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United States Patent	12395390
Kind Code	B2
Date of Patent	August 19, 2025
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Methods and apparatuses for signaling and determining reference signal offsets

Abstract

Methods and apparatuses disclosed herein enable the use of Demodulation Reference Signal (DMRS) sequences that are numbered relative to an overall system bandwidth, while simultaneously enabling wireless communication devices to determine the DRMS sequence elements mapped to their scheduled bandwidths within the system bandwidth. Advantageously, the wireless communication devices need not know the system bandwidth, or even be aware of where their scheduled bandwidths reside within the system bandwidth.

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Appl. No.: 18/744810

Filed: June 17, 2024

Prior Publication Data

Document Identifier	Publication Date
US 20240340207 A1	Oct. 10, 2024

Related U.S. Application Data

continuation parent-doc US 17510673 20211026 US 12052125 child-doc US 18744810
continuation parent-doc US 16868127 20200506 US 11190376 20211130 child-doc US 17510673
continuation parent-doc US 15569970 US 10680854 20200609 WO PCT/SE2017/050926

Publication Classification

Int. Cl.: **H04L27/26** (20060101); **H04L5/00** (20060101); **H04L25/02** (20060101); **H04W72/0453** (20230101); **H04W72/23** (20230101); **H04W74/04** (20090101); H04B17/336 (20150101)

U.S. Cl.:

CPC **H04L27/2613** (20130101); **H04L5/0037** (20130101); **H04L5/0048** (20130101); **H04L5/0051** (20130101); **H04L5/0058** (20130101); **H04L5/0094** (20130101); **H04L25/0224** (20130101); **H04L27/2607** (20130101); **H04L27/2662** (20130101); **H04L27/2691** (20130101); **H04W72/0453** (20130101); **H04W72/23** (20230101); **H04W74/04** (20130101); H04B17/336 (20150115); H04L5/0007 (20130101); H04L5/0044 (20130101)

Field of Classification Search

USPC: None

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Background/Summary

RELATED APPLICATIONS (1) This application is a continuation of U.S. application Ser. No. 17/510,673 filed 26 Oct. 2021, which is a continuation of U.S. application Ser. No. 16/868,127 filed 6 May 2020, which is a continuation of U.S. application Ser. No. 15/569,970 filed 27 Oct. 2017, now U.S. Pat. No. 10,680,854, which is a U.S. National Phase Application of PCT/SE2017/050926 filed 25 Sep. 2017, which claims benefit of Provisional Application No. 62/443,042 filed 6 Jan. 2017. The entire contents of each aforementioned application is incorporated herein by reference.

TECHNICAL FIELD

(1) The present invention relates to communication networks and particularly relates to determining reference signal offsets in a communication network.

BACKGROUND

(2) Networks based on the Long Term Evolution, LTE, specifications, as promulgated by the Third Generation Partnership Project, 3GPP, use two kinds of reference signals: Cell-specific Reference Signals or CRS, and Demodulation Reference Signals or DMRS, which are also denoted as DM-RS. CRS span the complete “system” bandwidth involved and they are “always on.” In contrast, DMRS span only the scheduled bandwidth to which they pertain and they are only transmitted when transmitting data.

(3) The advantage of reference signals that are always transmitted is that a wireless communication device, referred to as a UE or User Equipment in 3GPP parlance, can rely on their presence. Drawbacks associated with CRS include a high network energy consumption because CRS are even transmitted if no data are transmitted. CRS also create unnecessary interference because they are transmitted even if not needed.

(4) See FIG. 1, which illustrates an example system bandwidth and the transmission of CRS and DMRS within the system bandwidth. In an Orthogonal Frequency Division Multiplex, OFDM, example applicable to the LTE context, the system bandwidth comprises a plurality of spaced-apart, narrow-band subcarriers that, in the aggregate, span the system bandwidth. Each subcarrier taken at each transmission time may be regarded as Resource Element, or RE, and FIG. 1 can be understood as depicting some portion of an OFDM time-frequency grid, with CRS and DMRS being transmitted on specific subcarriers at specific times. More particularly, one sees regular

transmissions of CRS across the system bandwidth, along with the transmission of DMRS in conjunction with data transmission on scheduled resources.

(5) In LTE, the DRMS sequence element transmitted on a given subcarrier depends on the position of the subcarrier within the overall plurality of subcarriers constituting the overall system bandwidth. For example, with the subcarriers are numbered from 0 to N, the sequence element associated with the m-th subcarrier depends on the value of m. This approach can be understood as a “global” numbering scheme that applies to the system bandwidth and, importantly, LTE UEs support the full system bandwidth.

(6) In more detail, in LTE, for any of the antenna ports $p \in \{7, 8, \dots, v+6\}$, the reference-signal sequence $r(m)$ used for DMRS on subcarrier m within the downlink, DL, system bandwidth $N_{\text{sub.RB.sup.max,DL}}$ resource blocks, is defined by

$$(7) \quad r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot \text{Math. } c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot \text{Math. } c(2m + 1)),$$

$$m = \begin{cases} 0, 1, \dots, 12N_{\text{RB}}^{\text{max,DL}} - 1 & \text{normalcyclicprefix} \\ 0, 1, \dots, 16N_{\text{RB}}^{\text{max,DL}} - 1 & \text{extendedcyclicprefix} \end{cases}$$

(8) The pseudo-random sequence $c(i)$ is defined by a length-31 Gold sequence.

(9) The output sequence $c(n)$ of length $M_{\text{sub.PN}}$, where $n=0, 1, \dots, M_{\text{sub.PN}}-1$, is defined by

$$(10) \quad c(n) = (x_1(n + N_C) + x_2(n + N_C)) \bmod 2, x_1(n + 31) = (x_1(n + 3) + x_1(n)) \bmod 2$$

$$x_2(n + 31) = (x_2(n + 3) + x_2(n + 2) + x_2(n + 1) + x_2(n)) \bmod 2$$

where $N_{\text{sub.C}}=1600$ and the first m-sequence shall be initialized with $x_{\text{sub.1}}(0)=1$, $x_{\text{sub.1}}(n)=0$, $n=1, 2, \dots, 30$. The initialization of the second m-sequence is denoted by

$c_{\text{sub.init}} = \sum_{\text{sub.i}=0}^{\text{sup.30}} x_{\text{sub.2}}(i) \cdot \text{Math. } 2^{\text{sup.i}}$ with the value depending on the application of the sequence.

