overlapping bandwidths, orthogonality is lost when the bandwidths differ and/or when the interfering UE employs another base sequence.

[0010] In order to increase interference randomization between different UEs (e.g., at different cells), a pseudo-random offset to the CS values is applied (CS hopping, CSH). The randomization pattern is cell-specific in Rel-8/9/10. A different CS offset is in general applied in each slot and it is known at both UE and eNB sides, so that it can be compensated at the receiver side during channel estimation. A CSH is generated according to a sequence initialization parameter c_{init} having 31 bits.

[0011] OCC is a multiplexing technique based on orthogonal time domain codes, operating on the 2 RS provided for each UL subframe. The OCC code [1 -1] is able to suppress an interfering DMRS as long as its contribution after the matched filter at the receiver is identical on

both DMRSs of the same subframe. Similarly, the OCC code [1 1] is able to suppress an interfering DMRS as long as its contribution after the eNB matched filter has opposite sign respectively on the two RSs of the same subframe. It is straightforward to assume that CS and OCC will be supported also by Rel-11 UEs.

[0012] While base-sequences are assigned in a semi-static fashion, CS and OCC are dynamically assigned as part of the scheduling grant for each UL PUSCH transmission. Even though joint processing techniques may be applied for PUSCH, channel estimates based on DMRS are typically performed in an independent fashion at each reception point, even in case of UL CoMP. Therefore, it is crucial to keep the interference level at an acceptably low level, especially for RSs.

[0013] In case of SRS, the RSs are also generated according to a BSI (which may differ from the DMRS BSI for some UEs). Different SRS may be multiplexed by use of CS and COMBs. A COMB indicates a specific interleaved mapping of the RS to a subset of subcarriers. SRS assigned to different COMBS (i.e., non overlapping sets of subcarriers) are thus ideally orthogonal.

[0014] In case of PUCCH-RS, one or more RS per slot are generated, depending on the PUCCH format and other parameters. PUCCH-RS for different UEs are separated by use of CS and OCC, which spans over each slot. Also PUCCH-RS are generated according to a BSI that may in general differ from the DMRS BSI.

[0015] One of the improvements being discussed in LTE Rel-11 consists of the possibility of configuring the parameters for BSI and CSH initialization in a UE specific fashion, either semi-statically or dynamically, e.g., by signaling in the scheduling grants. Such configurability allows additional RS allocations options enabling, e.g., inter-cell orthogonality between UEs. R1-121028 – “Details about UL DMRS configuration and signaling.” In order to achieve orthogonality by OCC, it is necessary to configure the paired UEs with the same CSH pattern. Problematically, however, the CSH initialization c_{init} is a 31 bit parameter, requiring significant overhead for being signaled.

SUMMARY

[0016] One or more embodiments herein advantageously reduce control signaling between a base station and a wireless device in a wireless communication system, as compared to known control signaling approaches. The embodiments in particular reduce the control signaling for initializing pseudo-random sequence generators on which wireless devices base generation of uplink reference signals.

[0017] More particularly, one or more embodiments include a base station configured to initialize pseudo-random sequence generators on which wireless devices base generation of uplink reference signals. The base station is configured to determine a first sequence from a first subset of possible initialization sequences for a pseudo-random sequence generator of a first wireless device, and to determine a second sequence from a second subset of possible initialization sequences for a pseudo-random sequence generator of a second wireless device. The range of this second subset spans at least the range of the first subset.

[0018] The base station further encodes the first sequence as a first set of two or more parameters, and encodes the second sequence as a second set of one or more parameters. This second set of parameters includes at least one parameter not included in the first set of parameters, and comprises fewer bits than the first set. Having performed this encoding, processing the base station initializes the sequence generators of the first and second devices with the first and second sequences by transmitting the first and second sets of parameters to the first and second devices. Upon receiving the sets of parameters, the devices decode the sequences according to one or more rules that define the sequences as a function of those sets of parameters and then generate the uplink reference signals based on those sequences.

[0019] In at least some embodiments, the base station encodes the second sequence as a single parameter. In one embodiment, for example, this single parameter comprises a defined number of least significant bits from the second sequence corresponding to the range of the second subset. In another embodiment, by contrast, the second sequence is encoded based on a defined one-to-one mapping of possible initialization sequences within the second subset to possible values for the single parameter, wherein the range of the single parameter is smaller than the range of the second subset.

[0020] In other embodiments, the base station encodes the second sequence as a linear combination of two parameters. In this case, a first one of the two parameters encodes a defined number of least significant bits from the second sequence, and a second one of the two parameters encodes a defined number of more significant bits from the second sequence (not including one or more most significant bits from the second sequence).

[0021] In any case, the second sequence is encoded as a second set of parameters that comprises only 9 or 10 bits in some embodiments, which is significantly fewer bits than the 31 bits required to signal the second sequence itself in those embodiments. The embodiments thereby prove to reduce control signaling associated with the signaling of the second sequence.

[0022] In one or more embodiments where the initialization sequences correspond to cyclic shift hopping patterns for the devices, the first initialization sequence comprises a cell-specific sequence and the second initialization sequence comprises a device-specific sequence. The base station initializes the sequence generators in this way in order to maintain backwards compatibility with respect to the first device, while achieving inter-cell orthogonality for the second device with respect to a third wireless device in a different cell. Where the embodiments employ LTE, for example, the first and third devices comprise legacy devices that are configured for LTE Rel-8/9/10, and the second device comprises a newer device that is configured for LTE Rel-11.

[0023] In this case, the base station determines the second sequence for the second device by selecting from the second subset the initialization sequence that matches the initialization sequence for a pseudo-random sequence generator of the third device. The base station is able to do this because the range of the second subset spans at least the range of the subset of possible initialization sequences for the third device; that is, the initialization sequence for the second device is able to take on values that are possible for the third device. With the initialization sequences (and therefore the cyclic shift hopping patterns) for the second and third devices the same, the base station is able to achieve inter-cell orthogonality for these paired devices through use of different orthogonal cover codes (OCCs) for the devices. Notably, therefore, by configuring the initialization sequences in this way, the base station is able to arbitrarily pair a newer device in one cell with any legacy device in a different cell for achieving

inter-cell orthogonality between those devices' uplink reference signals.

[0024] Of course, the present invention is not limited to the above features and advantages. Indeed, those skilled in the art will recognize additional features and advantages upon reading the following detailed description, and upon viewing the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Figure 1 is a block diagram of a wireless communication system with a base station and a wireless device configured according to one or more embodiments herein for sequence generator initialization.

[0026] Figure 2 is a logic flow diagram of processing performed by a base station for initializing pseudo-random sequence generators according to one or more embodiments herein.

[0027] Figure 3 illustrates an example of a base station's encoding of initialization sequences for different wireless devices according to one or more embodiments.

[0028] Figure 4 is a logic flow diagram of processing performed by a base station for initializing pseudo-random sequence generators according to one or more other embodiments herein.

[0029] Figure 5 is a table that illustrates an example one-to-one mapping between the decimal representation of possible initialization sequences and possible values for a single parameter according to one or more embodiments.

[0030] Figures 6A-6B are tables that illustrate different examples of joint encoding according to one or more embodiments.

[0031] Figure 7 is a logic flow diagram of processing performed by a wireless device for initializing a pseudo-random sequence generator according to one or more embodiments herein.

[0032] Figure 8 is a table that illustrates an example one-to-one mapping between the decimal representation of possible initialization sequences and possible values for a set of parameters according to one or more embodiments.

[0033] Figure 9 is a block diagram that illustrates a wireless device configured to initialize a pseudo-random sequence generator according to one or more embodiments herein.

[0034] Figure 10 is a block diagram that illustrates a base station configured to initialize

pseudo-random sequence generators according to one or more embodiments herein.

DETAILED DESCRIPTION

[0035] Figure 1 depicts a wireless communication system 10 according to one or more embodiments. The system 10 includes a radio access network (RAN) that comprises a plurality of geographically distributed base stations 12-1, 12-2,... 12-N. The base stations 12-1, 12-2,... 12-N (referred to collectively as base stations 12) provide wireless communication coverage to wireless devices 16-1, 16-2,... 16-M within respective areas referred to as cells 14-1, 14-2,... 14-N. Through the base stations 12, the wireless devices 16 access a core network 18, which in turn connects the devices 16 to one or more external networks 20, e.g., the Internet.

[0036] The wireless devices 16 transmit respective uplink reference signals 22 to the base stations 12. The base stations 12 employ the uplink reference signals for various reasons, such as to estimate the respective wireless channels between the base stations 12 and the devices 16. The uplink reference signals may comprise, for instance, demodulation reference signals (DMRS) that the base stations 12 use to demodulate uplink data and/or control signals, sounding reference signals (SRSs), or the like. Regardless, the devices 16 employ pseudo-random sequence generators in order to generate these uplink reference signals 22. Any given device 16-m may, for example, employ two sequence generators to generate two maximal-length sequences and then modulo-2 add those sequences to form a Gold sequence on which an uplink reference signal 22 for the device 16 is based. This Gold sequence in some embodiments, for instance, dictates a cyclic shift hopping (CSH) pattern that the device 16 applies to a cyclic shift and then applies the resulting cyclic shift to a base sequence in order to generate the uplink reference signal 22.

[0037] A base station 12-n governs the uplink reference signal 22-m that any given device 16-m transmits by, among other things, governing initialization of one or more of the device's pseudo-random sequence generators. In this regard, a base station 12-n initializes a device's sequence generator by informing the device of an initialization sequence to which the generator is to be initialized, such as an initialization sequence represented in decimal form c_{init} in LTE

embodiments. In some embodiments, a base station 12-n initializes different devices' sequence generators with different (i.e., device-specific) initialization sequences, e.g., to distinguish the devices' uplink reference signals 22 on that basis. In other embodiments, though, a base station 12-n initializes different devices' sequence generators with a common (e.g., cell-specific) initialization sequence, while distinguishing the devices' uplink reference signals 22 on other bases. In still other embodiments, the a base station 12-n initializes some devices' sequence generators with device-specific sequences, and other devices' sequence generators with cell-specific sequences. Regardless, a base station 12-n herein advantageously encodes initialization sequences for at least some devices 16 in different ways, so as to reduce the amount of control signaling required for indicating those sequences as compared to known approaches.

[0038] Figure 2 illustrates base station processing according to one or more embodiments in this regard, with reference to base station 12-1, wireless device 16-1, and wireless device 16-2 as an example. Wireless devices 16-1 and 16-2 need not be present within the base station's cell 14-1 at the same time in order for the base station 12-1 to perform the processing illustrated in Figure 2. Indeed, as described below, the base station 12-1 determines, encodes, and signals an initialization sequence for device 16-1 independently from its determination, encoding, and signaling of an initialization sequence for device 16-2. Such remains the case regardless of whether or not the same initialization sequence is determined for the devices 16-1, 16-2 (e.g., where the sequence is cell-specific) and regardless of whether or not the initialization sequences for the devices 16-1, 16-2 are encoded using at least one common parameter. This independent processing means that the base station 12-1 may be configured in at least some embodiments to determine, encode, and signal an initialization sequence for device 16-1 at a different time than its determination, encoding, and signaling of an initialization sequence for device 16-2.

