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Wang et al.

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(54) **APERIODIC CSI-RS RESOURCE SET TRIGGERING BY DCI WITH APERIODIC TRIGGERING OFFSET**

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H04W 72/1273 (2023.01)

(52) **U.S. Cl.**
CPC *H04W 72/1273* (2013.01)

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CPC H04L 5/0035; H04L 5/005; H04L 5/0053; H04L 5/0094; H04W 72/1273
See application file for complete search history.

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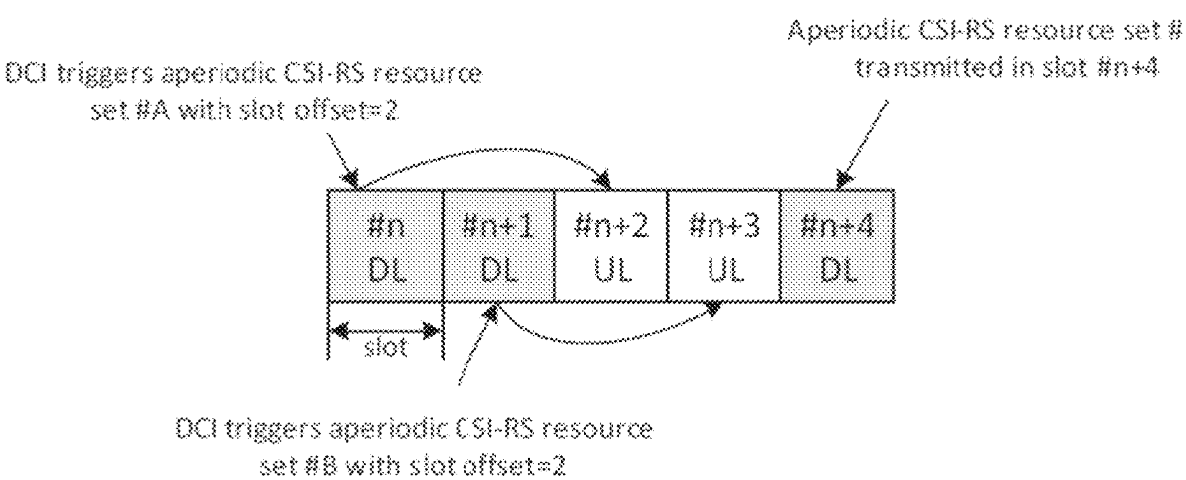
(74) *Attorney, Agent, or Firm* — Schwegman Lundberg & Woessner, P.A.

(57) **ABSTRACT**

A generation node B (gNB) configured for aperiodic channel state information reference signal (CSI-RS) triggering and transmission may encode signalling for transmission to a user equipment (UE). The signalling to indicate an aperiodic Triggering Offset (aperiodicTriggeringOffset). The aperiodic Triggering Offset may comprise a slot offset. The gNB may encode a downlink control information (DCI) for transmission that may trigger transmission of a CSI-RS in one or more aperiodic CSI-RS resource set(s) (i.e., in one or more slots (n)). The DCI triggers transmission of the aperiodic CSI-RS within a triggered slot with the slot offset (i.e., the aperiodic TriggeringOffset). The gNB may transmit the CSI-RS in resource elements of the triggered slot in accordance with the slot offset, when CSI-RS resources are available in the slot at the slot offset. The gNB may postpone transmission of the aperiodically triggered CSI-RS to a first available downlink slot when the CSI-RS resources are not available in the triggered slot at the slot offset.

20 Claims, 10 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 63/104,425, filed on Oct. 22, 2020.

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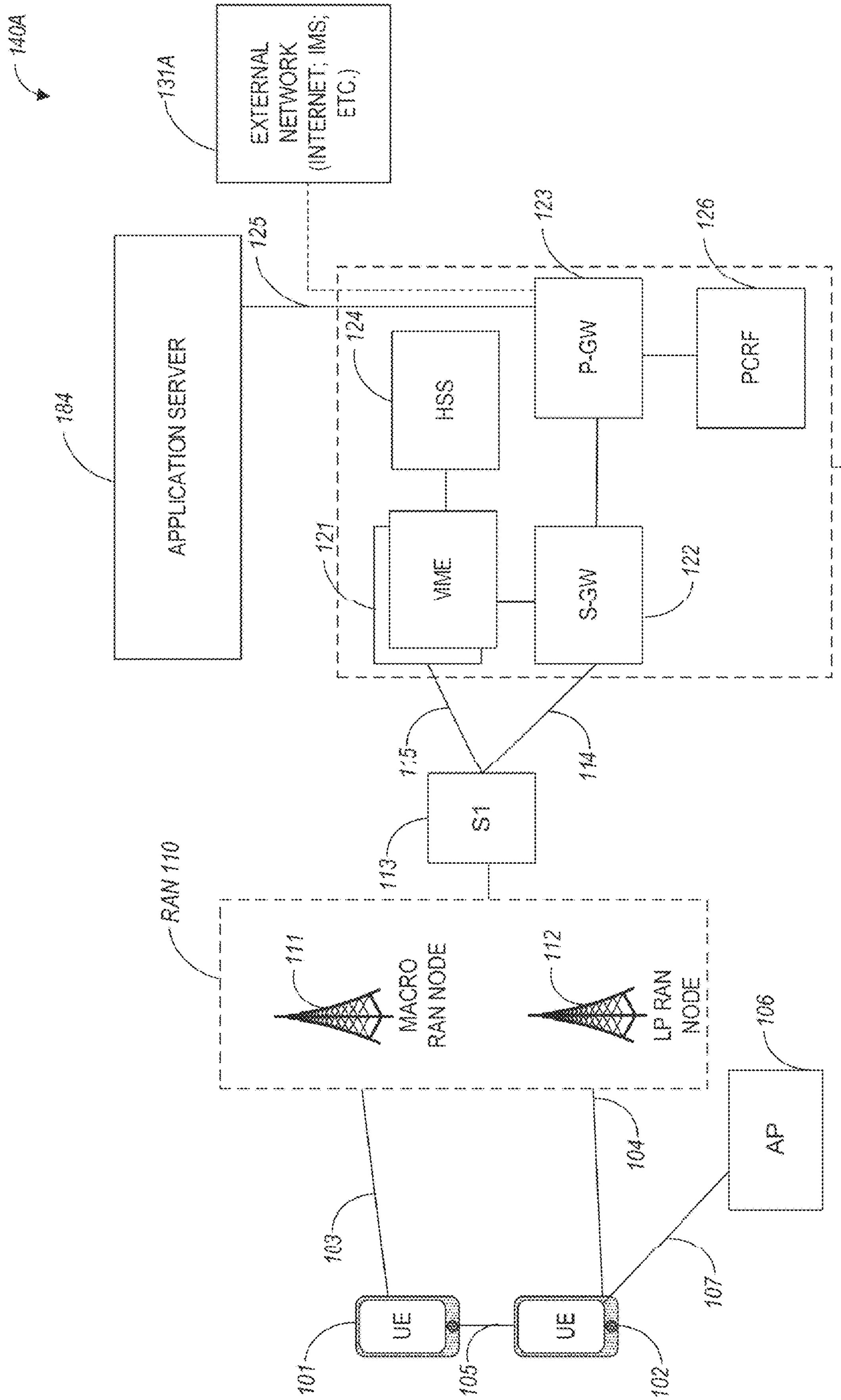
140A
131A
EXTERNAL NETWORK (INTERNET, IMS, ETC.)
184
APPLICATION SERVER
125
123
126
124
HSS
P-GW
PCRF
121
MME
S-GW
122
CN (EPC) 120
115
114
S1
113
RAN 110
111
MACRO RAN NODE
112
LP RAN NODE
106
AP
104
103
107
UE
UE
101
105
102