(11) The pseudo-random sequence generator shall for DMRS in LTE be initialized with

$$(12) \quad c_{\text{init}} = (\text{Math. } n_s / 2 \cdot \text{Math. } + 1) \cdot \text{Math. } (2n_{\text{ID}}^{(n_{\text{SCID}})} + 1) \cdot \text{Math. } 2^{16} + n_{\text{SCID}}$$

at the start of each subframe.

(13) The quantities $n_{\text{sub.ID.sup}}(i)$, $i=0,1$, are given by $n_{\text{sub.ID.sup}}(i)=N_{\text{sub.ID.sup.cell}}$ if no value for $n_{\text{sub.ID.sup.MRS},i}$ is provided by higher layers or if DCI format 1A, 2B or 2C is used for the DCI associated with the PDSCH transmission $n_{\text{sub.ID.sup}}(i)=n_{\text{sub.ID.sup.MRS},i}$ otherwise where this value is indicated in the downlink control information used to schedule the PDSCH. Here, “DCI” denotes Downlink Control Information, and “PDSCH” denotes Physical Downlink Shared Channel.

(14) It is recognized herein that certain complications arise concerning the generation and use of DRMS signals in the context of NR, where “NR” denotes the New Radio standard at issue in the ongoing development of next-generation communication networks, which are also referred to as 5G networks. NR contemplates wide system bandwidths—e.g., bandwidths of 1 GHz or more—and not every terminal operating in an NR system will have the capability to operate over the complete system bandwidth

(15) NR will, therefore, provide support for terminals capable of supporting only a fraction of the system bandwidth. For example, the network configures a portion of the system bandwidth for use by the terminal, referred to as terminal's configured bandwidth, and then uses bandwidth within the configured bandwidth for scheduling the terminal, referred to as the terminal's scheduled bandwidth.

(16) A terminal may perform access to an NR carrier by detecting a synchronization signal and broadcast channel and performing a subsequent random access. After random access, the network could configure the terminal to a new frequency relative to the frequency used for initial access. This approach does not require the terminal to know the system bandwidth or know where its configured bandwidth lies within the system bandwidth.

SUMMARY

(17) Methods and apparatuses disclosed herein enable the use of Demodulation Reference Signal, DMRS, sequences that are numbered relative to an overall system bandwidth, while simultaneously enabling wireless communication devices to determine the DMRS sequence elements mapped to their scheduled bandwidths within the system bandwidth. Advantageously, the wireless communication devices need not know the system bandwidth or even be aware of where their scheduled bandwidths reside within the system bandwidth.

(18) An example method of operation at a wireless communication device includes determining, based on information received from a wireless communication network, a sequence offset for a reference signal sequence, e.g., a DMRS sequence. The method further includes determining, based on the sequence offset, which portion of the reference signal sequence overlays a scheduled bandwidth of the wireless communication device, referred to as an overlaying portion **44** of the reference signal sequence. Here, the scheduled bandwidth is a portion of a larger, system bandwidth associated with the network, and the reference signal sequence overlays the system bandwidth according to a defined mapping between respective sequence elements constituting the reference signal sequence and respective subcarriers constituting the system bandwidth.

(19) In a corresponding example, a wireless communication device is configured for operation in a wireless communication network and comprises communication circuitry configured for wirelessly communicating with one or more nodes in the network, and processing circuitry that is operatively associated with the communication circuitry. The processing circuitry is configured to determine, based on information received from the network, a sequence offset for a reference signal sequence, and determine, based on the sequence offset, which portion of the reference signal sequence overlays a scheduled bandwidth of the wireless communication device. Such portion is referred to as an overlaying portion of the reference signal sequence. As before, the scheduled bandwidth is a portion of a larger, system bandwidth associated with the network, and the reference signal sequence overlays the system bandwidth according to a defined mapping between respective sequence elements constituting the reference signal sequence and respective subcarriers constituting the system bandwidth.

(20) In another example embodiment, a method of operation at a network node configured for operation in a wireless communication network includes determining a value from which a wireless communication device can determine which portion of a reference signal sequence overlays a scheduled bandwidth of the wireless communication device. The scheduled bandwidth is within a configured bandwidth that is configured for the wireless communication device and within a larger system bandwidth, and the reference signal sequence overlays the system bandwidth according to a defined mapping between respective sequence elements comprising the reference signal sequence and respective subcarriers comprising the system bandwidth. The method further includes the network node signaling the value to the wireless communication device, thereby enabling the wireless communication device to determine the overlaying portion of the reference signal sequence and correspondingly identify which sequence elements of the reference signal sequence are associated with the subcarriers in the scheduled bandwidth.

(21) In a corresponding example, a network node comprises communication circuitry configured to communicate directly or indirectly with a wireless communication device operating in the network. The network node further includes processing circuitry that is operatively associated with the communication circuitry and configured to determine a value from which a wireless communication device can determine which portion of a reference signal sequence overlays a scheduled bandwidth of the wireless communication device. That portion of the sequence is referred to as an overlying portion, and the scheduled bandwidth is within a configured bandwidth that is configured for the wireless communication device. In turn, the configured bandwidth is within a larger system bandwidth, and the reference signal sequence overlays the system bandwidth according to a defined mapping between respective sequence elements constituting the reference signal sequence and respective subcarriers constituting the system bandwidth.

(22) The processing circuitry is further configured to signal the value to the wireless communication device. Such signaling enables the wireless communication device to determine the overlaying portion of the reference signal sequence and correspondingly identify which sequence elements of the reference signal sequence are associated with the subcarriers in the configured bandwidth.