[0039] With this in mind, processing implemented by base station 12-1 in Figure 2 includes determining a first sequence from a first subset of possible initialization sequences for a pseudo-random sequence generator of a first wireless device 16-1 (Block 100). Processing further includes determining a second sequence from a second subset of possible initialization

sequences for a pseudo-random sequence generator of a second wireless device 16-2 (Block 110). The range of this second subset of possible sequences spans at least the range of the first subset of possible sequences. Determining a sequence in this way may involve computing the sequence, obtaining the sequence from memory, or acquiring the sequence in some other fashion, and may comprise determining a cell-specific sequence employed by another cell (e.g., cell 14-2).

[0040] Regardless of how these sequences are determined, processing at base station 12-1 also entails encoding the first sequence as a first set of two or more parameters (Block 120), and encoding the second sequence as a second set of one or more parameters (Block 130). This second set of parameters includes at least one parameter not included in the first set of parameters, and comprises fewer bits than the first set. That is, the initialization sequence for the second device 16-2 is encoded with fewer bits than the initialization sequence for the first device 16-1, even though the range of possible initialization sequences to be signaled to the second device 16-2 (i.e., the range of the second subset) spans at least the range of possible initialization sequences to be signaled to the first device 16-1 (i.e., the range of the first subset). Having performed this encoding, processing at the base station 12-1 finally includes initializing the sequence generators of the first and second devices 16-1, 16-2 with the first and second sequences by transmitting the first and second sets of parameters to the first and second devices 16-1, 16-2 (Block 140). As mentioned above, such initialization and transmission may be performed independently and at different times for the different devices 16-1, 16-2.

[0041] Upon receiving the first set of parameters, the first device 16-1 decodes the first sequence according to one or more rules that define the sequence as a function of the first set of parameters and then generates the uplink reference signal with the device's sequence generator initialized to that sequence. When the first device 16-1 transmits the uplink reference signal to the base station 12-1, the base station 12-1 employs the first set of parameters in order to estimate the wireless communication channel to the first device 16-1 based on the uplink reference signal. Likewise, upon receiving the second set of parameters, the second device 16-2 decodes the second sequence according to one or more rules that define the sequence as a function of the second set of parameters and then generates the uplink reference signal with the

device's sequence generator initialized to that sequence. When the second device 16-2 transmits the uplink reference signal to the base station 12-1, the base station 12-1 employs the second set of parameters in order to estimate the wireless communication channel to the second device 16-2 based on the uplink reference signal.

[0042] Figure 3 illustrates a pictorial representation of one simple example of the base station processing. (This simple example, however, is non-limiting in terms of the number of bits used and the position of the subsets). As shown in Figure 3, the sequence generator of a first wireless device 16-1 comprises 31 bits (labeled 0 through 30 from the least significant bit). Thus, a full set 24-1 of possible initialization sequences for the sequence generator of the first device 16-1 at least nominally includes sequence '000….000' to sequence '111…111' (i.e., a decimal range from 2^0 to 2^{30}). The same can be said for a full set 24-2 of possible initialization sequences for the sequence generator of the second device 16-2 in this example.

[0043] Despite the nominal possibilities provided by the full sets 24-1, 24-2 of initialization sequences, though, the base station 12-1 excludes some of those possibilities from consideration in determining the actual initialization sequences for the devices 16-1, 16-2, so as to thereby artificially limit the initialization sequences to be signaled. Specifically, the base station 12-1 determines a first sequence 26-1 for the first device 16-1 from only a subset 28-1 of possible initialization sequences, and determines a second sequences 26-2 for the second device 16-2 from only a subset 28-2 of possible initialization sequences. As shown, the possible sequences within these subsets 28-1, 28-2 still comprise 31 bits; that is the number of bits corresponding to the range of the full sets 24-1, 24-2 of possible sequences. However, the sequences within the subsets 28-1, 28-2 have 0's for the 21 most significant bits, meaning that the ranges 30-1, 30-2 of the subsets 28-1, 28-2 are represented by only the 10 least significant bits. In this case, the range 30-2 of the second subset 28-2 spans the same range as the range 30-1 of the first subset 28-1. In general, though, the range 30-2 of the second subset 28-2 may span a greater range than the range 30-1 of the first subset 28-1 (e.g., decimal 1023 vs. 541), even if the two subsets 28-1, 28-2 are represented by the same number of bits.

[0044] Regardless, the base station 12-1 encodes the first sequence 26-1 for the first device

16-1 differently than the way it encodes the second sequence 26-2 for the second device 16-2. In some embodiments, for instance, the first and second devices 16-1, 16-2 are different types or models of devices and are therefore configured to decode the sequences 26-1, 26-2 in different ways. The first device 16-1 in one example comprises a legacy device that is configured for LTE Rel-8/9/10 and the second device 16-2 comprises a newer device that is configured for LTE Rel-11. As explained in greater detail below, because the range 30-2 of the second subset 28-2 spans at least as great as range as the range 30-1 of the first subset 28-1, the base station 12-1 is advantageously able in this case to allocate the same initialization sequence to a legacy device and a new device, but to signal the initialization sequence to the new device in a more efficient manner.

[0045] In any event, the base station 12-1 encodes the first sequence 26-1 as a first set 32-1 of two or more parameters, and encodes the second sequence 26-2 as a second set 32-2 of one or more parameters. The encoding of the second sequence 26-2 is optimized with respect to the encoding of the first sequence 26-1 at least in the sense that the second set 32-2 comprises fewer bits than the first set 32-1, even though the second set 32-2 is capable of representing at least as great of range of possible initialization sequences as the first set 32-1. These sets 32-1, 32-2 of parameters are then signaled to the wireless devices 16-1, 16-2 rather than the actual initialization sequences 26-1, 26-2. Each set 32-1, 32-2 of parameters requires fewer bits to signal than that required to signal the 31 bit sequences 26-1, 26-2 themselves, meaning that the encoding advantageously reduces the amount of control signaling required to indicate the sequences 26-1, 26-2 to the devices 16-1, 16-2.

[0046] In some embodiments, the second sequence 26-2 is encoded as a single parameter z, while the first sequence 26-1 is encoded as two or more parameters. That is, the second set 32-2 has only one parameter, namely z, even though the first set 32-1 has more than one parameter.

[0047] Figure 4 depicts processing at the base station 12-1 with particular regard to this single parameter encoding. As shown in Figure 4, processing at the base station 12-1 entails determining a sequence 26-2 from a subset 28-2 of possible initialization sequences for the sequence generator of a wireless device 16-2 (Block 200). Processing then includes encoding

the determined sequence 26-2 as a single parameter z (Block 210). Different values for this single parameter z represent different possible initialization sequences within the subset 28-2. Processing finally includes initializing the sequence generator fo the wireless device 16-2 with the determined sequence 26-2 by transmitting the single parameter z to the device 16-2 (Block 220).

[0048] In at least one embodiment, the single parameter z comprises a defined number of least significant bits from the second sequence 26-2, where the defined number corresponds to the range 30-2 of the second subset 28-2. In the example of Figure 3, this single parameter z would therefore comprise the 10 least significant bits of the second sequence 26-2. Regardless, in this embodiment, the base station 12-1's encoding entails truncating a defined number of most significant bits of the second sequence 26-2 (e.g., the 21 most significant bits, namely bits 10 to 30), since those bits are 0's in all possible sequences within the second subset 28-2. The second device 16-2 will perform a decoding that pads the single parameter z with 0's, e.g., by pre-pending 0's to the single parameter z. Those skilled in the art will appreciate, however, that padding may be performed by the second device 16-2 in different ways in other embodiments. For example, in some embodiments the second device16-2 pads the single parameter z by appending 0's to that parameter.

[0049] In at least one other embodiment, the second sequence 26-2 is encoded based on a defined one-to-one mapping of possible initialization sequences within the second subset 30-2 to possible values for the single parameter z. Notably, though, the range of the single parameter z is smaller than the range 30-2 of the second subset 28-2. The defined mapping in this sense effectively compresses the range 30-2 of the second subset 28-2 into the single parameter z so as to signal the second sequence 26-2 with fewer bits.

[0050] Figure 5 illustrates an example defined mapping in the context of an LTE embodiment where the second sequence 26-2 selected from the second subset 28-2 is represented as c_{init}, which is a decimal representation of the second sequence 26-2. As shown in Figure 4, the subset 28-2 of possible initialization sequences c_{init} is sparse in the sense that it does not include all initialization sequences within the subset's range 30-2. For example, the

subset 28-2 does not include c_{init} values of 30, 31, 62, 63, 94, 95, and so forth, even though the subset's range 30-2 spans from c_{init} values of 0 to 541. The defined mapping maps those possible initialization sequences c_{init} within the subset 28-2 to possible values for the single parameter z (here, shown as a decimal representation), so that z is not sparse. According to the mapping, the initialization sequences $c_{\text{init}} = 32$ is encoded as $z = 30$, $c_{\text{init}} = 33$ is encoded as $z = 31$, $c_{\text{init}} = 64$ is encoded as $z = 60$, $c_{\text{init}} = 65$ is encoded as $z = 61$, and so forth. Due to the nature of this mapping, the {0,541} range 30-2 of the second subset 28-2 of possible initialization sequences c_{init} is compressed into a {0,509} range of the single parameter z. Notably, therefore, signaling of the single parameter z requires 9 bits, which is 1 fewer bit to signal than the 10 bits that would be required to signal the parameter z as described above without this compression.

[0051] Figure 5 of course illustrates the defined mapping as being a look-up table that is obtained by the base station 12-1 for encoding. The base station 12-1 in some embodiments obtains the table from memory, while in other embodiments the base station 12-1 obtains the table by generating it on an as needed basis, according to a predefined formula. In either case, the base station 12-1 selects the second sequence 26-2 c_{init} from the second subset 28-2 and then determines the parameter z that corresponds to the selected sequence c_{init} in the look-up table.

[0052] In other embodiments, the mapping is embodied in ways other than a look-up table. In one embodiment, for example, the defined mapping exists as an algorithm or formula used by the base station 12-1 for encoding. Specifically, the base station 12-1 encodes the selected initialization sequence c_{init} as the single parameter $z = c_{init} - 2\left\lfloor \frac{c_{init}}{32} \right\rfloor$, where $\lfloor x \rfloor$ denotes a floor function that rounds x to the nearest integer less than or equal to x.