FIG. 1A

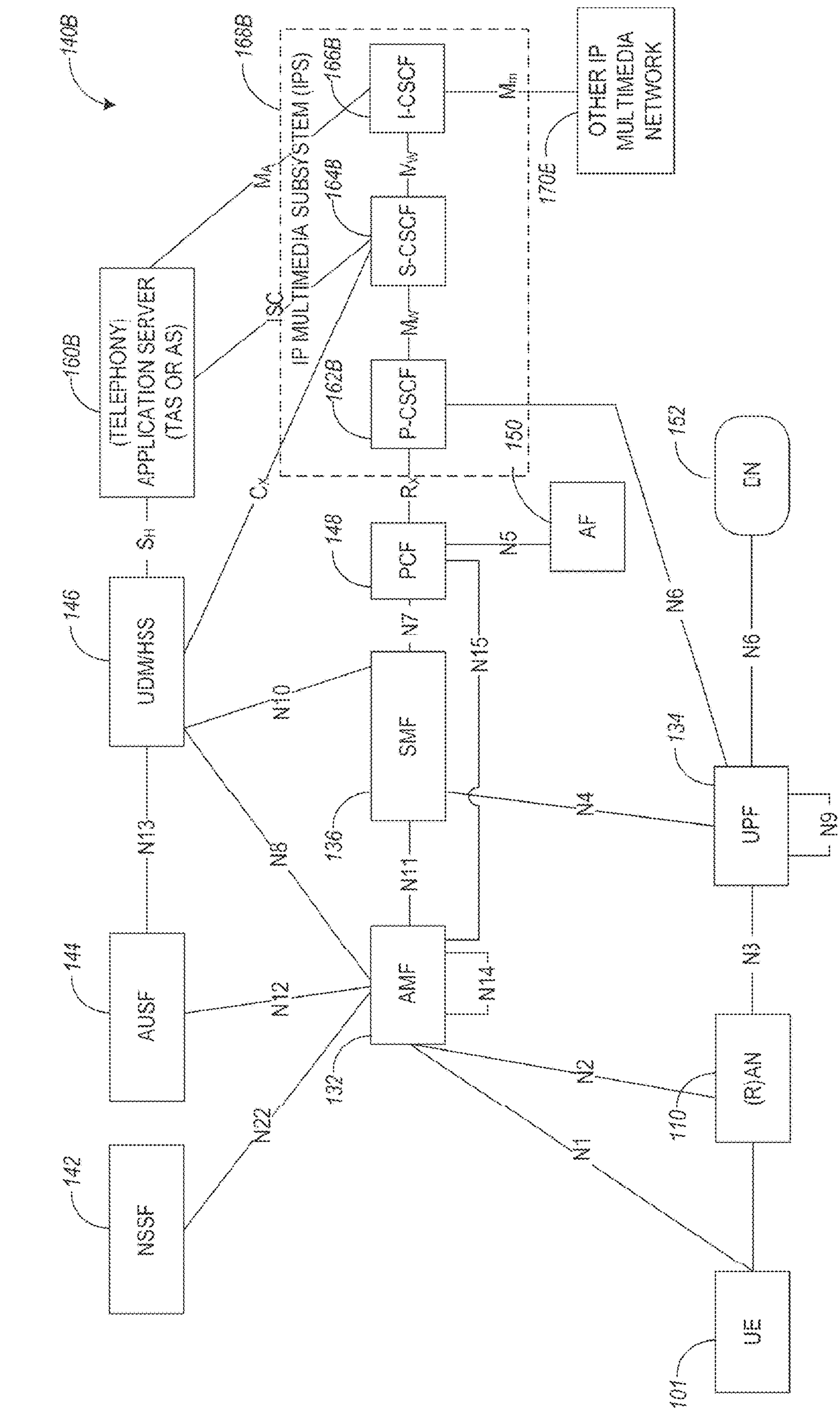
140B
168B
IP MULTIMEDIA SUBSYSTEM (IPS)
166B
I-CSCF
164B
S-CSCF
162B
P-CSCF
OTHER IP MULTIMEDIA NETWORK
170E
(TELEPHONY) APPLICATION SERVER (TAS OR AS)
160B
UDM/HSS
146
AUSF
144
NSSF
142
AMF
132
SMF
136
PCF
148
AF
150
DN
152
UPF
134
(R)AN
110
UE
101
N1
N2
N3
N4
N5
N6
N7
N8
N9
N10
N11
N12
N13
N14
N15
N22
ISC
Cx
Rx
Mw
Mr
Mm

FIG. 1B

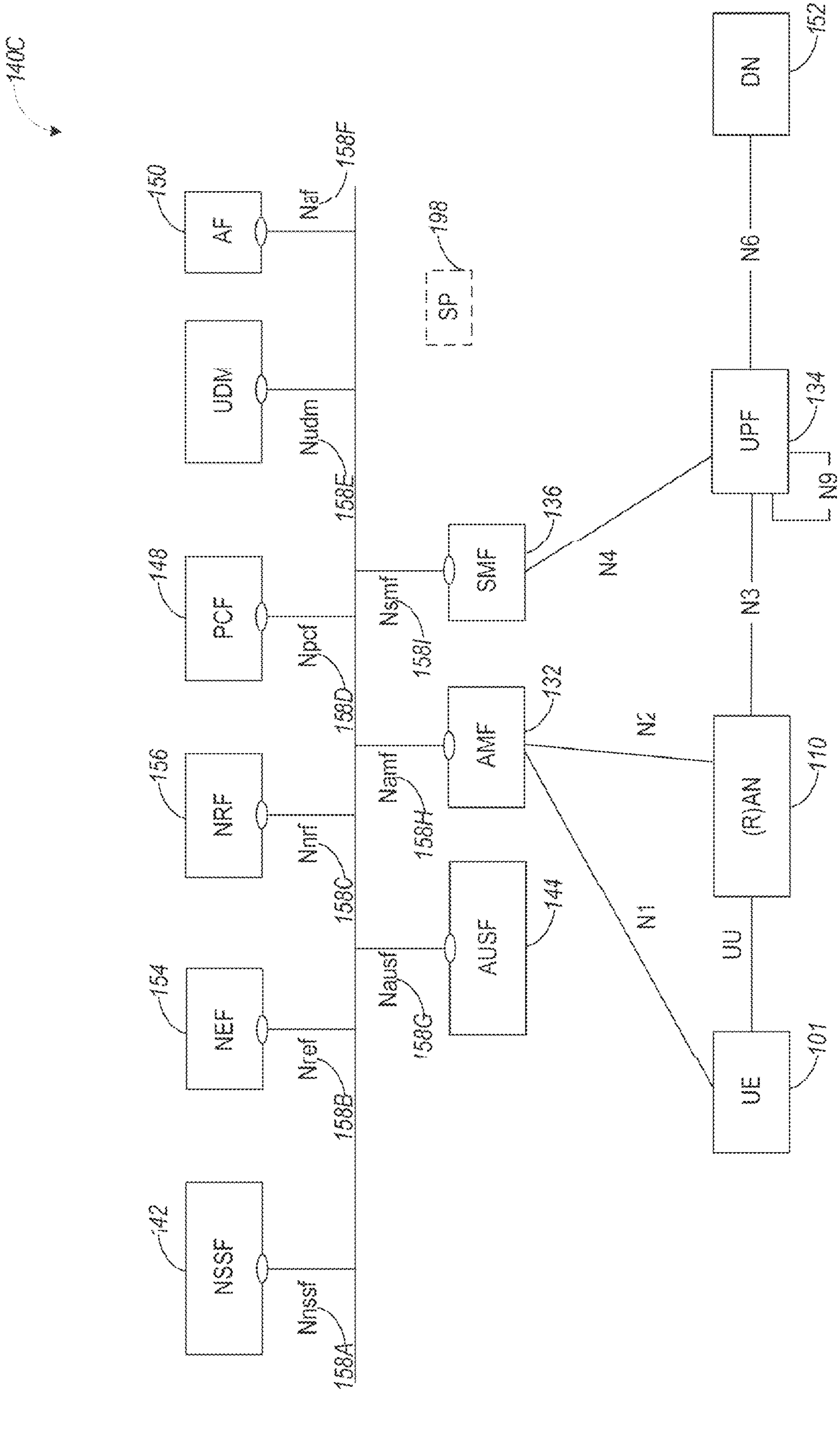
140C
NSSF
142
Nnssf
158A
NEF
154
Nnef
158B
NRF
156
Nnrf
158C
PCF
148
Npcf
158D
UDM
Nudm
158E
AF
150
Naf
158F
AUSF
144
Nausf
158G
AMF
132
Namf
158H
SMF
136
Nsmf
158I
SP
198
UE
101
UU
(R)AN
110
N1
N2
N3
N4
UPF
134
N9
N6
DN
152