(23) Of course, the present invention is not limited to the above features and advantages. Those of ordinary skill in the art will recognize additional features and advantages upon reading the following detailed description, and upon viewing the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 is a diagram of example CRS and DMRS transmission.
- (2) FIG. 2 is a block diagram of one embodiment of a wireless communication network.
- (3) FIG. 3 is a diagram of one embodiment of a defined mapping between a reference signal sequence and a system bandwidth.
- (4) FIG. 4 is a diagram illustrating resource elements corresponding to a time-frequency grid.
- (5) FIG. 5 is a block diagram illustrating example embodiments of a wireless communication device and a network node.
- (6) FIG. 6 is a logic flow diagram illustrating one embodiment of a method of processing at a wireless communication device.
- (7) FIG. 7 is a logic flow diagram illustrating one embodiment of a method of processing at a network node.
- (8) FIGS. 8 and 9 are diagrams illustrating example cases of victim and aggressor devices having overlapping scheduled bandwidths.

DETAILED DESCRIPTION

- (9) FIG. 2 illustrates one embodiment of a wireless communication network **16**, “network **16**”. The network **16** provides one or more communication services to a wireless communication device **12**, “device **12**”, such as by communicatively coupling the device **12** to one or more external networks **14** such as the Internet or other Packet Data Networks, PDNs. The network **16** includes a Radio Access Network, RAN, **18**. The RAN **18** includes one or more radio network nodes **20**, which may be referred to as base stations, access points, transmission points, etc. A Core Network, CN, **22** provides, e.g., mobility management and packet routing for the device **12**, and includes one or more CN nodes **24**, such as packet gateways, mobility management entities, authentication servers, etc. The network **16** may further include or be associated with one or more cloud-based or centralized processing nodes that provide processing services for various functions within the network **16**.
- (10) The diagram shall be understood as being simplified, as the network **16** may include multiple other nodes of the same or different types, and may include multiple radio network nodes **20** and may include more than one RAN and may operate with more than one Radio Access Technology, RAT. In one example, different types of radio network nodes **20** provide a heterogeneous radio access network, which may involve more than one RAT. Further, in the context of New Radio, NR, 5G implementations, the network **16** may use beamforming, e.g., wherein allocated beams within a potentially large plurality of beams from one or more radio network nodes **20** are used to provide coverage to the device **12**.
- (11) Still further, unless otherwise noted, the terms “device,” “wireless communication device,” “user equipment,” and “UE” are used interchangeably herein. Unless otherwise specified, the device **12** comprises essentially any apparatus configured for wirelessly connecting to the network **16** via any one or more of the Radio Access Technologies, RATs, used by the network **16**. The device **12** may be mobile, although fixed devices are also contemplated, and non-limiting examples

include cellular radiotelephones, which may be smartphones or feature phones, laptops, tablets, wireless modems or adapters, Machine-to-Machine, M2M, or Machine-Type-Communication, MTC, devices, Internet-of-Things, IoT, devices, etc.

(12) FIG. 3 depicts an example embodiment contemplated in the context of the device 12 and the network 16, where a system bandwidth 30 is associated with the network 16. As a non-limiting example, the system bandwidth represents the air-interface bandwidth supported by a radio network node 20 in the RAN 18, operating as an NR transmission point or transceiver. The device 12 supports a fraction of the system bandwidth 30, which constitutes a plurality of frequency subcarriers 32. The subcarriers 32 may be numbered from low to high frequency, high to low frequency, or according to some other ordered scheme. Thus, FIG. 3 may be regarded as depicting a scenario where the operation bandwidth capabilities of the radio network node 20 differ from the operation bandwidth capabilities of the device 12.

(13) The device 12 is associated with a configured bandwidth 34, as configured by the network 16, which is contained within the system bandwidth 30 but comports with the bandwidth limitations of the device 12. The network 16 schedules the device 12, for data transmissions or receptions, using a scheduled bandwidth 36, which is contained within the configured bandwidth 34. A given node 20 in the RAN 18 may support many devices 12 within its system bandwidth 30 and may locate the corresponding configured bandwidths 34 at various positions within the overall system bandwidth 30.

(14) As a non-limiting example, the collection of subcarriers 32 shown as constituting the system bandwidth 30—seen on the left side of the page—may be numbered according to some global scheme. Correspondingly, a reference signal sequence 40—seen on the right side of the page—maps to or aligns with the system bandwidth 30. The correspondence between respective sequence elements 42 in the reference signal sequence 40 and respective subcarriers 32 in the system bandwidth 30 is suggested by the horizontal alignment shown between them in the diagram.

(15) However, the depicted mapping is shown by way of example and not limitation, and it will be appreciated that the general idea here is that there is a defined association between subcarriers 32 in the system bandwidth 30 and sequence elements 42 in the reference signal sequence 40. In an example, the reference signal sequence 40 comprises a DMRS sequence generated such that each sequence element 42 depends on the number of its corresponding subcarrier 32, which subcarriers 32 are numbered within the “global” system bandwidth 30. See, for example, the DMRS sequence generation scheme explained in the Background of this disclosure for LTE.

(16) Within this framework, then, the sequence elements 42 that correspond to the subcarriers 32 included within the scheduled bandwidth 36 of a given device 12 depend on where the scheduled bandwidth 36 is positioned within the system bandwidth 30. In the diagrammed example, the configured bandwidth 34 of the device 12 is positioned at a frequency offset relative to a starting point of the system bandwidth 30, and the scheduled bandwidth 36 is positioned at a further offset relative to the start of the configured bandwidth 34. Here, it may be noted that the scheduled bandwidth 36 size and position may vary within configured bandwidth 34, as part of ongoing scheduling operations. Referencing the global numbering of the system bandwidth 30, the configured bandwidth 34 starts at point A in the system bandwidth 30 and goes to point C in the system bandwidth 30, while the scheduled bandwidth 36 goes from points B to C.

(17) Because the reference signal sequence 40 maps to, corresponds to, aligns with, or “overlays” the system bandwidth 30, according to a defined mapping, a particular portion 44 of the reference signal sequence 40 overlays the scheduled bandwidth 36 of the device 12. According to the labeling, the sequence elements 42 going from point E to point F in the reference signal sequence 40 overlay—map to—the subcarriers 32 going from point B to C in the system bandwidth 30. More generally, the sequence segment from point D to F overlays the bandwidth segment from point A to C.