[0053] Furthermore, although Figure 5 illustrates the single parameter z as if it has the minimum range needed for compressing the range of the second subset 28-2 of possible initialization sequences c_{init}, this need not be the case. Consider, for example, embodiments

where the second sequence 26-2 c_{init} corresponds to a CSH that the device 16-2 applies to a cyclic shift for generating the uplink reference signal 22-2. In one or more embodiments in this case, the base station 12-1 jointly encodes the second sequence 26-2 c_{init} and an indication of whether or not CSH is enabled as the second set 32-2 of one or more parameters. Thus, where the second set 32-2 of parameters just includes the single parameter z, the range of z is extended in order to indicate whether or not CSH is enabled.

[0054] Figures 6A-6B illustrate two different examples of this. In both examples, the base station 12-1 performs joint encoding such that the single parameter z not only indicates the second sequence 26-2 c_{init} as described above, but also indicates a flag called CSH_ENABLE. If CSH_ENABLE = 1, CSH is enabled. If CSH_ENABEL = 0, CSH is not enabled.

[0055] According to the joint encoding in Figure 6A, the base station 12-1 performs joint encoding such that the single parameter z indicates that CSH_ENABLE = 1 if the parameter z has a decimal value between 0 and 509. These possible values of z similarly map to possible initialization sequences c_{init}, as shown in Figure 5, meaning that the joint encoding also indicates the initialization sequence c_{init} to be used when CSH_ENABLE = 1. By contrast, if the parameter z has any other decimal value, the parameter z indicates that CSH_ENABLE = 0. With CSH disabled in this case, the initialization sequences c_{init} is not defined, or at least is not relevant.

[0056] Although Figure 6A contemplates that one or more values of the single parameter z (jointly or individually) indicate that CSH is disabled, Figure 6B more specifically shows a single value (i.e., z =511) as indicating that CSH is disabled. Indicating CSH_ENABLE with only a single value of the parameter z proves simpler in practice, and also allows for the signaling of additional information other than the initialization sequence c_{init} and CSH_ENABLE. Of course, embodiments that only utilize 512 values for the parameter z prove advantageous for signaling z with only 9 bits, rather than 10 bits for embodiments that utilize more than 512 values for z.

[0057] Regardless of whether or not such joint encoding is employed, though, the second wireless device 16-2 herein is configured to receive the single parameter z from the base

station 12-1 and to initialize a pseudo-random sequence generator on which to base uplink reference signal generation according to that single parameter z. Figure 7 illustrates processing that the device 16-2 performs in this regard.

[0058] As shown in Figure 7, processing at the device 16-2 entails selectively deriving one of the second initialization sequences 26-2 within the second subset 28-2 of possible initialization sequences for the sequence generator, according to one or more rules that define different initialization sequences in the subset 28-2 as a function of the single parameter z (Block 300). Processing further includes generating the uplink reference signal 22-2 with the sequence generator initialized to the derived initialization sequence 26-2 (Block 310), and transmitting the generated signal 22-2 (Block 320).

[0059] In embodiments where the base station 12-1 has encoded the second initialization sequence 26-2 to be a single parameter z that comprises a defined number of least significant bits from the second sequence 26-2, the wireless device's derivation entails padding the single parameter z with a defined number of zeroes. In some embodiments, this padding involves appending the defined number of zeroes to the single parameter z. In other embodiments, though, padding includes pre-pending the defined number of zeroes to the single parameter z. In this case, the device 16-2 effectively derives a second sequence 26-2 that has its most significant bits padded with zeroes.

[0060] By contrast, in embodiments where the base station 12-1 has encoded the second initialization sequence 26-2 according to a defined one-to-one mapping with the single parameter z (e.g., as in Figure 5), the device 16-2 derives the sequence 26-2 based on that same mapping. In some embodiments, for example, the device 16-2 stores the look-up table of Figure 5 in memory and references that table to map the received parameter z to the second initialization sequence 26-2 c_{init}. Such may entail converting the decimal representation of c_{init} into a corresponding binary representation. In other embodiments, the device 16-2 derives the second initialization sequence 26-2 c_{init} according to an algorithm or formula that is the counterpart to that used by the base station 12-1 to encode the sequence 26-2. For example,

the device 16-2 derives the sequence 26-2 c_{init} according to $c_{init} = z + 2\left\lfloor \frac{z}{30} \right\rfloor$.

[0061] In embodiments where the sequence 26-2 c_{init} corresponds to a CSH pattern, the device 16-2 generates the uplink reference signal 22-2 by determining the CSH pattern from the derived sequence 26-2. The device 16-2 then applies the CSH pattern to a cyclic shift, and finally applies the resulting cyclic shift to a base sequence to generate the uplink reference signal 22-2. Of course, where the single parameter z jointly encodes the sequence 26-2 as well as CSH_ENABLE, the device 16-2 derives CSH_ENABLE according to one or more rules that define CSH_ENABLE as a function of the parameter z, and then selectively determine and apply a CSH pattern depending on CSH_ENABLE.

[0062] Although embodiments illustrated with respect to Figures 5-7 show the second sequence 26-2 encoded as a single parameter z, other embodiments herein encode the second sequence 26-2 as a linear combination of two parameters x, y; that is, instead of the second set 32-2 of parameters in Figure 3 comprising only a single parameter z, the second set 32-2 comprises two parameters x, y. In this case, parameter y encodes a defined number of least significant bits from the second sequence 26-2. Parameter x encodes a defined number of more significant bits from the second sequence 26-2, not including one or more most significant bits from the second sequence 26-2, i.e., those defined number (e.g., 21) of most significant bits that are 0's. Figure 8 illustrates an example of this where a look-up table embodies the linear combination of x, y.

[0063] As shown in Figure 8, the look-up table maps the linear combination of $x = 0$ and $y = \{0,1,...29\}$ to possible initialization sequences $c_{\text{init}} = \{0,1,...29\}$. Similarly, the table maps the linear combination of $x = 1$ and $y = \{0,1,...29\}$ to possible initialization sequences $c_{\text{init}} = \{32,33,...61\}$, and so forth up. With the range of x being {0,16} and the range of y being {0,29}, the second sequence 26-2 is encoded with 10 bits, including 5 bits for x and 5 bits for y.

[0064] Figure 8 of course illustrates the defined mapping as being a look-up table that is

obtained by the base station 12-1 for encoding. The base station 12-1 in some embodiments obtains the table from memory, while in other embodiments the base station 12-1 obtains the table by generating it on an as needed basis, according to a predefined formula. In either case, the base station 12-1 selects the second sequence 26-2 c_{init} from the second subset 28-2 and then determines the parameters x, y that correspond to the selected sequence c_{init} in the look-up table. The device 16-2 receives these parameters x, y and correspondingly derives the second sequence 26-2 according to this same mapping.

[0065] In other embodiments, the mapping is embodied in ways other than a look-up table. In one embodiment, for example, the defined mapping exists as an algorithm or formula used by the base station 12-1 for encoding and by the device 16-2 for decoding. Specifically, the base station 12-1 encodes the selected initialization sequence c_{init} as the parameters x, y, and the device 16-2 decodes the sequence c_{init} as a function of the parameters x, y, according to $c_{\text{init}} = 32x + y$.

[0066] As briefly mentioned above, the base station 12-1 in some embodiments initializes the sequence generators for the different devices 16-1, 16-2 with a common initialization sequence. Thus, in this case, the base station 12-1 selects the first and second sequences 26-1, 26-2 so that they are the same. In some embodiments, the initialization sequence selected is a common sequence because it is common among at least some of the devices 16 in the cell 14-1. For example, the initialization sequence selected, and the subsequent encoding thereof, depends on a physical cell identity for the cell 14-1.

[0067] Where such embodiments employ LTE, for instance, the base station 12-1 determines the decimal representation of the first and second initialization sequence 26-1, 26-2 according to $c_{\text{init}} = \left\lfloor \frac{N_{\text{ID}}^{\text{cell}}}{30} \right\rfloor \cdot 2^5 + f_{\text{ss}}^{\text{PUSCH}}$, where $N_{\text{ID}}^{\text{cell}}$ is the physical cell identity for cell 14-1 and takes on 504 different integer values, and $f_{\text{ss}}^{\text{PUSCH}}$ is the sequence-shift pattern for PUSCH that takes on 30 different integer values {0,29}. Hence, it can be seen that the range for c_{init} is {0,541}. The base station 12-1 encodes the first initialization sequence 26-1 for the first device

16-1 as a set 32-1 of parameters that simply includes $N_{\mathrm{ID}}^{\mathrm{cell}}$ and $f_{\mathrm{ss}}^{\mathrm{PUSCH}}$. Even though the second initialization sequence 26-2 for the second device 16-2 is the same as the first sequence 26-1, the base station 12-1 encodes that second sequence 26-2 differently, according to any of the embodiments described above. The base station 12-1 may for instance encode the second sequence 26-2 as the single parameter z (either directly as the 10 least significant digits of the sequence, or by mapping the sequence to the parameter z), or encode the second sequence 26-2 as the parameters x, y, where $x = \left\lfloor \frac{N_{\mathrm{ID}}^{\mathrm{cell}}}{30} \right\rfloor$ and $y = f_{\mathrm{ss}}^{\mathrm{PUSCH}}$.

[0068] In other embodiments, the base station 12-1 initializes the sequence generators for the different devices 16-1, 16-2 with different sequences that are device-specific. In this case, the base station 12-1 determines the initialization sequences 26-1, 26-2 based on at least one parameter that is device-specific. In at least some embodiments, the base station 12-1 determines the sequences 26-1, 26-2 without regard to the physical cell identity.

[0069] In still other embodiments, the base station 12-1 initializes the sequence generator for the first device 16-1 with a cell-specific sequence, but initializes the sequence generator for the second device 16-2 with a device-specific sequence. Where the embodiments employ LTE, for instance, the base station 12-1 encodes the first initialization sequence 26-1 for the first device 16-1 as a set 32-1 of parameters that simply includes $N_{\mathrm{ID}}^{\mathrm{cell}}$ and $f_{\mathrm{ss}}^{\mathrm{PUSCH}}$. By contrast, the base station-12 determines the second initialization sequence 26-2 for the second device 16-2 without regard to $N_{\mathrm{ID}}^{\mathrm{cell}}$ and then encodes the second sequence 26-2 as the single parameter z, or encodes the second sequence 26-2 as the parameters x, y, where those parameters do not depend on $N_{\mathrm{ID}}^{\mathrm{cell}}$.

[0070] In at least some of these embodiments, the base station 12-1 initializes the sequence generators in this way (i.e., in a cell-specific manner for the first device 16-1 and in a device-specific manner for the second device 16-2) in order to maintain backwards compatibility with respect to the first device 16-1, while achieving inter-cell orthogonality for the second device 16-2 with respect to a third wireless device 16-3 in a different cell 14-2. Where the

embodiments employ LTE, for example, the first device 16-1 comprises a legacy device that is configured for LTE Rel-8/9/10 and the second device 16-2 comprises a newer device that is configured for LTE Rel-11.