FIG. 1C

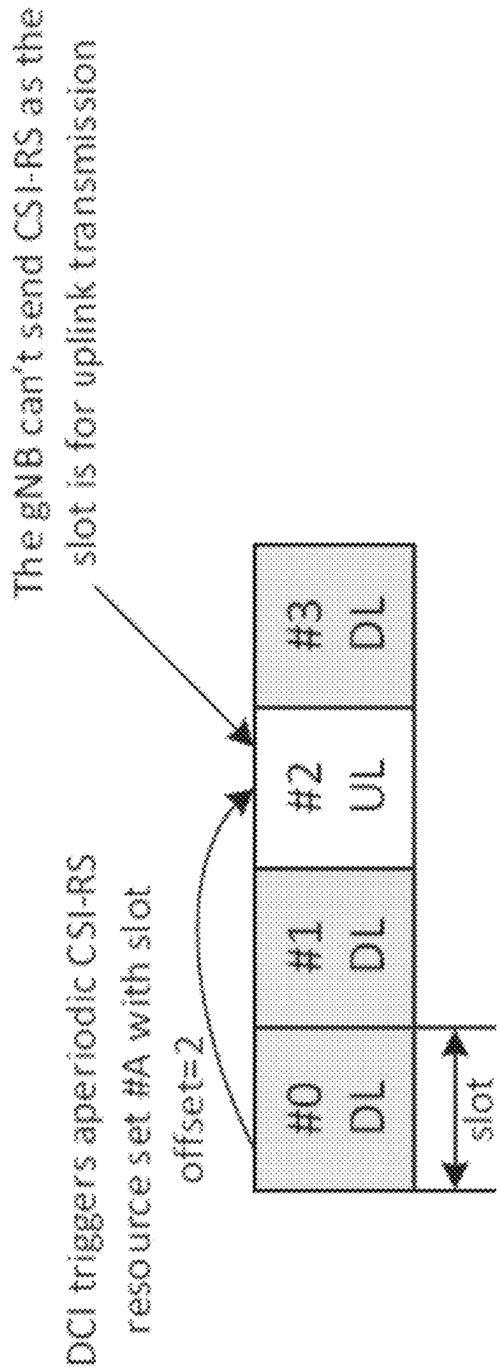
The gNB can't send CSI-RS as the slot is for uplink transmission
DCI triggers aperiodic CSI-RS resource set #A with slot offset=2
#0 DL
#1 DL
#2 UL
#3 DL
slot

FIG. 2A

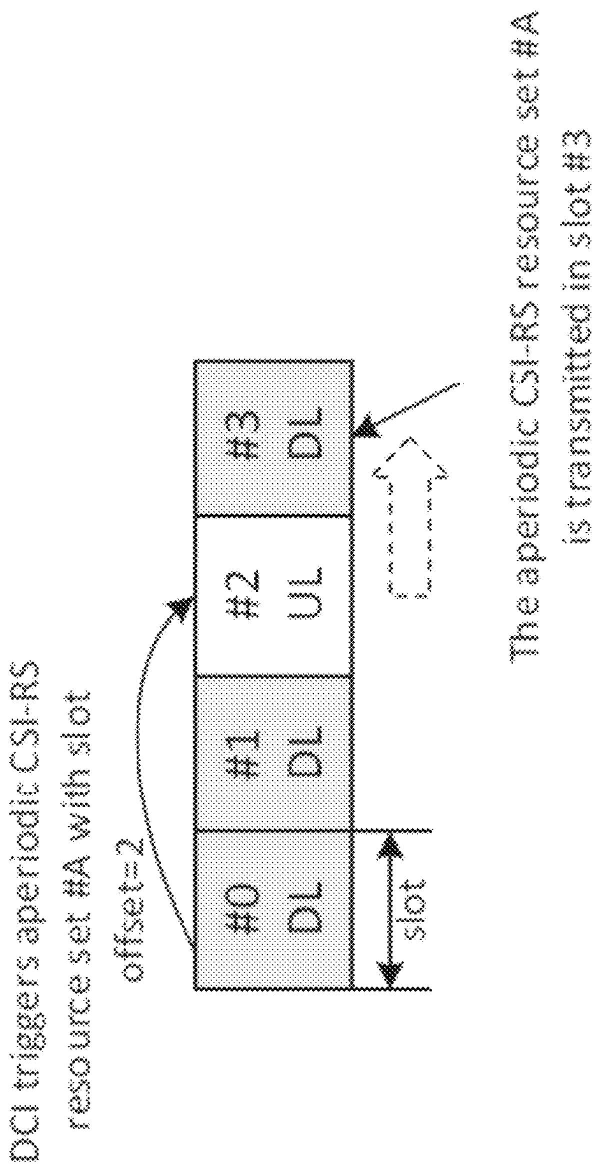
DCI triggers aperiodic CSI-RS resource set #A with slot offset=2
#0 DL
#1 DL
#2 UL
#3 DL
slot
The aperiodic CSI-RS resource set #A is transmitted in slot #3

FIG. 2B

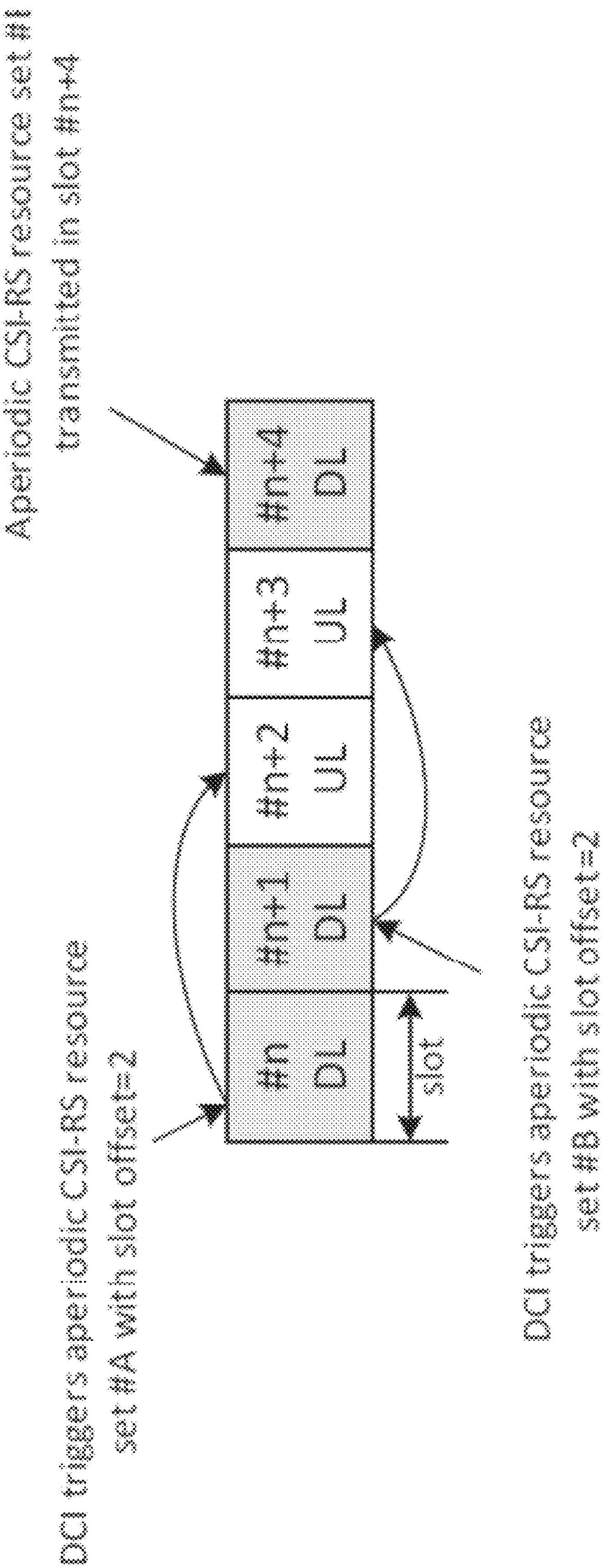
Aperiodic CSI-RS resource set #I transmited in slot #n+4
#n DL
#n+1 DL
#n+2 UL
#n+3 UL
#n+4 DL
slot
DCI triggers aperiodic CSI-RS resource set #A with slot offset=2
DCI triggers aperiodic CSI-RS resource set #B with slot offset=2