(18) FIG. 4 illustrates another view of the system bandwidth 30, this time shown in the context of a

time-frequency grid, where the intersection between transmission times and subcarriers **32** represents “resource elements” or REs **38**. It will be understood that the transmission or reception of a sequence element **42** on its corresponding subcarrier **32** means the transmission or reception on a resource element **38** defined on that subcarrier **32**.

(19) With the above framework in mind, methods and apparatuses disclosed herein enable the device **12** to determine the overlaying portion **44** of the reference signal sequence **40**, without having to know the system bandwidth **30**. In at least some embodiments, the device **12** determines the overlaying portion **44** of the reference signal sequence **40** without an explicit knowledge of where its scheduled bandwidth **36** is positioned within the system bandwidth **30**.

(20) FIG. 5 depicts example embodiments of a device **12** and a network node **50**, which are configured to carry out the respective device-side and network-side operations disclosed herein. The node **50** may be implemented in various network locations, such as in the RAN **18**, in the CN **22**, or as a cloud-based node **26**. Further, the node **50** may comprise two or more nodes—i.e., its functionality may be distributed. In at least one embodiment, the node **50** is co-located with or implemented in the radio network node **20** seen in FIG. 2, and it will be understood that there may be multiple such nodes **20** in the network **16**.

(21) Wherever implemented, in an example embodiment the node **50** includes communication circuitry **52** that is configured for communicating directly or indirectly with the device **12**. For example, the communication circuitry **52** includes radio frequency, RF, transceiver circuitry, i.e., transmit and receive circuits, configured for transmitting signals on the downlink to one or more devices **12** and for receiving signals on the uplink from such devices **12**. Additionally, or alternatively, the communication circuitry **52** includes one or more network or computer data interfaces, for communicating with one or more other nodes in the network **16**. In at least one such example, the node **50** communicates indirectly with the device **12** by sending signaling towards another node that provides the air interface for wirelessly coupling to the device **12**.

(22) The node **50** further includes processing circuitry **54** that is operatively associated with the communication circuitry **52** and includes or is associated with storage **56**. The processing circuitry **54** comprises fixed circuitry, or programmed circuitry, or a mix of fixed and programmed circuitry. In at least one embodiment, the processing circuitry **54** comprises one or more microprocessors, Digital Signal Processors, DSPs, Field Programmable Gate Arrays, FPGAs, Application Specific Integrated Circuits, ASICs, or other digital processing circuitry. In at least one such embodiment, the processing circuitry **54** is configured according to the teachings herein based on its execution of computer program instructions stored in one or more computer programs **58** held in the storage **56**. The storage **56** may further hold one or more items of configuration data **60** that are pre-provisioned and/or dynamically acquired by the processing circuitry **54**.

(23) In one or more embodiments, the storage **56** comprises one or more types of computer-readable media, such as a mix of nonvolatile memory circuits or disk storage, along with volatile, working memory. Non-limiting examples of non-volatile storage include Solid State Disk, SSD, storage, FLASH, and EEPROM, while non-limiting examples of volatile, working memory include DRAM or SRAM circuitry.

(24) In at least one embodiment, the communication circuitry **52** is configured to communicate directly or indirectly with a device **12** operating in the network **16**, and the processing circuitry **54** is operatively associated with the communication circuitry **52** and configured to perform several functions or operations. The processing circuitry **54** is configured to determine a value from which the device **12** can determine which portion of a reference signal sequence **40** overlays a scheduled bandwidth **36** of the device **12**.

(25) As before, that portion of the reference signal sequence **40** is referred to as an overlying portion **44**, and the scheduled bandwidth **36** is in a configured bandwidth **34** that is configured for the device **12**. In turn, the configured bandwidth **34** lies within the system bandwidth **30**. A defined mapping determines the correspondence between sequence **40** and the system bandwidth **30**, i.e.,

defines a mapping between respective sequence elements **42** constituting the reference signal sequence **40** and respective subcarriers **32** constituting the system bandwidth **30**. Here, the configured bandwidth **34** for the wireless communication device **12** may be configured by the processing circuitry **54**. Similarly, the scheduled bandwidth **36** may be dynamically selected by the processing circuitry **54**, as part of a scheduling function implemented therein.

(26) The processing circuitry **54** is further configured to signal the value to the device **12**, thereby enabling the device **12** to determine the overlaying portion **44** of the reference signal sequence **40** and correspondingly identify which sequence elements **42** of the reference signal sequence **40** are associated with the subcarriers **32** in the scheduled bandwidth **36**. For example, the value may be signaled to the device **12** in conjunction with configuring the configured bandwidth **34**.

(27) The processing circuitry **54** in one example determines the value as a seed value for seeding a sequence element generation function at the wireless communication device. Because the seed value controls where in the reference signal sequence **40** the generator “begins”, the processing circuitry **54** can provide the device **12** with the applicable sequence offset on an implicit basis. That is, the processing circuitry **54** can provide the device **12** with the seed value corresponding to the start of its configured bandwidth **34**, such that sequence element generation at the device **12** begins with the first sequence element **42** in the configured bandwidth **34**.

(28) Because the device **12** knows the position of its scheduled bandwidth **36** within the configured bandwidth **34**, knowing the starting sequence element **42** means that it knows the sequence elements **42** that correspond to the subcarriers **32** in its scheduled bandwidth **36**—i.e., it knows the overlaying portion **44** of the reference signal sequence **40**. Advantageously, the approach works without the device **12** having to know the system bandwidth **30** and without the device having to know the position of its configured bandwidth **34** within the system bandwidth **30**. Significant reductions in signaling overhead and bandwidth management complexity attend the approach.

(29) In another example, the processing circuitry **54** is configured to determine the value it signals to the device **12** as an offset value that identifies a sequence offset corresponding to the overlaying portion **44** of the reference signal sequence **40**, or that identifies a position offset of the configured bandwidth **34** within the system bandwidth **30**. In this latter case, the sequence offset is derivable at the wireless communication device **12**. In a similar approach, the processing circuitry **54** is configured to determine the value as an offset value that relates the configured bandwidth **34** to a reference position within the system bandwidth **30**.