[0071] In some embodiments, the third device 16-3 is a legacy device. In this case, the base station 12-1 determines the second sequence 26-2 for the second device 16-2 by selecting from the second subset 28-2 the initialization sequence that matches the initialization sequence for a pseudo-random sequence generator of the third device 28-1. The base station 12-1 is able to do this because the range of the second subset 28-2 spans at least the range of the subset of possible initialization sequences for the third device 16-3; that is, the initialization sequence for the second device 16-1 is able to take on values that are possible for the third device 16-3. With the initialization sequences for the second and third devices 16-2, 16-3 the same, the base station 12-1 is able to achieve inter-cell orthogonality for these paired devices 16-2, 16-3 through use of different orthogonal cover codes (OCCs) for the devices. Notably, therefore, by configuring the initialization sequences in this way, the base station 12-1 is able to arbitrarily pair a newer device 16-2 in cell 14-1 with any legacy device 16-3 in a different cell 14-2 for achieving inter-cell orthogonality between those devices' uplink reference signals 22-2, 22-3.

[0072] In the above embodiment, the base station 12-1 may receive the initialization sequence for the third device 16-3 from the base station 12-2 serving cell 14-2. Alternatively, the base station 12-1 may otherwise obtain that sequence, such as through knowledge of $N_{\mathrm{ID}}^{\mathrm{cell}}$ for cell 14-2 in embodiments wherein the sequence for the third device 16-3 is cell-specific. Of course, the base station 12-1 may pair a newer device 16-1 in cell 14-1 with newer devices in a different cell 14-2 in analogous manner.

[0073] Those skilled in the art will appreciate that while the above embodiments were illustrated with particular values, the embodiments are not limited in this respect. For example, although the second set 32-2 of parameters was described as being 9 or 10 bits, and the second sequence 26-2 as being 31 bits, other bit sizes are possible. Likewise, while the ranges of the first and second subsets 28-1, 28-2 were described as spanning between a minimum value of 0 and a maximum value no greater than 541, other ranges are possible.

[0074] Furthermore, those skilled in the art will appreciate that although terminology from 3GPP LTE-Advanced has been used to describe embodiments herein, this should not be seen as limiting the scope of the invention to only the aforementioned system. Other wireless systems, including WCDMA, WiMax, UMB and GSM, may also benefit from exploiting the techniques herein.

[0075] Also note that terminology such as base station and wireless device (e.g., UE) should be considering non-limiting and does in particular not imply a certain hierarchical relation between the two; in general "base station" could be considered as device 1 and "UE" device 2, and these two devices communicate with each other over some radio channel.

[0076] Although the above embodiments focused on the UL of an LTE Rel-11 network, other embodiments may be applied even to the DL and to other communication protocols.

[0077] In view of the above modifications and variations, those skilled in the art will appreciate that Figure 9 illustrates an example wireless device 16-2 configured according to one or more embodiments herein. As shown in Figure 9, the wireless device 16-2 is at least logically divided into an application processor 46 that runs user-oriented functions (software applications, user interface control, etc.) and an access processor 48 that implements the air interface protocols, including any encryption and authentication processing needed for network access and subscriber accounting via transceiver circuits 42 and antenna(s) 40.

[0078] In general, the wireless device 16-2 includes one or more processing circuits 44, such as microprocessors, digital signal processors, or other digital processors, and associated memory or other computer-readable media, for storing, e.g., a computer program the execution of which configures the device 16-2 according to the teachings herein. In particular, the device 16-2 includes a processing circuit (e.g., a reference signal generator) 46 that is specially configured, e.g., by the execution of stored computer program instructions, to generate a reference signal for transmission as described above.

[0079] Specifically, the processing circuit 46 is configured to selectively derive one of the initialization sequences within a subset of possible initialization sequences for the sequence generator, according to one or more rules that define different initialization sequences in the subset as a function of a single parameter. The processing circuit 46 is further configured to

generate the uplink reference signal based on the derived initialization sequence, and to transmit the generated signal via the transceiver 42.

[0080] Figure 10 likewise illustrates an example base station 12-1 configured according to one or more embodiments herein. Those skilled in the art will recognize that the base station 12-1 in one or more embodiments includes one or more processing circuits 56, such as microprocessors, digital signal processors, or other digital processors, and associated memory or other computer-readable media, for storing, e.g., a computer program the execution of which configures the base station 12-1 to perform the processing shown in Figures 2 or 4

[0081] When configured to perform the processing shown in Figure 2, the base station 12-1 includes one or more processing circuits (e.g., control / signaling circuits) 58 that are specially configured, e.g., by the execution of stored computer program instructions, to initialize pseudo-random sequence generators on which wireless devices 16 base generation of uplink reference signals 22 as described above. The one or more processing circuits 58 are configured to determine a first sequence 26-1 from a first subset 28-1 of possible initialization sequences for a pseudo-random sequence generator of a first wireless device 16-1. The one or more processing circuits 58 are further configured to determine a second sequence 26-2 from a second subset 28-2 of possible initialization sequences for a pseudo-random sequence generator of a second wireless device 16-2. The range of this second subset 28-2 spans at least the range of the first subset 28-1. Moreover, the one or more processing circuits 58 are configured to encode the first sequence 26-1 as a first set 32-1 of two or more parameters, and to encode the second sequence 26-2 as a second set 32-2 of one or more parameters. This second set 32-2 comprises fewer bits than the first set 32-1, and includes at least one parameter not included in the first set 32-1. Finally, the one or more processing circuits 58 are configured to initialize the sequence generators of the first and second devices 16-1, 16-2 with the first and second sequences 26-1, 26-2 by transmitting the first and second sets 32-1, 32-2 of parameters to the first and second devices 16-1, 16-2.

[0082] When configured to perform the processing shown in Figure 4, the base station 12-1 includes one or more processing circuits (e.g., control / signaling circuits) 58 that are specially configured, e.g., by the execution of stored computer program instructions, to initialize a

pseudo-random sequence generator on which a wireless device 16-2 bases generation of an uplink reference signal. The one or more processing circuits 58 are configured in this regard to determine a sequence 26-2 from a subset 28-2 of possible initialization sequences for the pseudo-random sequence generator of the device 16-2. The one or more processing circuits 58 are configured to then encode the determined sequence 26-2 as a single parameter z. Different values for this single parameter z represent different possible initialization sequences within the subset 28-2. Finally, the one or more processing circuits 58 are configured to initialize the pseudo-random sequence generator of the wireless device 16-2 with the determined sequence 26-2 by transmitting the single parameter z to the wireless device 16-2.

[0083] Some further embodiments will now be described.

[0084] As explained above, in order to enable flexible pairing of UEs for intercell RS orthogonality, it is beneficial that CSH initialization (c_{init}) for new UEs is able to at least take on all values that are possible for legacy UEs in the network, including the values taken by UEs in neighboring cells (e.g., for inter-cell orthogonality based on OCC). On the other hand, the CSH initialization c_{init} is a 31 bits parameter, requiring significant overhead for being signaled.

[0085] In the standard TS 36.211 V10.4.0, the specified pseudo-random sequence generator c_{init} in section 5.5.1.4 of TS 36.211 V10.4.0 is defined as

[0001] $$c_{\text{init}} = \left\lfloor \frac{N_{\text{ID}}^{\text{cell}}}{30} \right\rfloor \cdot 2^5 + f_{\text{ss}}^{\text{PUSCH}},$$

[0002] where $N_{\text{ID}}^{\text{cell}}$ is the cell id that takes on 504 different integer values, and $f_{\text{ss}}^{\text{PUSCH}}$ is the sequence-shift pattern for PUSCH that takes on 30 different integer values. Hence, it can be seen that the dynamic range (i.e., the interval between min and max) for c_{init} is $[0,541]$.

[0086] It is observed here that only the values of c_{init} that are spanned by legacy UEs are necessary in order to pair new and legacy UEs with inter-cell orthogonality of RS and OCC. Therefore, one or more embodiments herein consist of signaling a parameter z instead of c_{init},

and obtain c_{init} by padding z with zeros. Specifically, 10 bits are necessary for z in this case, and 21 bits are pre-pended (as most significant bits) to z to form c_{init}.

[0087] Another possibility is to observe that c_{init} can be expressed by the following formula, letting $x = \left\lfloor \frac{N_{\text{ID}}^{\text{cell}}}{30} \right\rfloor$ and $y = f_{\text{ss}}^{\text{PUSCH}}$, i.e.,:

[0003] $$c_{\text{init}} = 32x + y, \qquad (1)$$

where $x \in [0,1,...,16]$ and $y \in [0,1,...,29]$.

[0088] With this representation it is clear that 5 bits are needed to encode x and 5 bits to encode y, giving a total of 10 bits to encode c_{init}. In this example, only x and y are signaled by the network, and the 31 bits representation of c_{init} is obtained by converting the integer representation of c_{init} in (1) to a 31 bits binary representation.

[0089] Some embodiments consist of the network, e.g. the LTE BS, indicating the 10 bits c_{init} (without the compression discussed below) to the UE. This would allow the network to signaling directly the c_{init} without deriving it as in TS 36.211 V10.4.0.

[0090] Further study reveals that c_{init} does not span the full linear range from $[0,1,...,541]$ for legacy UEs, but only less than 512 values are indexed which means that 9 bits are sufficient to encode c_{init}. Furthermore, it is observed that it is beneficial to allow c_{init} to take on the same set of values as a legacy UE, in order to guarantee flexible resource allocation and UE pairing with arbitrary legacy UEs.

[0091] In fact, one or more embodiments herein use a table mapping an index z to the indexed values of c_{init}, and vice-versa (bi-univocal correspondence). Alternatively, the legacy values of c_{init} may be obtained from a formula as a function of z. Another formula generates z as a function of c_{init}. The table is evaluated based on such mapping formulas. Clearly, z is represented with fewer bits than c_{init}. In the examples below, z is represented with 9 bits.

[0092] When aiming at matching a certain c_{init} value, the network evaluates the table (or equivalently the corresponding formula) by reading the z value corresponding to c_{init}. The network signals z to the UE. The UE evaluates c_{init} based on z and the table (or corresponding formula). The UE applies c_{init} for RS generation. The table or proposed formulas are known (typically pre-stored in memory) at both UE and network sides.

[0093] At least one embodiment consists of a table with 510 values that cover only the useful values of c_{init}. Hence only these values need to be signaled to the UE(s). The table may be stored in the UE and network, or generated based on some predefined formula when needed. That is, instead of the original formula in TS 36.211 V10.4.0, one or more embodiments use the following table to encode c_{init}:

x	y	z	c_{init}
0	0,1,…,29	0,1,…,29	0,1,…,29
1	0,1,…,29	30,31,…,59	32,33,…,61
2	0,1,…,29	60,61,…,89	64,64,…,93
3	0,1,…,29	90,91,…,119	96,97,… 125
4	0,1,…,29	120,121,…,149	128,129,… 157,
5	0,1,…,29	150,151,…,179	160,161,…,189
6	0,1,…,29	180,181,…,209	192,193,…,221
7	0,1,…,29	210,211,…,239	224,225,…, 253
8	0,1,…,29	240,241,…,269	256,257,…, 285
9	0,1,…,29	270,271,…,299	288, 289, …,317

10	0,1,...,29	300,301,...,329	320,321,..., 349
11	0,1,...,29	330,331,..., 359	352,353, ..., 381
12	0,1,...,29	360,361,..., 389	384,385,..., 413
13	0,1,...,29	390,391,..., 419	416,417,..., 445
14	0,1,...,29	420,421,..., 449	448,449,..., 477
15	0,1,...,29	450,451,..., 479	480,481,..., 509
16	0,1,...,29	480,481,...,509	512, 513,...,541

Table 1: The useful values of c_{init} that need to be sent to the UEs. Note that only 510 values are needed. The table maps in a unique way z to c_{init}, and vice versa.