FIG. 3

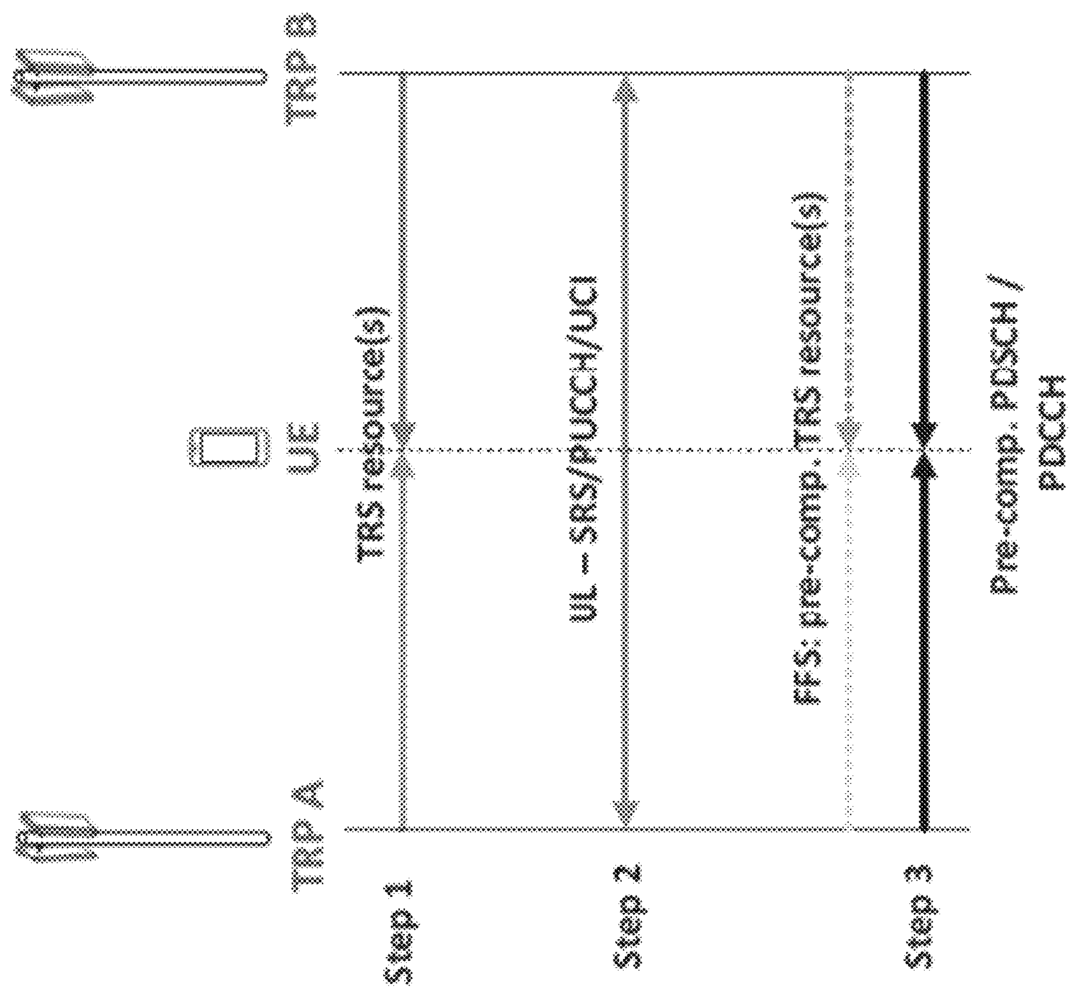
TRP A
UE
TRP B
Step 1
TRS resource(s)
Step 2
UL – SRS/PUCCH/UCI
Step 3
FFS: pre-comp. TRS resource(s)
Pre-comp. PDSCH /
PDCCH

FIG. 4

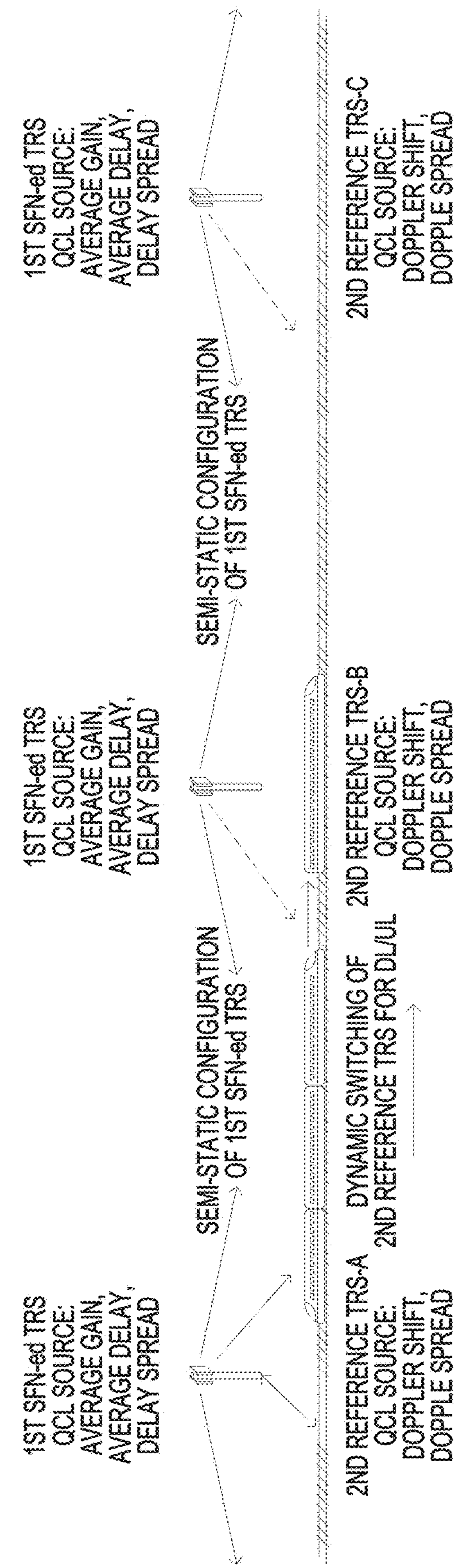
1ST SFN-ed TRS
QCL SOURCE:
AVERAGE GAIN,
AVERAGE DELAY,
DELAY SPREAD
SEMI-STATIC CONFIGURATION
OF 1ST SFN-ed TRS
1ST SFN-ed TRS
QCL SOURCE:
AVERAGE GAIN,
AVERAGE DELAY,
DELAY SPREAD
SEMI-STATIC CONFIGURATION
OF 1ST SFN-ed TRS
1ST SFN-ed TRS
QCL SOURCE:
AVERAGE GAIN,
AVERAGE DELAY,
DELAY SPREAD
2ND REFERENCE TRS-A
QCL SOURCE:
DOPPLER SHIFT,
DOPPLE SPREAD
DYNAMIC SWITCHING OF
2ND REFERENCE TRS FOR DL/UL
2ND REFERENCE TRS-B
QCL SOURCE:
DOPPLER SHIFT,
DOPPLE SPREAD
2ND REFERENCE TRS-C
QCL SOURCE:
DOPPLER SHIFT,
DOPPLE SPREAD