(30) In the same or another embodiment and with respect to an uplink transmission received at the network **16** from a device **12**, the processing circuitry **54** is configured to determine which sequence elements from an uplink reference signal sequence are included in, or interfere with, the uplink transmission. The determination is based on a position of the scheduled bandwidth **36** within the system bandwidth **30** and the defined mapping.

(31) Although the device **12** may be less complex than the node **50**, it may similarly comprise digital processing circuitry and associated communication circuitry. From the example of FIG. 5, the device **12** includes communication circuitry **72** that is configured for receiving downlink signals from the network **16** and transmitting uplink signals to the network **16**. For example, the communication circuitry **72** includes radio frequency, RF, transceiver circuitry configured for transmitting on the uplink to one or more radio network nodes **20** and for receiving on the downlink from one or more radio network nodes **20**. The communication circuitry **72** may also support Device-to-Device, D2D, communications directly with other devices **12** and may include WLAN communications, Bluetooth communications, Near-Field Communication, NFC, etc.

(32) The device **12** further includes processing circuitry **74** that is operatively associated with the communication circuitry **72** and includes or is associated with storage **76**. The processing circuitry **74** comprises fixed circuitry, or programmed circuitry, or a mix of fixed and programmed circuitry. In at least one embodiment, the processing circuitry **74** comprises one or more microprocessors, DSPs, FPGAs, ASICs, or other digital processing circuitry.

(33) In at least one such embodiment, the processing circuitry **74** is configured according to the teachings herein based on the execution of computer program instructions stored in one or more computer programs **78** held in storage **76**. The storage **76** may further hold one or more items of configuration data **80** that are pre-provisioned and/or dynamically acquired by the processing circuitry **74**. The configuration data **80** includes, for example, the value signaled to the device **12** by the network **16**, for determining the overlaying portion **44** of the reference signal sequence **40**.

(34) In one or more embodiments, the storage **76** comprises one or more types of computer-readable media, such as a mix of nonvolatile memory circuits or disk storage and volatile, working memory. Non-limiting examples of non-volatile storage include SSD storage, FLASH, and EEPROM, while non-limiting examples of the volatile, working memory include DRAM or SRAM circuitry.

(35) The communication circuitry **72** is configured for wirelessly communicating with one or more nodes in the network **16**, e.g., with one or more radio network nodes **20**. The processing circuitry **74** is operatively associated with the communication circuitry **72**, e.g., it obtains data or control information via received signals incoming to the communication circuitry **72**, and it sends data or control information via signals transmitted from communication circuitry **72**. Further, the processing circuitry **74** is configured to determine, based on information received from the network **16**, a sequence offset for a reference signal sequence **40** and determine, based on the sequence offset, which portion of the reference signal sequence **40** overlays a scheduled bandwidth **36** of the device **12**.

(36) The overlaying portion referred to as an overlaying portion **44** of the reference signal sequence **40** and, as noted before, the scheduled bandwidth **36** is a portion of a larger, system bandwidth **30** associated with the network **16**. In this context, the reference signal sequence **40** overlays the system bandwidth **30** according to a defined mapping between respective sequence elements **42** constituting the reference signal sequence **40** and respective subcarriers **32** constituting the system bandwidth **30**.

(37) In an example embodiment, the processing circuitry **74** is configured to perform at least one of: transmit one or more of the sequence elements **42** contained in the overlaying portion **44** of the reference signal sequence **40**; decode based on one or more of the sequence elements **42** contained in the overlaying portion **44** of the reference signal sequence **40**; cancel interference based on one or more of the sequence elements **42** contained in the overlaying portion **44** of the reference signal sequence **40**; and estimate a channel based on one or more of the sequence elements **42** contained in the overlaying portion **44** of the reference signal sequence **40**.

(38) In at least some embodiments, the information received from the network **16** directly or indirectly indicates a position of a configured bandwidth **34** within the system bandwidth **30**. Correspondingly, the processing circuitry **74** is configured to determine the sequence offset based on the position of the configured bandwidth **34** and a position of the scheduled bandwidth **36** within the configured bandwidth **34**. That is, the position of the configured bandwidth **34** within the system bandwidth **30** defines a first offset into the reference signal sequence **40**, and the position of the scheduled bandwidth **36** within the configured bandwidth **34** defines a further offset into the reference signal sequence **40**.

(39) A seed value also may be provided by the network **16** as the information used by the processing circuitry **74** to determine the sequence offset. Here, the processing circuitry **74** is configured to determine the sequence offset implicitly, by using the seed value to seed a sequence element generation function, wherein the seed value is a function of the sequence offset. In operation, the sequence element generation function, as seeded by the seed value, generates sequence elements **42** corresponding to the configured bandwidth **34** of the device **12**. The scheduled bandwidth **36** lies within the configured bandwidth **34** and the processing circuitry **74** is configured to determine the overlaying portion **44** of the reference signal sequence **40**, based on a position of the scheduled bandwidth **36** within the configured bandwidth **34**.

(40) In another example, the information received from the network **16** indicates an offset relating a position of a configured bandwidth **34** of the device **12** to a reference position within the system bandwidth **30**, e.g., a reference subcarrier. Correspondingly, the processing circuitry **74** is configured to determine the sequence offset based on the position of the configured bandwidth **34** in relation to the reference position, and further based on a position of the scheduled bandwidth **36** within the configured bandwidth **34**.

(41) Knowing which sequence elements **42** correspond to the subcarriers **32** in its scheduled bandwidth **36** enables the device **12** to perform one or more receive and/or transmit operations. For example, knowing which sequence element **42** maps to a given subcarrier **32** within its scheduled bandwidth **36** allows the processing circuitry **74** to estimate the interference arising at the device **16** from the reception of that sequence element **42** from another node or device in the network **16**.