[0094] Note that Table 1 shows the exact mapping from $z = [0,1,...,509]$ to c_{init}, i.e., the two most right columns. To avoid a table with 510 rows, one or more embodiments let each row contain a set of 30 values that are mapped *one-to-one* to the corresponding values of the sets for c_{init}.

[0095] Moreover, when the network wants to signaling c_{init} to the UE(s), it reads the table right to left and finds z which is signaled to the UE. The UE receives z, which it knows represents a table address, and hence reads the table left to right from which it finds c_{init}.

[0096] At least one embodiment consists of representing the new encoding, defined in the first embodiment, by a formula. Hence, it can be concluded that the following derived formula allows such representation

[0004] $$c_{\text{init}} = z + 2\left\lfloor \frac{z}{30} \right\rfloor, \qquad (2)$$

[0005] where $\lfloor x \rfloor$ denotes the *floor* function that rounds x to the nearest integer less than or equal to x, and $z \in [0,1,...,509]$.

[0097] The formula (2) enables the network, i.e., a LTE BS, to easily calculate c_{init} to be sent to the UE(s). Note that c_{init} depends on the parameters $x = \left\lfloor \frac{N_{\text{ID}}^{\text{cell}}}{30} \right\rfloor$ and $y = f_{\text{ss}}^{\text{PUSCH}}$ as described previously, and whose relations are also stated in the table.

[0098] Similarly, the following inversion formula (3) can be derived that maps c_{init} to z, which then e.g. corresponds to what an UE would do upon receiving c_{init} from the BS, i.e.,

[0006] $$z = c_{\text{init}} - 2\left\lfloor \frac{c_{\text{init}}}{32} \right\rfloor \qquad (3)$$

[0099] With the proposed encoding, reduced signaling overhead is required between LTE BS and UEs for indicating UE-specific CSH patterns. More specifically, only 9 or 10 bits need to be signaled for the pseudo-random initialization sequence c_{init} instead of current 31 bits as in TS 36.211 V10.4.0.

[00100] Those skilled in the art will recognize that the present invention may be carried out in other ways than those specifically set forth herein without departing from essential characteristics of the invention. The embodiments are thus to be considered in all respects as illustrative and not restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

CLAIMS

What is claimed is:

1. A method implemented by a base station for initializing pseudo-random sequence generators on which wireless devices base generation of uplink reference signals, comprising:

determining (100) a first sequence from a first subset of possible initialization sequences for a pseudo-random sequence generator of a first wireless device;

determining (110) a second sequence from a second subset of possible initialization sequences for a pseudo-random sequence generator of a second wireless device, the range of the second subset spanning at least the range of the first subset;

encoding (120) the first sequence as a first set of two or more parameters;

encoding (130) the second sequence as a second set of one or more parameters, wherein the second set comprises fewer bits than the first set and includes at least one parameter not included in the first set; and

initializing (140) the sequence generators of the first and second devices with the first and second sequences by transmitting the first and second sets of parameters to the first and second devices.

2. The method of claim 1, wherein the second sequence is encoded as a single parameter comprising the second set.

3. The method of claim 2, wherein the first and second sequences each comprise a defined number of bits corresponding to the range of a full set of possible initialization sequences, and wherein the single parameter comprises a defined number of least significant bits from the second sequence, the defined number of least significant bits corresponding to the range of the second subset.

4. The method of claim 2, wherein the second sequence is encoded based on a defined one-to-one mapping of possible initialization sequences within the second subset to possible

values for the single parameter, wherein the range of the single parameter is smaller than the range of the second subset.

5. The method of claim 4, wherein the second sequence c_{init} is encoded as a single parameter $z = c_{init} - 2\left\lfloor \frac{c_{init}}{32} \right\rfloor$, wherein $\lfloor x \rfloor$ denotes a floor function that rounds x to the nearest integer less than or equal to x.

6. The method of claim 1, wherein the second sequence is encoded as a linear combination of two parameters comprising the second set, wherein a first one of the two parameters encodes a defined number of least significant bits from the second sequence and a second one of the two parameters encodes a defined number of more significant bits from the second sequence not including one or more most significant bits from the second sequence.

7. The method of claim 1, wherein the second set of parameters comprises 9 or 10 bits, and wherein the second sequence comprises 31 bits.

8. The method of claim 1, wherein the ranges of the first and second subsets each spans between a minimum value of 0 and a maximum value no greater than 541.

9. The method of claim 1, wherein the ranges of the first and second subsets are different, but correspond to the same number of bits.

10. The method of claim 1, wherein the first initialization sequence comprises a cell-specific sequence and the second initialization sequence comprises a device-specific sequence.

11 The method of claim 1, wherein each sequence corresponds to a cyclic shift hopping pattern, wherein a wireless device generates an uplink reference signal by applying a cyclic shift hopping pattern to a cyclic shift and by applying the resulting cyclic shift to a base sequence.

12. The method of claim 11, wherein determining (110) the second sequence comprises selecting from the second subset the possible initialization sequence that matches an initialization sequence for a pseudo-random sequence generator of a third wireless device, wherein the third device is served by a different cell than the second wireless device.

13. The method of claim 11, wherein encoding (130) the second sequence comprises jointly encoding the second sequence and an indication of whether or not cyclic shift hopping is enabled for the second device as the second set of one or more parameters.

14. A method implemented by a wireless device for initializing a pseudo-random sequence generator on which to base generation of an uplink reference signal, comprising:

selectively deriving (300) one of the initialization sequences within a subset of possible initialization sequences for the sequence generator, according to one or more rules that define different initialization sequences in the subset as a function of a single parameter, wherein the single parameter is received from a base station;

generating (310) the uplink reference signal with the sequence generator initialized to the derived initialization sequence; and

transmitting (320) the generated signal.

15. The method of claim 14, wherein deriving (300) the initialization sequence comprises padding the single parameter with a defined number of zeroes.

16. The method of claim 14, wherein said deriving (300) comprises deriving the initialization sequence based on a defined one-to-one mapping of possible initialization sequences in the subset to possible values for the single parameter, wherein the range of the single parameter is smaller than the range of the subset.

17. The method of claim 16, wherein said deriving (300) comprises deriving the initialization

sequence c_{init} according to $c_{init} = z + 2\left\lfloor \frac{z}{30} \right\rfloor$, wherein z is the single parameter and $\lfloor x \rfloor$ denotes a floor function that rounds x to the nearest integer less than or equal to x.

18. The method of claim 14, wherein the single parameter comprises 9 or 10 bits, and the initialization sequence comprises 31 bits.

19. The method of claim 14, wherein the range of the single parameter spans between a minimum value of 0 and a maximum value no greater than 541.

20. The method of claim 14, wherein the initialization sequence comprises a device-specific sequence.

21. The method of claim 14, wherein when cyclic shift hopping is enabled for the device said generating comprises:

determining a cyclic shift hopping pattern from the derived initialization sequence;

applying the cyclic shift hopping pattern to a cyclic shift; and

applying the resulting cyclic shift to a base sequence.

22. The method of claim 21, further comprising deriving an indication of whether or not cyclic shift hopping is enabled for the device according to one or more rules that define such indication as a function of the single parameter.

23. A base station (12-1) configured to initialize pseudo-random sequence generators on which wireless devices base generation of uplink reference signals, comprising a transceiver circuit (52) and one or more processing circuits (56) configured to:

determine a first sequence from a first subset of possible initialization sequences for a pseudo-random sequence generator of a first wireless device;

determine a second sequence from a second subset of possible initialization sequences

for a pseudo-random sequence generator of a second wireless device, the range of the second subset spanning at least the range of the first subset;

encode the first sequence as a first set of two or more parameters;

encode the second sequence as a second set of one or more parameters, wherein the second set comprises fewer bits than the first set and includes at least one parameter not included in the first set; and

initialize the sequence generators of the first and second devices with the first and second sequences by transmitting the first and second sets of parameters to the first and second devices.

24. The base station (12-1) of claim 23, wherein the second sequence is encoded as a single parameter comprising the second set.

25. The base station (12-1) of claim 24, wherein the first and second sequences each comprise a defined number of bits corresponding to the range of a full set of possible initialization sequences, and wherein the single parameter comprises a defined number of least significant bits from the second sequence, the defined number of least significant bits corresponding to the range of the second subset.

26. The base station (12-1) of claim 24, wherein the second sequence is encoded based on a defined one-to-one mapping of possible initialization sequences within the second subset to possible values for the single parameter, wherein the range of the single parameter is smaller than the range of the second subset.

27. The base station (12-1) of claim 26, wherein the second sequence c_{init} is encoded as a single parameter $z = c_{init} - 2\left\lfloor \frac{c_{init}}{32} \right\rfloor$, wherein $\lfloor x \rfloor$ denotes a floor function that rounds x to the nearest integer less than or equal to x.

28. The base station (12-1) of claim 23, wherein the second sequence is encoded as a linear combination of two parameters comprising the second set, wherein a first one of the two parameters encodes a defined number of least significant bits from the second sequence and a second one of the two parameters encodes a defined number of more significant bits from the second sequence not including one or more most significant bits from the second sequence.

29. The base station (12-1) of claim 23, wherein second set of parameters comprises 9 or 10 bits, and wherein the second sequence comprises 31 bits.

30. The base station (12-1) of claim 23, wherein the ranges of the first and second subsets each spans between a minimum value of 0 and a maximum value no greater than 541.

31. The base station (12-1) of claim 23, wherein the ranges of the first and second subsets are different, but correspond to the same number of bits.

32. The base station (12-1) of claim 23, wherein the first initialization sequence comprises a cell-specific sequence and the second initialization sequence comprises a device-specific sequence.

33. The base station (12-1) of claim 23, wherein each sequence corresponds to a cyclic shift hopping pattern, wherein a wireless device generates an uplink reference signal by applying a cyclic shift hopping pattern to a cyclic shift and by applying the resulting cyclic shift to a base sequence.

34. The base station (12-1) of claim 33, wherein the one or more processing circuits (56) are configured to determine the second sequence by selecting from the second subset the possible initialization sequence that matches an initialization sequence for a pseudo-random sequence generator of a third wireless device, wherein the third device is served by a different cell than the second wireless device.