FIG. 5

Table 1 Possible UL TCI structure to support TRP pre-compensation

Type of 1^{st} DL reference signal and ID, (e.g. TRS of the reference TRS)	Type of 2^{nd} DL reference signal and ID, (e.g. TRS of the non-reference TRP)
Usage of 1^{st} DL reference signal (e.g., carrier frequency)	Usage of 2^{nd} DL reference signal (e.g. UL power control, spatial Tx filter)

FIG. 6

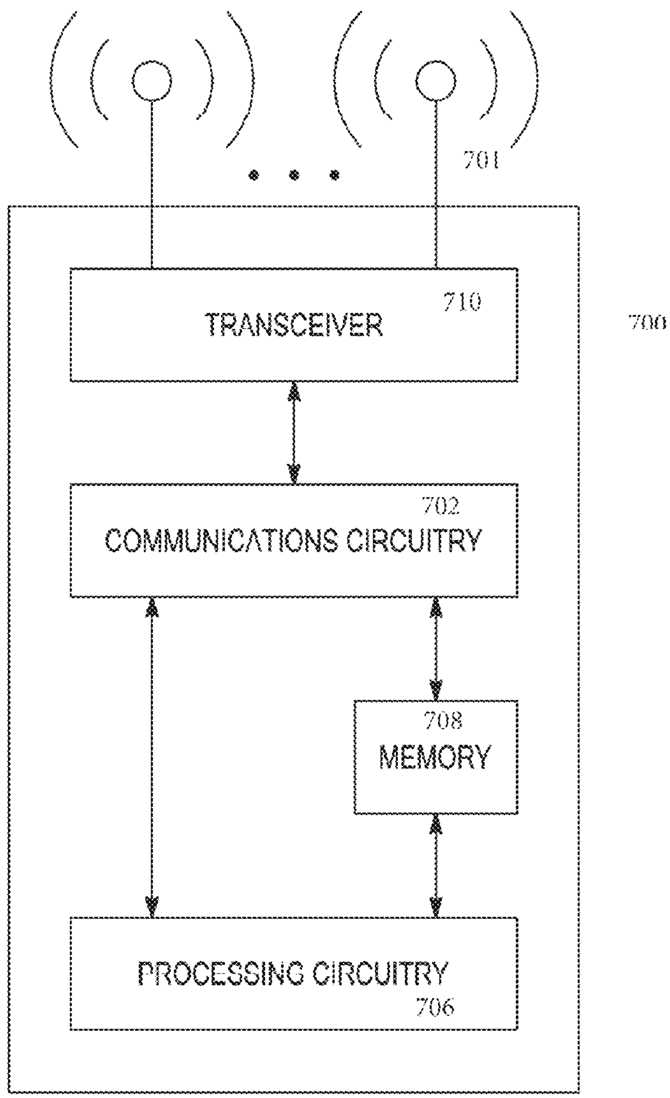
701
TRANSCEIVER
710
700
702
COMMUNICATIONS CIRCUITRY
708
MEMORY
PROCESSING CIRCUITRY
706

FIG. 7

APERIODIC CSI-RS RESOURCE SET TRIGGERING BY DCI WITH APERIODIC TRIGGERING OFFSET

PRIORITY CLAIM

This application is a continuation of U.S. patent application Ser. No. 17/496,323, filed Oct. 7, 2021, which claims priority to International Application No. PCT/CN2020/121603, filed Oct. 16, 2020, and which claims the benefit of priority under 35 USC 119(e) to U.S. Provisional Patent Application Ser. No. 63/104,425, filed Oct. 22, 2020, each of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

Some embodiments relate to wireless networks including 3GPP (Third Generation Partnership Project) and fifth-generation (5G) networks including 5G new radio (NR) (or 5G-NR) networks. Some embodiments relate to sixth-generation (6G) networks. Some embodiments relate to channel state information reference signal (CSI-RS) configuration and transmission. Some embodiments relate to downlink transmission by multiple transmission reception points (TRPs) with frequency offset compensation.

BACKGROUND

Mobile communications have evolved significantly from early voice systems to today's highly sophisticated integrated communication platform. With the increase in different types of devices communicating with various network devices, usage of 3GPP 5G NR systems has increased. The penetration of mobile devices (user equipment or UEs) in modern society has continued to drive demand for a wide variety of networked devices in many disparate environments. 5G NR wireless systems are forthcoming and are expected to enable even greater speed, connectivity, and usability, and are expected to increase throughput, coverage, and robustness and reduce latency and operational and capital expenditures. 5G-NR networks will continue to evolve based on 3GPP LTE-Advanced with additional potential new radio access technologies (RATs) to enrich people's lives with seamless wireless connectivity solutions delivering fast, rich content and services. As current cellular network frequency is saturated, higher frequencies, such as millimeter wave (mmWave) frequency, can be beneficial due to their high bandwidth.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates an architecture of a network, in accordance with some embodiments.

FIG. **1**B and FIG. **1**C illustrate a non-roaming 5G system architecture in accordance with some embodiments.

FIG. **2**A illustrates an example of aperiodic CSI-RS triggering in accordance with some embodiments.

FIG. **2**B illustrates postponed aperiodic CSI-RS transmission in accordance with some embodiments.

FIG. **3** illustrates multiple pending CSI-RS resource sets in accordance with some embodiments.

FIG. **4** illustrates a high-level flow of TRP-based frequency offset compensation in accordance with some embodiments.

FIG. **5** illustrates the signalling rate for TRS reconfiguration in accordance with some embodiments.

FIG. **6** illustrates Table 1 showing an example UL TCI structure in accordance with some embodiments.

FIG. **7** illustrates a functional block diagram of a wireless communication device in accordance with some embodiments.

SUMMARY

A user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) network decodes Radio Resource Control (RRC) signalling received from a gNB. The RRC signalling indicates an aperiodic Triggering Offset (aperiodicTriggeringOffset) for aperiodic channel state information reference signal (CSI-RS) resources. The aperiodic Triggering Offset indicates an offset comprising a value indicating a number of slots between a first slot containing a downlink control information (DCI) that triggers a set of aperiodic CSI-RS resources and a second slot in which the set is transmitted by the gNB. The UE decodes the DCI triggers the set of aperiodic CSI-RS resources and determines, based on the offset and the first slot containing the DCI, a location of the second slot. The UE may receive the set of aperiodic CSI-RS resources in the second slot.