(42) Here it should be understood that there may be more than one sequence element **40** defined within the network **16**, e.g., a base sequence and one or more cyclically-shifted versions of the base sequence. If all such sequences **40** have the same element-to-subcarrier mapping defined relative to the system bandwidth **30**, the device **16** may not know precisely which sequence element **42** it receives as interference, but it will know the set of possible sequence elements **42**, which greatly limits the number of interference hypotheses it must consider.

(43) Thus, in at least some embodiments, the processing circuitry **74** is configured to estimate interference at the device **12**, as arising from a reference signal transmission by another device or node, as a function of one or more of the sequence elements **42** contained in the overlaying portion **44** of a reference signal sequence **40**. The sequence elements **42** contained in the overlaying portion **44** of the reference signal sequence **40** depend on a cyclic shift used by the interfering node or device, and the processing circuitry **74** is configured to estimate the interference by hypothesizing the cyclic shift according to a known set of possible cyclic shifts.

(44) FIGS. **6** and **7** depict example embodiments of processing at a device **12** and a network node **50**, respectively. The method **600**, as performed by a device **12**, includes determining (Block **602**), based on information received from the network **16**, a sequence offset for a reference signal sequence **40**, and determining (Block **604**), based on the sequence offset, which portion of the reference signal sequence **40** overlays a scheduled bandwidth **36** of the device **12**. The method **600** may further include an earlier step or operation of receiving the information in question, such as during a configuration operation in which the network **16** determines the configured bandwidth **34** of the device **16**.

(45) The method **700**, as performed by a network node **50**, includes determining (Block **702**) a value from which a device **12** can determine which portion of a reference signal sequence **40** overlays a scheduled bandwidth **36** of the device **12**, and signaling (Block **704**) the value to the device **12**. As before, the scheduled bandwidth **36** is contained within a configured bandwidth **34** of the device **12**, and the method **700** may further include a step or operation of configuring the configured bandwidth **34** for the device **12** and signaling the value to the device **12** may occur in conjunction with the bandwidth configuration operations. Signaling such information to the device **12** enables it to determine the overlaying portion **44** of the reference signal sequence **40** and correspondingly identify which sequence elements **42** of the reference signal sequence **40** are associated with the subcarriers **32** in the scheduled bandwidth **36**.

(46) In further example details for at least some embodiments, an offset parameter, which may also be referred to as a “value” or as “information”, is signaled from the network **16** to the device **12**, which enables the device **12** to determine the sequence elements **42** of a reference signal sequence **40** that overlap with its scheduled bandwidth **36** or its configured bandwidth **34**. The reference signal sequence **40** is, for example, a DMRS sequence, and its sequence elements are numbered globally, e.g., relative to the system bandwidth **30**. The device **12** may not know the system bandwidth **30**.

(47) With the reference signal sequence **40** and its constituent sequence elements **42** being referred

to as a DMRS sequence and DMRS sequence elements, one possibility is that the signaled parameter enables the device **12** to determine the DMRS sequence element that is mapped to the lowest frequency of its configured bandwidth **34**. The offset parameter indicates the start of the DMRS sequence, for example. The offset parameter could, of course, be configured to indicate the DMRS sequence element mapped to other positions, such as the highest frequency, the middle frequency, etc.

(48) FIG. **8** depicts a corresponding example involving victim device **12** and two aggressor devices—e.g., the victim device **12** is a first UE and the two aggressor devices are other, nearby UEs. Based on the signaled parameters, the device **12** can determine that DMRS sequence element **3** is the sequence element that maps to the first DMRS position within its configured bandwidth **34**. So, in the simplest case, the parameter signaled to the device **12** by the network **16** could indicate “3”.

(49) The signaled parameter—**3** in the example—together with the scheduling assignment, which typically is relative to the device's configured bandwidth **34**, enables the device **12** to determine the DMRS sequence positions that correspond to the frequency positions represented by its scheduled bandwidth **36**. That is, in FIG. **8**, receiving the signaled value of “3” from the network **16** enables the device **12** to know that the bottom frequency position of its configured bandwidth **34** is “3”, which corresponds to the DMRS sequence position **3**, DRMS**3**. As the device **12** knows the position of its scheduled bandwidth **36** within the configured bandwidth **34**, the device **12** then knows that the frequency positions contained in its scheduled bandwidth correspond to or map with DMRS sequence positions **4**, **5**, and **6**.

(50) The actual values of the DMRS sequence elements that map to its scheduled bandwidth **36** can be derived from device **12** specific parameters and/or cell-wide parameters such as virtual cell ID. In principle, it is also possible that the signaled parameter directly indicates the first or a specified DMRS sequence element of the scheduled bandwidth **36** instead of the configured bandwidth **34**. However, there may be certain advantages associated with relating the parameter to the configured bandwidth **34**. For example, the parameter would need to be signaled only with changes in the configured bandwidth **34**.

(51) If the device **12** only supports a fraction of the system bandwidth **30**, the device **12** is configured with a bandwidth after the device **12** makes an initial access. In at least one embodiment, the parameter required to determine the DMRS sequence alignment with the device's scheduled bandwidth **36** is derivable at the device **12** from the configuration and explicit signaling is not needed.

(52) In a related embodiment, a reference subcarrier in the system bandwidth **30** is defined. For example, the primary synchronization signal, PSS, is transmitted by the network **16** and received and detected by the device **12**. The center position of the detected PSS can be identified as the reference subcarrier, or, more generally, any subcarrier **32** in the system bandwidth **30** can be defined as a reference subcarrier. The operating bandwidth that is configured to the device **12** is signaled, by indicating a frequency distance relative to the reference subcarrier **32**. The distance may be indicated in terms of subcarriers **32**, or corresponding Resource Blocks, etc.

(53) The DMRS sequence $r(m)$ is generated per subcarrier m relative to the reference subcarrier, where m may be both positive and negative, as to create a global numbering scheme. Knowing the frequency distance from the reference subcarrier, although it is outside the operating bandwidth for the device **12**, enables the device **12** to determine the DMRS sequence for its scheduled resource blocks.