35. The base station (12-1) of claim 33, wherein the one or more processing circuits (56) are configured to encode the second sequence by jointly encoding the second sequence and an indication of whether or not cyclic shift hopping is enabled for the second device as the second set of one or more parameters.

36. A wireless device (16-2) configured to initialize a pseudo-random sequence generator on which to base generation of an uplink reference signal, comprising a transceiver (42) and one or more processing circuits (44) configured to:

selectively derive one of the initialization sequences within a subset of possible initialization sequences for the sequence generator, according to one or more rules that define different initialization sequences in the subset as a function of a single parameter;

generate the uplink reference signal with the sequence generator initialized to the derived initialization sequence; and

transmit the generated signal via the transceiver.

37. The device (12-1) of claim 36, wherein the one or more processing circuits (44) are configured to derive the initialization sequence by padding the single parameter with a defined number of zeroes.

38. The device (12-1) of claim 36, wherein the one or more processing circuits (44) are configured to derive the initialization sequence based on a defined one-to-one mapping of possible initialization sequences to possible values for the single parameter, wherein the range of the single parameter is smaller than the range of the subset.

39. The device (12-1) of claim 38, wherein the one or more processing circuits (44) are configured to derive the initialization sequence c_{init} according to $c_{init} = z + 2\left\lfloor \frac{z}{30} \right\rfloor$, wherein z is

the single parameter and $\lfloor x \rfloor$ denotes a floor function that rounds x to the nearest integer less than or equal to x.

40. The device (12-1) of claim 36, wherein the single parameter comprises 9 or 10 bits, and the initialization sequence comprises 31 bits.

41. The device (12-1) of claim 36, wherein the range of the single parameter spans between a minimum value of 0 and a maximum value no greater than 541.

42. The device (12-1) of claim 36, wherein the initialization sequence comprises a device-specific sequence.

43. The device (12-1) of claim 36, wherein when cyclic shift hopping is enabled for the device the one or more processing circuits (44) are configured to generate the uplink reference signal by:

determining a cyclic shift hopping pattern from the derived initialization sequence;

applying the cyclic shift hopping pattern to a cyclic shift; and

applying the resulting cyclic shift to a base sequence.

44. The device (12-1) of claim 43, wherein the one or more processing circuits (44) are further configured to derive an indication of whether or not cyclic shift hopping is enabled for the device according to one or more rules that define such indication as a function of the single parameter.

45. A method implemented by a base station for initializing a pseudo-random sequence generator on which a wireless device bases generation of an uplink reference signal, comprising:

determining (200) a sequence from a subset of possible initialization sequences for said

pseudo-random sequence generator;

encoding (210) the determined sequence as a single parameter, wherein different values for the single parameter represent different possible initialization sequences within the subset; and

initializing (220) said pseudo-random sequence generator of the wireless device with the determined sequence by transmitting the single parameter to the wireless device.

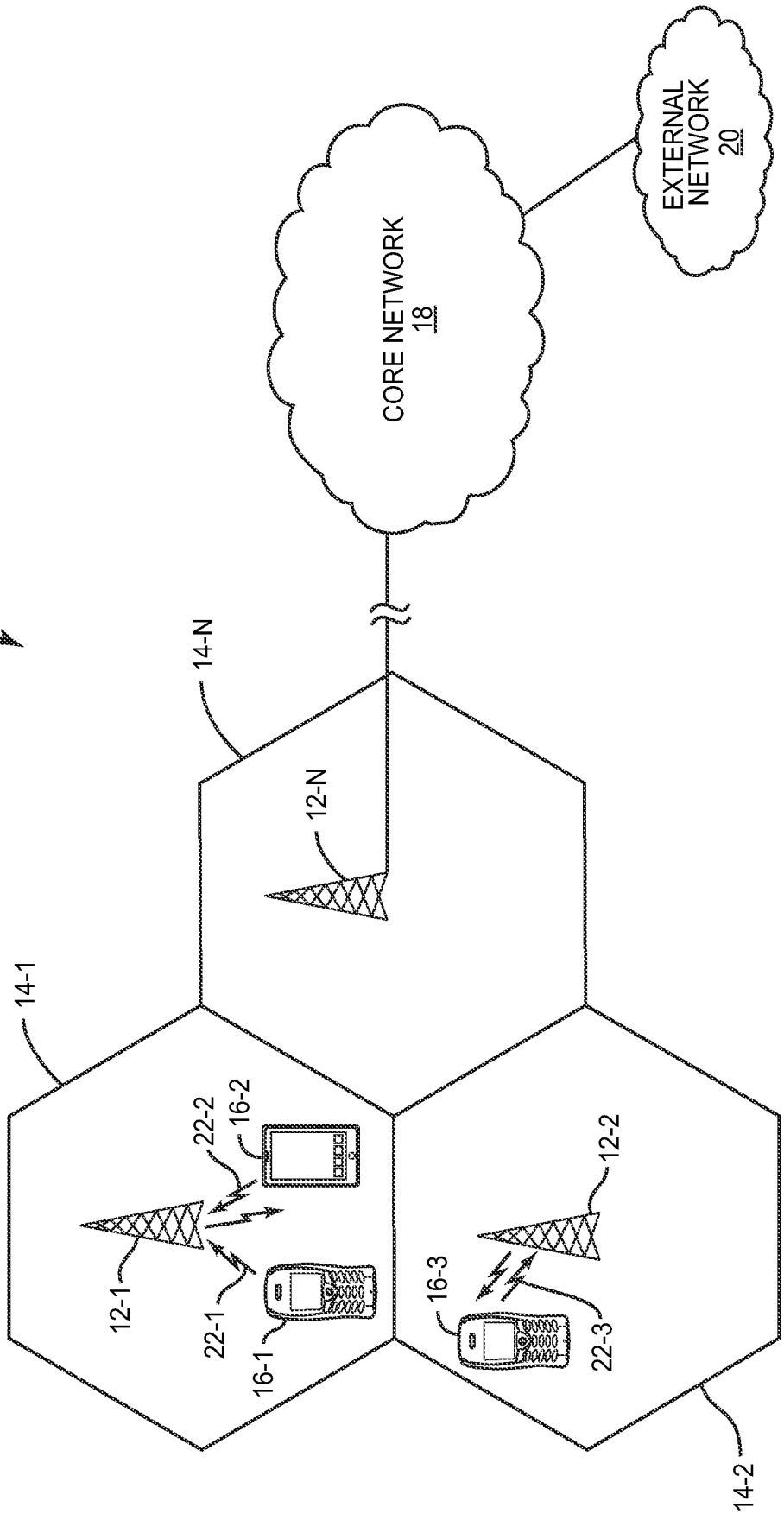
10
CORE NETWORK
18
EXTERNAL
NETWORK
20
14-N
12-N
14-1
12-1
22-1
16-1
22-2
16-2
14-2
12-2
16-3
22-3

FIG. 1

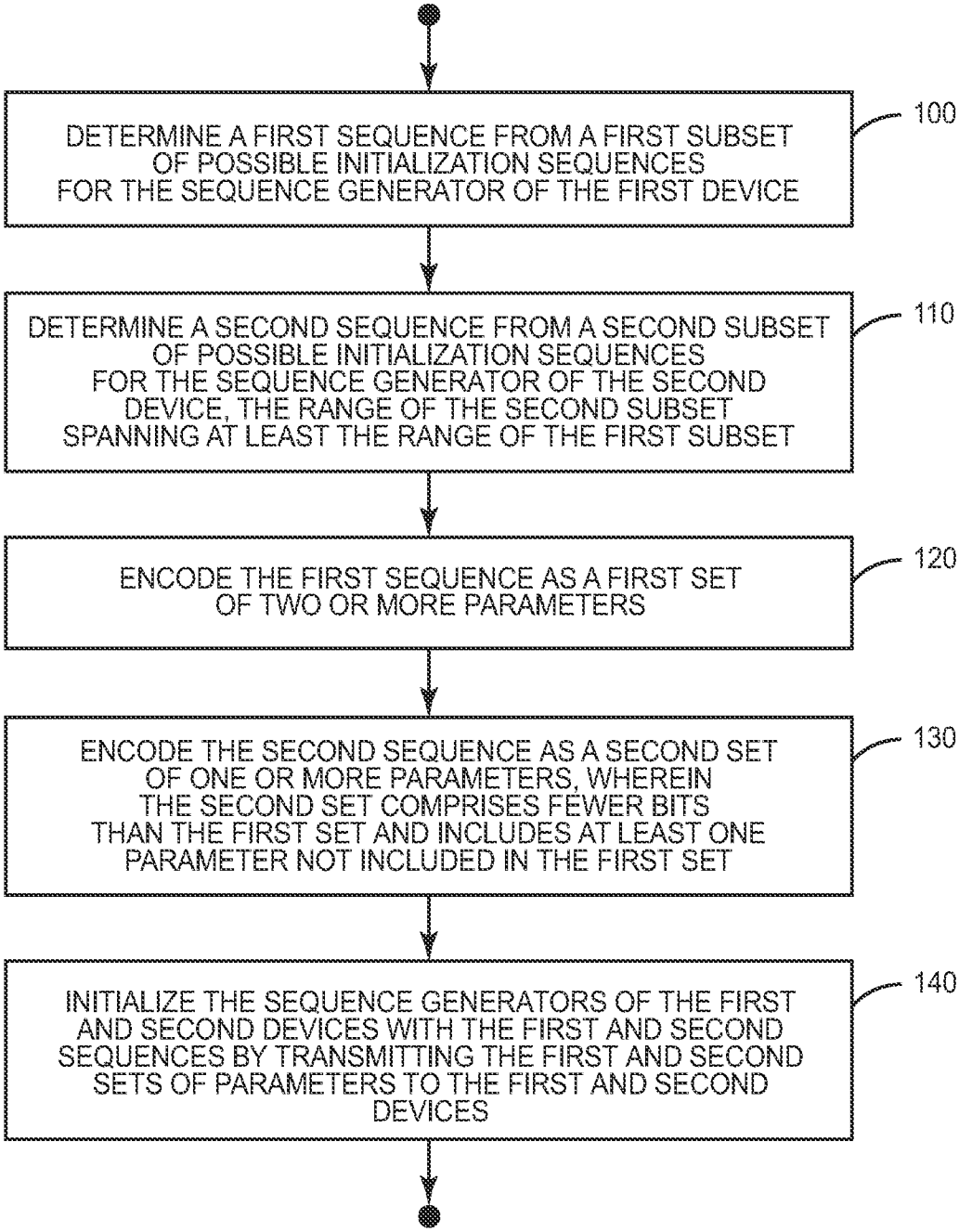
DETERMINE A FIRST SEQUENCE FROM A FIRST SUBSET OF POSSIBLE INITIALIZATION SEQUENCES FOR THE SEQUENCE GENERATOR OF THE FIRST DEVICE
100
DETERMINE A SECOND SEQUENCE FROM A SECOND SUBSET OF POSSIBLE INITIALIZATION SEQUENCES FOR THE SEQUENCE GENERATOR OF THE SECOND DEVICE, THE RANGE OF THE SECOND SUBSET SPANNING AT LEAST THE RANGE OF THE FIRST SUBSET
110
ENCODE THE FIRST SEQUENCE AS A FIRST SET OF TWO OR MORE PARAMETERS
120
ENCODE THE SECOND SEQUENCE AS A SECOND SET OF ONE OR MORE PARAMETERS, WHEREIN THE SECOND SET COMPRISES FEWER BITS THAN THE FIRST SET AND INCLUDES AT LEAST ONE PARAMETER NOT INCLUDED IN THE FIRST SET
130
INITIALIZE THE SEQUENCE GENERATORS OF THE FIRST AND SECOND DEVICES WITH THE FIRST AND SECOND SEQUENCES BY TRANSMITTING THE FIRST AND SECOND SETS OF PARAMETERS TO THE FIRST AND SECOND DEVICES
140