DETAILED DESCRIPTION

The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

Some embodiments relate to aperiodic channel state information reference signal (CSI-RS) resource set triggering by downlink control information (DCI) with aperiodic Triggering Offset. In these embodiments, a generation node B (gNB) may be configured for aperiodic channel state information reference signal (CSI-RS) triggering and transmission. In these embodiments, the gNB may be is configured to encode signalling for transmission to a user equipment (UE). The signalling may indicate an aperiodic Triggering Offset (aperiodicTriggeringOffset). The aperiodic Triggering Offset may comprise a slot offset. In these embodiments, the gNB may encode a downlink control information (DCI) for transmission. The DCI may trigger transmission of a CSI-RS in one or more aperiodic CSI-RS resource set(s) (i.e., in one or more slots (n)). In these embodiments, the DCI triggers transmission of the aperiodic CSI-RS within a triggered slot with the slot offset (i.e., the aperiodicTriggeringOffset). The gNB may transmit the CSI-RS in resource elements of the triggered slot in accordance with the slot offset, when CSI-RS resources are available in the slot at the slot offset. In these embodiments, the gNB may postpone transmission of the aperiodically triggered CSI-RS to a first available downlink slot when the CSI-RS resources are not available in the triggered slot at the slot offset.

In these embodiments, the DCI is used to trigger transmission of a CSI-RS in a slot (i.e., CSI-RS resource sets are triggered). In these embodiments, the CSI-RS resource may comprise a CSI-RS signal transmitted on the specific set of resource elements within a physical resource block (PRB) configured by the network. A slot may correspond to 14 adjacent OFDM symbols. One CSI-RS resource may be transmitted in a slot, although the scope of the embodiments is not limited in this respect. Conventionally, a CSI-RS may be aperiodically triggered by downlink control information (DCI) transmitted via a physical downlink control channel (PDCCH). The DCI may contain special bits indicating to the UE whether CSI-RS is transmitted in slot with slot offset configured by RRC.

In some embodiments, the signalling encoded to indicate the aperiodic Triggering Offset comprises Radio Resource Control (RRC) signalling.

In some embodiments, the signalling encoded to indicate the aperiodic Triggering Offset comprises a medium-access control layer control element (MAC-CE). In some embodiments, the gNB may encode a new MAC-CE to update the slot offset.

In some embodiments, the gNB may refrain from transmitting the aperiodically triggered CSI-RS when a collision would occur with a higher priority signal in the slot at the slot offset.

In some embodiments, for non-DCI triggered transmission of a CSI-RS, the gNB may configure parameters for a CSI-RS to a UE with RRC signalling to indicate a slot offset relative to a PDCCH, and encode a DCI for transmission on the PDCCH, the DCI indicating whether the configured CSI-RS is transmitted.

Some embodiments are related downlink frequency offset compensation by multiple transmission reception points (TRPs). In these embodiments, the gNB may use multiple TRPs for communicating with a UE. In these embodiments, for downlink frequency offset compensation by the multiple TRPs, the gNB may encode a downlink (DL) transmit control indicator (TCI) for a downlink channel. The DL TCI may comprise first and second tracking reference signal (TRS) configurations. In these embodiments, the first TRS configuration indicates a first one or more quasi co-location (QCL) parameters and the second TRS configuration indicates a second one or more QCL parameters. In these embodiments, the TRPs may be configured for transmission of TRSs in accordance with the first and second TRS configurations.

In some embodiments, the first TRS configuration indicates QCL parameters comprising average gain, average delay, and delay spread, but not including QCL parameter Doppler shift. In these embodiments, the second TRS configuration may indicate the QCL parameter Doppler shift, and the QCL parameter Doppler spread may be included in either the first or the second TRS configuration. In some embodiments, the DL TCI is for either a physical downlink shared channel (PDSCH) or a physical downlink control channel (PDCCH).

Some embodiments are directed to a user equipment (UE) configured for aperiodic channel state information reference signal (CSI-RS) triggering and transmission by a generation Node B (gNB). In these embodiments, the UE may be configured to decode signalling from the gNB. The signalling may indicate an aperiodic Triggering Offset (aperiodicTriggeringOffset). The aperiodic Triggering Offset may comprise a slot offset. In these embodiments, the UE may decode a downlink control information (DCI) from the gNB. The DCI may trigger transmission of a CSI-RS in one or more aperiodic CSI-RS resource set(s). In these embodiments, the DCI may trigger transmission of the aperiodic CSI-RS within a triggered slot with the slot offset (i.e., the aperiodic TriggeringOffset). The UE may also be configured to receive the CSI-RS in resource elements of the triggered slot in accordance with the slot offset when CSI-RS resources are available in the slot at the slot offset. In these embodiments, transmission of the aperiodically triggered CSI-RS by the gNB may be postponed to a first available downlink slot when the CSI-RS resources are not available in the triggered slot at the slot offset.

These embodiments are described in more detail below.

FIG. **1**A illustrates an architecture of a network in accordance with some embodiments. The network **140**A is shown to include user equipment (UE) **101** and UE **102**. The UEs **101** and **102** are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks) but may also include any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, drones, or any other computing device including a wired and/or wireless communications interface. The UEs **101** and **102** can be collectively referred to herein as UE **101**, and UE **101** can be used to perform one or more of the techniques disclosed herein.

Any of the radio links described herein (e.g., as used in the network **140**A or any other illustrated network) may operate according to any exemplary radio communication technology and/or standard.

LTE and LTE-Advanced are standards for wireless communications of high-speed data for UE such as mobile telephones. In LTE-Advanced and various wireless systems, carrier aggregation is a technology according to which multiple carrier signals operating on different frequencies may be used to carry communications for a single UE, thus increasing the bandwidth available to a single device. In some embodiments, carrier aggregation may be used where one or more component carriers operate on unlicensed frequencies.

Embodiments described herein can be used in the context of any spectrum management scheme including, for example, dedicated licensed spectrum, unlicensed spectrum, (licensed) shared spectrum (such as Licensed Shared Access (LSA) in 2.3-2.4 GHz, 3.4-3.6 GHZ, 3.6-3.8 GHz, and further frequencies and Spectrum Access System (SAS) in 3.55-3.7 GHZ and further frequencies).

Embodiments described herein can also be applied to different Single Carrier or OFDM flavors (CP-OFDM, SC-FDMA, SC-OFDM, filter bank-based multicarrier (FBMC), OFDMA, etc.) and in particular 3GPP NR (New Radio) by allocating the OFDM carrier data bit vectors to the corresponding symbol resources.

In some embodiments, any of the UEs **101** and **102** can comprise an Internet-of-Things (IoT) UE or a Cellular IoT (CIoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. In some embodiments, any of the UEs **101** and **102** can include a narrowband (NB) IoT UE (e.g., such as an enhanced NB-IoT (eNB-IoT) UE and Further Enhanced (FeNB-IoT) UE). An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network includes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

In some embodiments, any of the UEs **101** and **102** can include enhanced MTC (eMTC) UEs or further enhanced MTC (FeMTC) UEs.

The UEs **101** and **102** may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) **110**. The RAN **110** may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The UEs **101** and **102** utilize connections **103** and **104**, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections **103** and **104** are illustrated as an air interface to enable communicative coupling and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth-generation (5G) protocol, a New Radio (NR) protocol, and the like.

In an aspect, the UEs **101** and **102** may further directly exchange communication data via a ProSe interface **105**. The ProSe interface **105** may alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

The UE **102** is shown to be configured to access an access point (AP) **106** via connection **107**. The connection **107** can comprise a local wireless connection, such as, for example, a connection consistent with any IEEE 802.11 protocol, according to which the AP **106** can comprise a wireless fidelity (WiFi) router. In this example, the AP **106** is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

The RAN **110** can include one or more access nodes that enable the connections **103** and **104**. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), Next Generation NodeBs (gNBs), RAN nodes, and the like, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). In some embodiments, the communication nodes **111** and **112** can be transmission/reception points (TRPs). In instances when the communication nodes **111** and **112** are NodeBs (e.g., eNBs or gNBs), one or more TRPs can function within the communication cell of the NodeBs. The RAN **110** may include one or more RAN nodes for providing macrocells, e.g., macro-RAN node **111**, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node **112**.