(54) Now consider the aggressor devices **1** and **2** seen in FIG. **8**. Each aggressor device has a scheduled bandwidth that at least partially overlaps the scheduled bandwidth **36** of the device **12**. With the global numbering scheme, any frequency position that is common between the scheduled bandwidth **36** of the device **12** and the aggressor devices **1** and **2** will map to the same DMRS sequence position. Thus, if the device **12** knows which DMRS sequences could be in use at the aggressor devices, it knows precisely which DMRS sequence elements could be received at the

device **12** from the aggressor devices, on the subcarriers **32** included in its scheduled bandwidth **36**. (55) For example, there may be a limited number of DMRS sequences defined, e.g., by using a base DMRS sequence and a defined set of cyclic shifts. Each cyclic shift can be thought of as producing a different DMRS sequence. However, the sequence elements in each such DMRS sequence all observe the global mapping, i.e., the sequence positions in each DMRS sequence map to the frequency positions of the system bandwidth **30** per the same global numbering and mapping. Thus, the actual value of the sequence element in sequence position “x” in a first DMRS sequence will differ from the value of sequence element in sequence position “x” in a second DMRS sequence. However, the sequence position “x” from both sequences maps to the same frequency position in the global system bandwidth. Therefore, assuming as a simplified example that there are five DRMS sequences that could be used by a transmitter, there are no more than five possible sequence element values that could be transmitted by the transmitter in the sequence position “x”. Correspondingly, for a subcarrier **32** corresponding to the sequence position “x”, a receiver being interfered with by those transmissions could limit its interference hypotheses to the set of five possible sequence element values.

(56) In other words, if the device **12** knows the DMRS sequences that are possible for use at the aggressor devices—e.g., knows the possible cyclic shifts—it knows the universe of values possible for the DRMS sequence element(s) it receives on the subcarrier **32** corresponding to the involved sequence position. As seen in the figure, due to the global numbering of the DMRS sequence elements, the interfering DMRS sequence elements from the aggressor devices **1** and **2** overlapping the scheduled bandwidth **36** of the device **12** are also elements **4** to **6**. To cancel DM-RS interference, the device **12** needs only to test one or a few sequence candidates, but not different sequence positions. The device **12** could, for example, know the cell ID from neighboring transmission points—e.g., radio network nodes **20**—and derive the one or few DM-RS sequences connected to the transmission point from the virtual cell ID of that transmission point.

(57) Another possibility for the network **16** to provide the information needed by the device **12** to determine the DMRS sequence positions that correspond to the frequency positions of its scheduled bandwidth **36** is to signal a seed value. Often the sequence used for DMRS is a pseudo-random sequence generated by a pseudo random sequence generator that is initialized with a specified seed value, e.g., c_init . The pseudo random sequence generator could be initialized with a seed value and generates a sequence which is then mapped to the global DMRS sequence starting with sequence element **0**, which is mapped to the lowest DM-RS element within the system bandwidth **36**.

(58) In FIG. **8**, the 4th sequence element is the first DM-RS element within the configured bandwidth **34** of the device **12**. Thus, the pseudo random sequence generator in the device **12** could be configured with the seed value that produces the same pseudo random sequence but starting with sequence element **4**, labeled as DMRS3 in the diagram.

(59) In a further embodiment, there is a set of possible seed values c_init , corresponding to a set of reference subcarriers within the system bandwidth. The device **12** is signaled the offset to the nearest reference subcarrier and the identity of the reference subcarrier. To generate the DMRS sequence $r(m)$, corresponding to a c_init , the shift register values need to be stored. For example, if m -sequences are used as in LTE, $x_1(n)$, $x_2(n)$ needs to be stored for a range of n . A device **12** can store the shift register memory values corresponding to the sequence elements mapped to a set of reference subcarriers, e.g., with 100 MHz spacing. Depending if the device **12** is located to 0 to 100 MHz (original c_init) or $n*100$ to $(n+1)*100$ MHz ($n=1, 2, 3$, three c_init values) it would initialize the random generator with the original c_init or one of the three other c_init values. The benefit of this is that the forward generation of a sequence would be limited to at most 100 MHz, which is the longest distance from the device's configured bandwidth **34** to a reference subcarrier. Otherwise, for very large system bandwidths, e.g., 1 GHz, the forward generation of the sequence $r(m)$ to the configured bandwidth **34** would be demanding.

(60) Broadly, the network **16** in one or more embodiments is configured to signal a parameter to a device **12** that the device **12** uses to determine its reference signal, i.e., to determine which portion of a reference signal sequence corresponds to its scheduled bandwidth **36**. This arrangement enables the device **12** to determine which DMRS sequence elements apply to the scheduled bandwidth **36**, without the device **12** having to know the system bandwidth **30** or the position of its scheduled bandwidth **36** within the system bandwidth **30**. Such an approach allows the network **16** to relate or map DMRS sequence positions to frequency positions in the system bandwidth **30** using a global numbering scheme.

(61) The parameter signaled by the network **16** to a device **12** could be an offset parameter that informs the device **12** which part to “cut out” of a global DMRS sequence, e.g., it could be the reference signal sequence element number that maps to the beginning of the configured bandwidth **34** of the device **12**. This parameter, together with the device's knowledge of where its scheduled bandwidth **36** is within its configured bandwidth **34**, would enable the device **12** to determine the reference signal sequence elements mapped to its scheduled bandwidth **36**. The signaled parameter could also be a seed parameter that informs the device **12** how to initialize its pseudo random sequence generator, assuming a pseudo random sequence is used for DM-RS. The first generated sequence element would again correspond to the reference signal sequence element mapped to the beginning of the device's configured bandwidth **34**.

(62) Such operations enable a global numbering of DMRS sequences relative to system bandwidth, even if the device **12** is not aware of the system bandwidth **30** or its bandwidth position relative to the system bandwidth **30**. Independent of victim and aggressor frequency position, a victim device **12** knows which sequence element numbers of the aggressor DM-RS sequence overlap its scheduled bandwidth **36** and by that can easily cancel the interfering DMRS. In the simplest case, the DMRS only depend on the cell ID or a similar parameter such as virtual cell ID; if the victim device **12** knows the cell ID of the interfering node it also knows the interfering sequence elements. In a practical setup, a given transmission point may be associated with one cell ID but may create pseudo orthogonal reference signals. Even in this case, if the victim device **12** knows the cell ID it only has to test a few candidate sequences to cancel interference arising at the device **12** from transmission of the reference signal(s) by the transmission point.