FIG. 2

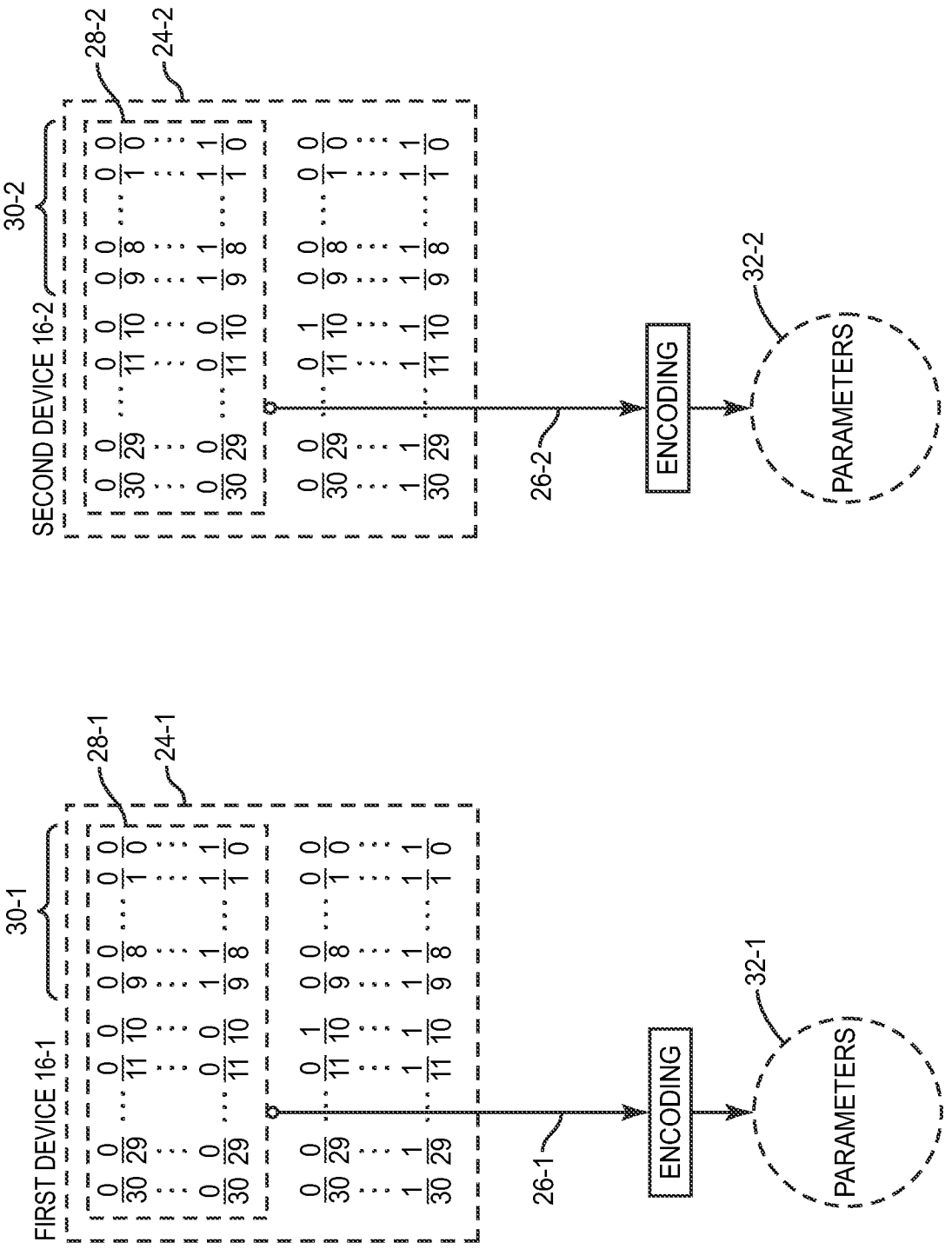
FIRST DEVICE 16-1
30-1
28-1
24-1
26-1
ENCODING
32-1
PARAMETERS
SECOND DEVICE 16-2
30-2
28-2
24-2
26-2
ENCODING
32-2
PARAMETERS

FIG. 3

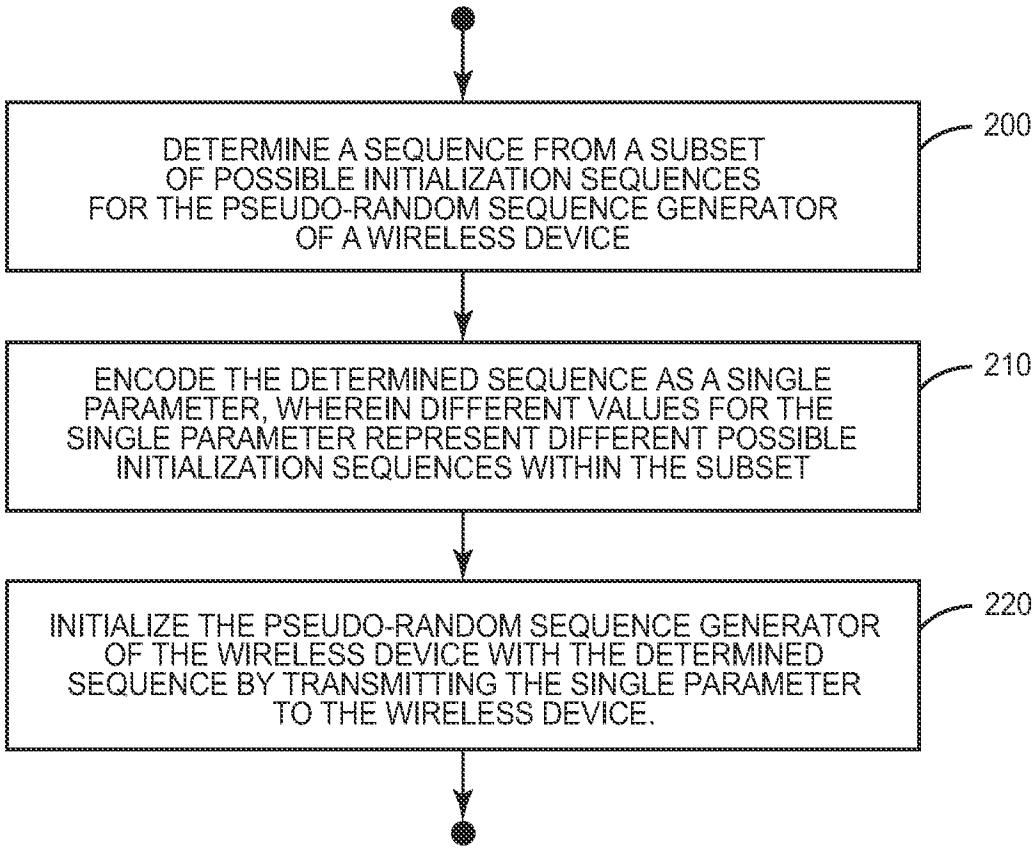
DETERMINE A SEQUENCE FROM A SUBSET OF POSSIBLE INITIALIZATION SEQUENCES FOR THE PSEUDO-RANDOM SEQUENCE GENERATOR OF A WIRELESS DEVICE
200
ENCODE THE DETERMINED SEQUENCE AS A SINGLE PARAMETER, WHEREIN DIFFERENT VALUES FOR THE SINGLE PARAMETER REPRESENT DIFFERENT POSSIBLE INITIALIZATION SEQUENCES WITHIN THE SUBSET
210
INITIALIZE THE PSEUDO-RANDOM SEQUENCE GENERATOR OF THE WIRELESS DEVICE WITH THE DETERMINED SEQUENCE BY TRANSMITTING THE SINGLE PARAMETER TO THE WIRELESS DEVICE.
220

FIG. 4

z	c_{init}
0,1,…,29	0,1,…,29
30,31,…,59	32,33,…,61
60,61,…,89	64,65,…,93
90,91,…,119	96,97,…125
120,121,…,149	128,129,…157,
150,151,…,179	160,161,…,189
180,181,…,209	192,193,…,221
210,211,…,239	224,225,…, 253
240,241,…,269	256,257,…, 285
270,271,…,299	288, 289, …,317
300,301,…,329	320,321,…, 349
330,331,..., 359	352,353, …, 381
360,361,…, 389	384,385,…, 413
390,391,…, 419	416,417,…, 445
420,421,…, 449	448,449,…, 477
450,451,…, 479	480,481,…, 509
480,481,…,509	512, 513,…,541