Any of the RAN nodes **111** and **112** can terminate the air interface protocol and can be the first point of contact for the UEs **101** and **102**. In some embodiments, any of the RAN nodes **111** and **112** can fulfill various logical functions for the RAN **110** including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management. In an example, any of the nodes **111** and/or **112** can be a new generation Node-B (gNB), an evolved node-B (eNB), or another type of RAN node.

The RAN **110** is shown to be communicatively coupled to a core network (CN) **120** via an S1 interface **113**. In embodiments, the CN **120** may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN (e.g., as illustrated in reference to FIGS. **1B-1C**). In this aspect, the S1 interface **113** is split into two parts: the S1-U interface **114**, which carries traffic data between the RAN nodes **111** and **112** and the serving gateway (S-GW) **122**, and the S1-mobility management entity (MME) interface **115**, which is a signaling interface between the RAN nodes **111** and **112** and MMEs **121**.

In this aspect, the CN **120** comprises the MMEs **121**, the S-GW **122**, the Packet Data Network (PDN) Gateway (P-GW) **123**, and a home subscriber server (HSS) **124**. The MMEs **121** may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs **121** may manage mobility embodiments in access such as gateway selection and tracking area list management. The HSS **124** may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN **120** may comprise one or several HSSs **124**, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS **124** can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

The S-GW **122** may terminate the S1 interface **113** towards the RAN **110**, and routes data packets between the RAN **110** and the CN **120**. In addition, the S-GW **122** may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities of the S-GW **122** may include a lawful intercept, charging, and some policy enforcement.

The P-GW **123** may terminate an SGi interface toward a PDN. The P-GW **123** may route data packets between the EPC network **120** and external networks such as a network including the application server **184** (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface **125**. The P-GW **123** can also communicate data to other external networks **131**A, which can include the Internet, IP multimedia subsystem (IPS) network, and other networks. Generally, the application server **184** may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this aspect, the P-GW **123** is shown to be communicatively coupled to an application server **184** via an IP interface **125**. The application server **184** can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VOIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs **101** and **102** via the CN **120**.

The P-GW **123** may further be a node for policy enforcement and charging data collection. Policy and Charging Rules Function (PCRF) **126** is the policy and charging control element of the CN **120**. In a non-roaming scenario, in some embodiments, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with a local breakout of traffic, there may be two PCRFs associated with a UE's IP-CAN session: a Home PCRF (H-PCRF) within an HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF **126** may be communicatively coupled to the application server **184** via the P-GW **123**.

In some embodiments, the communication network **140**A can be an IoT network or a 5G network, including 5G new radio network using communications in the licensed (5G NR) and the unlicensed (5G NR-U) spectrum. One of the current enablers of IoT is the narrowband-IoT (NB-IoT).

An NG system architecture can include the RAN **110** and a 5G network core (5GC) **120**. The NG-RAN **110** can include a plurality of nodes, such as gNBs and NG-eNBs. The core network **120** (e.g., a 5G core network or 5GC) can include an access and mobility function (AMF) and/or a user plane function (UPF). The AMF and the UPF can be communicatively coupled to the gNBs and the NG-eNBs via NG interfaces. More specifically, in some embodiments, the gNBs and the NG-eNBs can be connected to the AMF by NG-C interfaces, and to the UPF by NG-U interfaces. The gNBs and the NG-eNBs can be coupled to each other via Xn interfaces.

In some embodiments, the NG system architecture can use reference points between various nodes as provided by 3GPP Technical Specification (TS) 23.501 (e.g., V15.4.0, 2018-12). In some embodiments, each of the gNBs and the NG-eNBs can be implemented as a base station, a mobile edge server, a small cell, a home eNB, and so forth. In some embodiments, a gNB can be a master node (MN) and NG-eNB can be a secondary node (SN) in a 5G architecture.

FIG. **1**B illustrates a non-roaming 5G system architecture in accordance with some embodiments. Referring to FIG. **1**B, there is illustrated a 5G system architecture **140**B in a reference point representation. More specifically, UE **102** can be in communication with RAN **110** as well as one or more other 5G core (5GC) network entities. The 5G system architecture **140**B includes a plurality of network functions (NFs), such as access and mobility management function (AMF) **132**, session management function (SMF) **136**, policy control function (PCF) **148**, application function (AF) **150**, user plane function (UPF) **134**, network slice selection function (NSSF) **142**, authentication server function (AUSF) **144**, and unified data management (UDM)/home subscriber server (HSS) **146**. The UPF **134** can provide a connection to a data network (DN) **152**, which can include, for example, operator services, Internet access, or third-party services. The AMF **132** can be used to manage access control and mobility and can also include network slice selection functionality. The SMF **136** can be configured to set up and manage various sessions according to network policy. The UPF **134** can be deployed in one or more configurations according to the desired service type. The PCF **148** can be configured to provide a policy framework using network slicing, mobility management, and roaming (similar to PCRF in a 4G communication system). The UDM can be configured to store subscriber profiles and data (similar to an HSS in a 4G communication system).

In some embodiments, the 5G system architecture **140**B includes an IP multimedia subsystem (IMS) **168**B as well as a plurality of IP multimedia core network subsystem entities, such as call session control functions (CSCFs). More specifically, the IMS **168**B includes a CSCF, which can act as a proxy CSCF (P-CSCF) **162**BE, a serving CSCF (S-CSCF) **164**B, an emergency CSCF (E-CSCF) (not illustrated in FIG. **1**B), or interrogating CSCF (I-CSCF) **166**B. The P-CSCF **162**B can be configured to be the first contact point for the UE **102** within the IM subsystem (IMS) **168**B. The S-CSCF **164**B can be configured to handle the session states in the network, and the E-CSCF can be configured to handle certain embodiments of emergency sessions such as routing an emergency request to the correct emergency center or PSAP. The I-CSCF **166**B can be configured to function as the contact point within an operator's network for all IMS connections destined to a subscriber of that network operator, or a roaming subscriber currently located within that network operator's service area. In some embodiments, the I-CSCF **166**B can be connected to another IP multimedia network **170**E, e.g., an IMS operated by a different network operator.

In some embodiments, the UDM/HSS **146** can be coupled to an application server **160**E, which can include a telephony application server (TAS) or another application server (AS). The AS **160**B can be coupled to the IMS **168**B via the S-CSCF **164**B or the I-CSCF **166**B.

A reference point representation shows that interaction can exist between corresponding NF services. For example, FIG. **1**B illustrates the following reference points: N1 (between the UE **102** and the AMF **132**), N2 (between the RAN **110** and the AMF **132**), N3 (between the RAN **110** and the UPF **134**), N4 (between the SMF **136** and the UPF **134**), N5 (between the PCF **148** and the AF **150**, not shown), N6 (between the UPF **134** and the DN **152**), N7 (between the SMF **136** and the PCF **148**, not shown), N8 (between the UDM **146** and the AMF **132**, not shown), N9 (between two UPFs **134**, not shown), N10 (between the UDM **146** and the SMF **136**, not shown), N11 (between the AMF **132** and the SMF **136**, not shown), N12 (between the AUSF **144** and the AMF **132**, not shown), N13 (between the AUSF **144** and the UDM **146**, not shown), N14 (between two AMFs **132**, not shown), N15 (between the PCF **148** and the AMF **132** in case of a non-roaming scenario, or between the PCF **148** and a visited network and AMF **132** in case of a roaming scenario, not shown), N16 (between two SMFs, not shown), and N22 (between AMF **132** and NSSF **142**, not shown). Other reference point representations not shown in FIG. **1**B can also be used.

FIG. **1**C illustrates a 5G system architecture **140**C and a service-based representation. In addition to the network entities illustrated in FIG. **1**B, system architecture **140**C can also include a network exposure function (NEF) **154** and a network repository function (NRF) **156**. In some embodiments, 5G system architectures can be service-based and interaction between network functions can be represented by corresponding point-to-point reference points Ni or as service-based interfaces.