(63) FIG. **9** emphasizes this scenario by showing the global alignment between reference signal sequence positions for a victim device **12** and two aggressor devices **1** and **2**. Particularly, one sees that the same sequence position numbering—which generally relates to the frequency position numbering of the system bandwidth **30**—applies to the victim device **12** and to the aggressor devices **1** and **2**. That is, the portion **44-1** of a reference signal sequence that overlays the scheduled bandwidth of the victim device **12** uses the same sequence position numbering/mapping as is used for the portions **44-2** and **44-3** that overlay the scheduled bandwidths of the aggressor devices **1** and **2**. Note that actual reference signal sequences are not necessarily the same for the three devices. That is, the sequence element associated sequence position **4** in each of the overlaying portions **44-1**, **44-2**, and **44-3**, may have a different value, but the alignment or mapping of that sequence position is the same for all three devices.

(64) Taking a broad understanding of the above details, one or more reference signal sequences **40** are available or defined for use in a wireless communication network **16**. Each such reference signal sequence **40** comprises a series or set of sequence elements **42**, with each sequence element occupying a corresponding position in the reference signal sequence **40**. The network **16**, e.g., a given radio network node **20**, uses a global numbering scheme for its system bandwidth **30**, e.g., a global numbering scheme for the frequency subcarriers **32** constituting its system bandwidth **30**. Each subcarrier **32** may be regarded as occupying a frequency position, and the network **16** uses a defined mapping that relates reference signal positions to frequency positions.

(65) A device **12** is configured with a configured bandwidth **34**, where the configured bandwidth **34** is positioned somewhere within the system bandwidth **30**. In operation, the device **12** uses a

scheduled bandwidth **36** that occupies all or a portion of the configured bandwidth **34**. Because of the defined mapping or alignment between reference signal sequence positions and frequency positions, the sequence positions that correspond with the frequency positions associated with the device's scheduled bandwidth **36** are dictated by where the scheduled bandwidth **36** is positioned within the system bandwidth **30**. However, according to the teachings herein, the device **12** does not need to know the system bandwidth **30**, or even know the position of its configured/scheduled bandwidth **34/36**, to know which reference signal sequence positions correspond to its scheduled bandwidth **36**. Those needs are obviated by the network **16** signaling information to the device **12** from which the device **12** can implicitly or explicitly determine the sequence offset corresponding to its system bandwidth **36**.

(66) Notably, modifications and other embodiments of the disclosed invention(s) will come to mind to one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. As one example, the teachings herein have applicable both to the uplink and the downlink in a wireless communication network. Therefore, it is to be understood that the invention(s) is/are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of this disclosure. Although specific terms may be employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

Claims

1. A method of operation at a wireless communication device configured for operation in a wireless communication network, the method comprising: determining, based on information received from a network node in the network, a sequence offset for a demodulation reference signal (DMRS) sequence; determining, based on the sequence offset, which reference signal sequence elements of the DMRS sequence map to a scheduled bandwidth of the wireless communication device; and transmitting one or more of the determined DMRS sequence elements of the DMRS sequence; wherein the scheduled bandwidth is a portion of a larger, system bandwidth associated with the network, and where the DMRS sequence elements map to the system bandwidth according to a mapping between respective DMRS sequence elements and respective subcarriers constituting the system bandwidth.
2. The method of claim 1, wherein the information received from the network node indicates a position of a configured bandwidth within the system bandwidth, wherein determining the sequence offset comprises determining the sequence offset based on the position of the configured bandwidth and a position of the scheduled bandwidth, and wherein the scheduled bandwidth is contained within the configured bandwidth.
3. The method of claim 1, wherein the information received from the network node indicates a seed value, and wherein determining the sequence offset comprises determining the sequence offset by using the seed value to seed a sequence element generation function, wherein the seed value is a function of the sequence offset.
4. The method of claim 1, wherein the information received from the network node indicates an offset relating a position of a configured bandwidth of the wireless communication device to a reference position within the system bandwidth, and wherein determining the sequence offset comprises determining the sequence offset based on the position of the configured bandwidth in relation to the reference position, and further based on a position of the scheduled bandwidth within the configured bandwidth.
5. A wireless communication device configured for operation in a wireless communication network and comprising: communication circuitry configured for wirelessly communicating with one or more nodes in the network; and processing circuitry operatively associated with the communication circuitry and configured to: determine, based on information received from a network node in the

network, a sequence offset for a demodulation reference signal (DMRS) sequence; and determine, based on the sequence offset, which DMRS sequence elements of the DMRS sequence map to a scheduled bandwidth of the wireless communication device; and transmit one or more of the determined DMRS sequence elements of the DMRS sequence; wherein the scheduled bandwidth is a portion of a larger, system bandwidth associated with the network, and where the DMRS sequence elements map to the system bandwidth according to a mapping between respective DMRS sequence elements and respective subcarriers constituting the system bandwidth.

6. The wireless communication device of claim 5, wherein the information received from the network node indicates a position of a configured bandwidth within the system bandwidth, wherein the processing circuitry is configured to determine the sequence offset based on the position of the configured bandwidth and a position of the scheduled bandwidth, and wherein the scheduled bandwidth is contained within the configured bandwidth.

7. The wireless communication device of claim 5, wherein the information received from the network node indicates a seed value, and wherein the processing circuitry is configured to determine the sequence offset, by using the seed value to seed a sequence element generation function, wherein the seed value is a function of the sequence offset.

8. The wireless communication device of claim 5, wherein the information received from the network node indicates an offset relating a position of a configured bandwidth of the wireless communication device to a reference position within the system bandwidth, and wherein the processing circuitry is configured to determine the sequence offset based on the position of the configured bandwidth in relation to the reference position, and further based on a position of the scheduled bandwidth within the configured bandwidth.