FIG. 5

	CSH_ENABLE
$z \in [0,1,...,509]$	1
$z \notin [0,1,...,509]$	0

FIG. 6A

	CSH_ENABLE
$z \in [0,1,...,509]$	1
$z = 511$	0

FIG. 6B

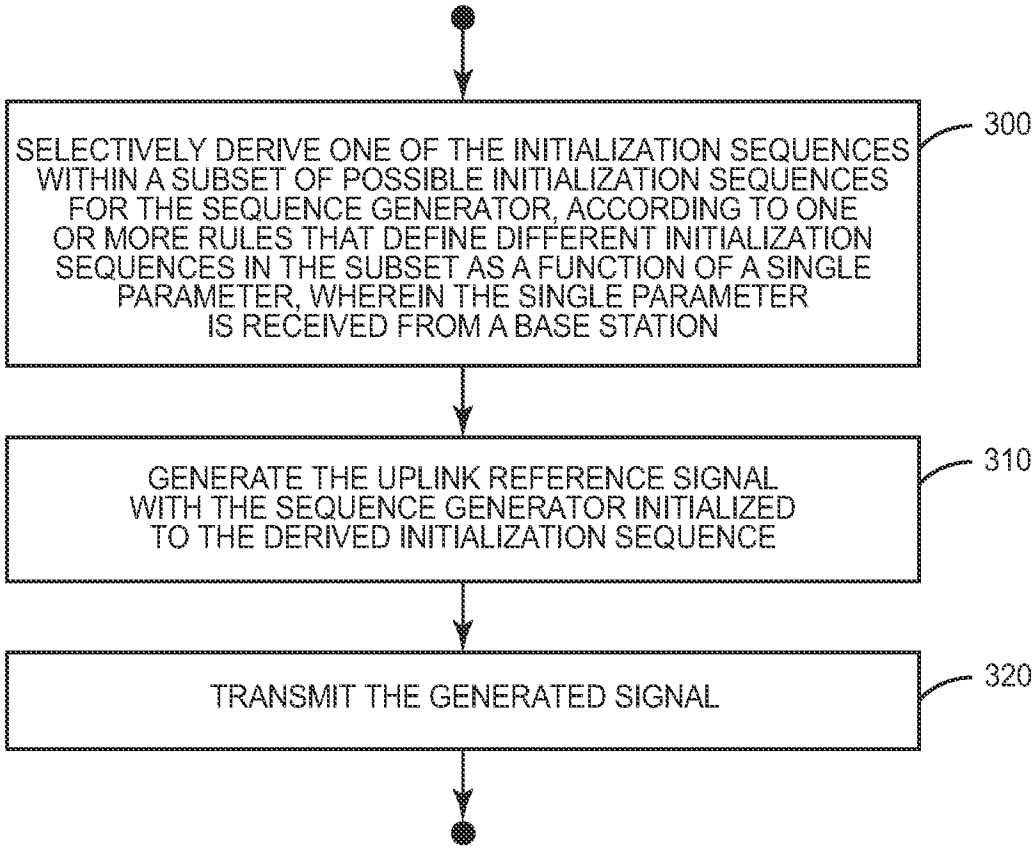
SELECTIVELY DERIVE ONE OF THE INITIALIZATION SEQUENCES WITHIN A SUBSET OF POSSIBLE INITIALIZATION SEQUENCES FOR THE SEQUENCE GENERATOR, ACCORDING TO ONE OR MORE RULES THAT DEFINE DIFFERENT INITIALIZATION SEQUENCES IN THE SUBSET AS A FUNCTION OF A SINGLE PARAMETER, WHEREIN THE SINGLE PARAMETER IS RECEIVED FROM A BASE STATION
300
GENERATE THE UPLINK REFERENCE SIGNAL WITH THE SEQUENCE GENERATOR INITIALIZED TO THE DERIVED INITIALIZATION SEQUENCE
310
TRANSMIT THE GENERATED SIGNAL
320

FIG. 7

x	y	c_{init}
0	0,1,…,29	0,1,…,29
1	0,1,…,29	32,33,…,61
2	0,1,…,29	64,65,…,93
3	0,1,…,29	96,97,…125
4	0,1,…,29	128,129,…157,
5	0,1,…,29	160,161,…,189
6	0,1,…,29	192,193,…,221
7	0,1,…,29	224,225,…, 253
8	0,1,…,29	256,257,…, 285
9	0,1,…,29	288, 289, …,317
10	0,1,…,29	320,321,…, 349
11	0,1,…,29	352,353, …, 381
12	0,1,…,29	384,385,…, 413
13	0,1,…,29	416,417,…, 445
14	0,1,…,29	448,449,…, 477
15	0,1,…,29	480,481,…, 509
16	0,1,…,29	512, 513,…,541

FIG. 8

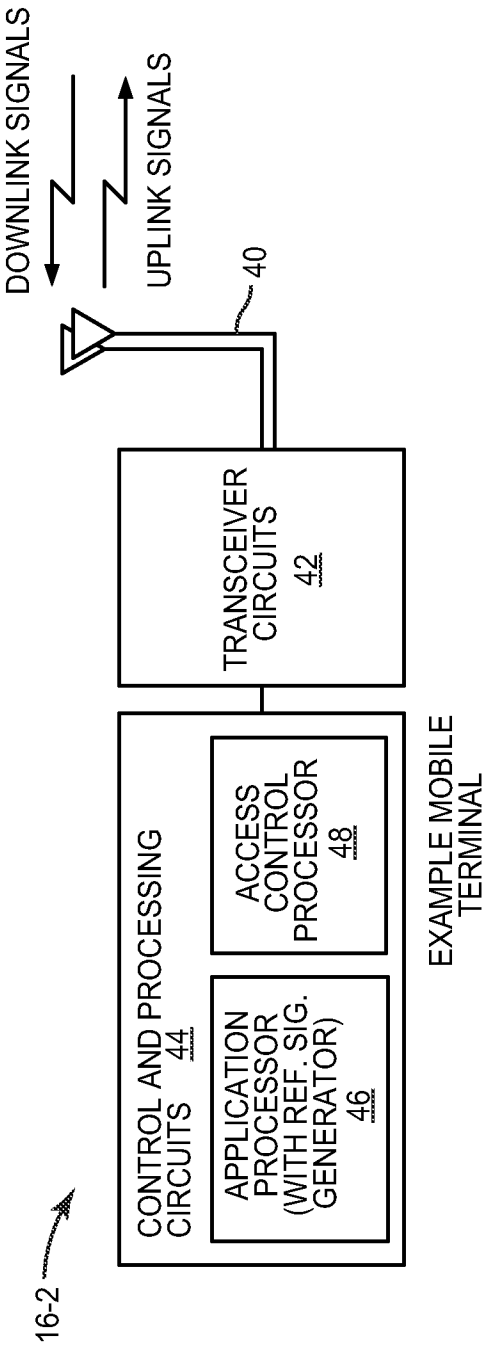
DOWNLINK SIGNALS
UPLINK SIGNALS
40
TRANSCEIVER CIRCUITS 42
CONTROL AND PROCESSING CIRCUITS 44
APPLICATION PROCESSOR (WITH REF. SIG. GENERATOR) 46
ACCESS CONTROL PROCESSOR 48
16-2
EXAMPLE MOBILE TERMINAL

FIG. 9

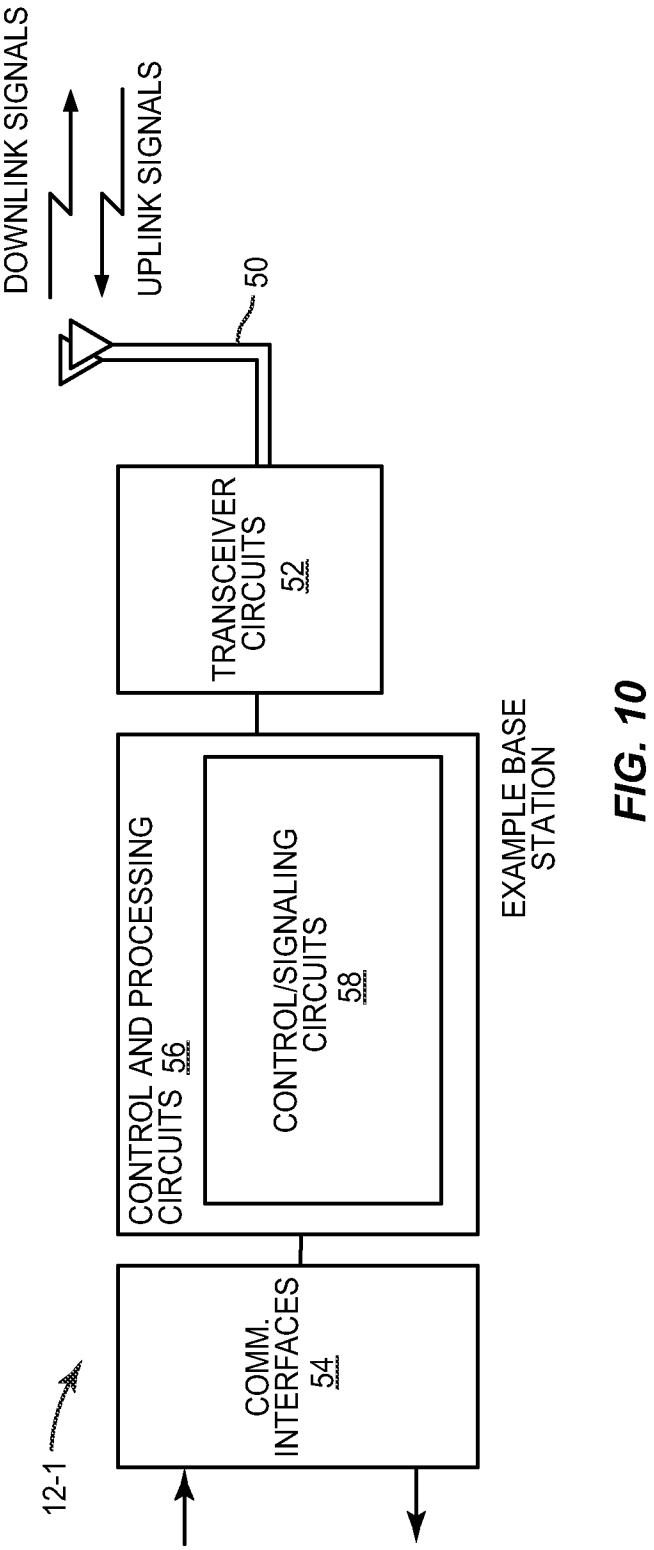
DOWNLINK SIGNALS
UPLINK SIGNALS
50
TRANSCEIVER CIRCUITS 52
CONTROL AND PROCESSING CIRCUITS 56
CONTROL/SIGNALING CIRCUITS 58
COMM. INTERFACES 54
12-1
EXAMPLE BASE STATION

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2013/050351

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L27/26 H04L1/00
ADD.

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)
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)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	RENESAS MOBILE EUROPE LTD: "Downlink DM-RS for Release 11", 3GPP DRAFT; R1-120379, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Dresden, Germany; 20120206 - 20120210, 31 January 2012 (2012-01-31), XP050562881, [retrieved on 2012-01-31] page 1, section 2 page 2 ----- -/--	1-45

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents :

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"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	Date of mailing of the international search report
23 July 2013	30/07/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Feng, Mei

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	INTERDIGITAL COMMUNICATIONS ET AL: "DM-RS sequence for CoMP", 3GPP DRAFT; R1-120134, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Dresden, Germany; 20120206 - 20120210, 1 February 2012 (2012-02-01), XP050563160, [retrieved on 2012-02-01] the whole document --- APPLE INC: "Scrambling Sequences for Enhanced PDCCH", 3GPP DRAFT; R1-120272, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Dresden, Germany; 20120206 - 20120210, 1 February 2012 (2012-02-01), XP050563182, [retrieved on 2012-02-01] the whole document --- INTEL CORPORATION: "Remaining details of downlink DM-RS", 3GPP DRAFT; R1-121520 REMAINING DETAILS OF DOWNLINK DM-RS, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Jeju, Korea; 20120326 - 20120330, 20 March 2012 (2012-03-20), XP050599793, [retrieved on 2012-03-20] page 2 ---	1,6-13, 23,28-35 14, 16-22, 36-45 1,6-13, 23,28-35

2