In some embodiments, as illustrated in FIG. **1**C, service-based representations can be used to represent network functions within the control plane that enable other authorized network functions to access their services. In this regard, 5G system architecture **140**C can include the following service-based interfaces: Namf **158**H (a service-based interface exhibited by the AMF **132**), Nsmf **158**I (a service-based interface exhibited by the SMF **136**), Nnef **158**B (a service-based interface exhibited by the NEF **154**), Npcf **158**D (a service-based interface exhibited by the PCF **148**), a Nudm **158**E (a service-based interface exhibited by the UDM **146**), Naf **158**F (a service-based interface exhibited by the AF **150**), Nnrf **158**C (a service-based interface exhibited by the NRF **156**), Nnssf **158**A (a service-based interface exhibited by the NSSF **142**), Nausf **158**G (a service-based interface exhibited by the AUSF **144**). Other service-based interfaces (e.g., Nudr, N5g-eir, and Nudsf) not shown in FIG. **1**C can also be used.

In some embodiments, any of the UEs or base stations described in connection with FIGS. **1**A-**1**C can be configured to perform the functionalities described herein.

Mobile communication has evolved significantly from early voice systems to today's highly sophisticated integrated communication platform. The next generation wireless communication system, 5G, or new radio (NR) will provide access to information and sharing of data anywhere, anytime by various users and applications. NR is expected to be a unified network/system that targets to meet vastly different and sometimes conflicting performance dimensions and services. Such diverse multi-dimensional requirements are driven by different services and applications. In general, NR will evolve based on 3GPP LTE-Advanced with additional potential new Radio Access Technologies (RATs) to enrich people's lives with better, simple, and seamless wireless connectivity solutions. NR will enable everything connected by wireless and deliver fast, rich content and services.

Rel-15 NR systems are designed to operate on the licensed spectrum. The NR-unlicensed (NR-U), a short-hand notation of the NR-based access to unlicensed spectrum, is a technology that enables the operation of NR systems on the unlicensed spectrum.

In previous new radio (NR) systems, a next-generation NodeB (gNB) could configure and transmit CSI-RS for channel measurements. Three types of CSI-RS transmissions are supported: periodic, semi-persistent, and aperiodic. Periodic CSI-RS is configured by RRC and periodically transmitted. Semi-persistent CSI-RS is configured by RRC, and the periodic transmission is activated/deactivated by MAC layer signaling (MAC-CE). Aperiodic CSI-RS is configured by RRC, and the transmission is triggered by physical layer signaling (DCI).

If a CSI-RS resource set is configured as 'aperiodic' by RRC, the CSI-RS resource set configuration includes a slot offset, aperiodicTriggeringOffset, which defines the time interval between the triggering DCI and the CSI-RS transmission.

When aperiodic CSI-RS is triggered, the gNB should send CSI-RS according to the slot offset defined by RRC, and accordingly the UE should receive the CSI-RS within the indicated slot. Due to the TDD characteristics, there is some restriction on the slots carrying DCI which triggers aperiodic CSI-RS. In some cases, the gNB may not be able to send the CSI-RS in the indicated slot, for example, if the indicated slot is an uplink slot. As the result, there might be PDCCH resource congestion in the specific DL slots. FIG. **2**A illustrates the issue.

Among other things, embodiments of the present disclosure are directed to aperiodic CSI-RS triggering and transmission. In some embodiments, triggered aperiodic CSI-RS could be postponed if there is no available resource for the transmission.

Postponed Aperiodic CSI-RS Transmission

In an embodiment, when aperiodic CSI-RS resource set(s) is triggered by DCI with aperiodicTriggeringOffset indicated by RRC, if the indicated slot is not downlink slot or the indicated slot is not available for CSI-RS transmission due to collision with other signals, the gNB could postpone the aperiodic CSI-RS transmission.

Assuming the aperiodic CSI-RS triggered by DCI in slot 'n' is configured with slot offset 'x', then the aperiodic CSI-RS is supposed to be transmitted by the gNB within slot 'n+x'. If the aperiodic CSI-RS can't be sent by the gNB in slot 'n+x', then the triggered aperiodic CSI-RS is viewed as pending CSI-RS. If the gNB has available resource for CSI-RS transmission within the time period of slot 'n+x' to slot 'n+x+y', then the pending CSI-RS could be delivered. If there is no available resource for aperiodic CSI-RS transmission within the time period of slot 'n+x' to slot 'n+x+y', then the pending CSI-RS should be cancelled. The value of 'y' could be pre-defined or up to UE capability. After the CSI-RS is delivered or cancelled, the pending status is stopped. FIG. **2**B shows an example of the postponed aperiodic CSI-RS transmission.

In an example, if the aperiodic CSI-RS can't be sent in the indicated slot, the aperiodic CSI-RS will be postponed to the next available downlink slot.

In another example, for aperiodic CSI-RS, the RRC parameter aperiodic TriggeringOffset with value 'i' could be defined as the i-th available slot for aperiodic CSI-RS transmission.

In another example, for aperiodic CSI-RS, the slot offset could be updated via a new MAC-CE.

In another example, for aperiodic CSI-RS, the slot offset could be indicated by RRC and DCI. In addition to the RRC parameter aperiodic TriggeringOffset, additional slot offset could be indicated by DCI. For aperiodic CSI-RS triggered by DCI in slot 'n' which is configured with RRC slot offset of 'x', and additional offset of 'm' is indicated by DCI, the aperiodic CSI-RS is transmitted in slot 'n+x+m'. The additional slot offset in DCI could be explicitly indicated by a new DCI field, e.g., CSI-RS Offset. Alternatively, the additional slot offset in DCI could be implicitly indicated by DCI codepoint. For example, the additional offset indicated by DCI could be defined by RRC as 2, 4, 6, 8 slots. In the DCI, the codepoint (of the new field or the existing CSI request field) indicates corresponding additional slot offset.

In another embodiment, only a subset of the pending CSI-RS resource sets is considered as valid. If the number of the pending aperiodic CSI-RS resource sets exceeds certain value, then some CSI-RS resource sets are dropped. For example, the first CSI-RS resource set is dropped by the latest triggered CSI-RS resource set. Once the gNB has resource for CSI-RS transmission, the gNB only transmit the first CSI-RS resource set in the pending CSI-RS resource set list.

In a special example of this embodiment, only one CSI-RS resource set which is the latest one triggered within K slots is considered to be valid. In this case every new CSI-RS resource set triggering by DCI always overrides the pending CSI-RS resource set. FIG. **3** shows an example of the operation.

In another embodiment, when delivering the pending CSI-RS, there might be collision with other downlink signals, such as PDSCH. Thus, some priority rules should be defined for the transmission. In an example, the CSI-RS transmission is de-prioritized, e.g., if collision happens between aperiodic CSI-RS and other downlink signals, then the CSI-RS is not transmitted but considered as pending for the next transmission opportunity. In another example, the CSI-RS transmission is prioritized, e.g., if collision happens between aperiodic CSI-RS and other downlink signals, then the postponed CSI-RS should be delivered.

In another embodiment, in FR2 different Rx beamforming are used for reception of aperiodic CSI-RS. In particular, if transmission interval between PDCCH and CSI-RS is less than threshold, e.g., corresponding to UE capability value, UE should use default Rx beamforming, where default Rx beamforming could be QCL type D reference signal corresponding to CORESET with lowest ID. Otherwise if the CSI-RS transmission interval is above the threshold the Rx beamforming should be determined according to TCI indication provided in DCI. For postponed CSI-RS transmission, the transmission time interval could be the actual interval between scheduling PDCCH and CSI-RS transmission. In the other example, of this embodiment, the time interval is the time interval is interval indicated by scheduling DCI.

Some embodiments relate to downlink transmission with frequency offset compensation. TRP based frequency offset pre-compensation scheme was identified as candidate for specification. The key idea of the scheme relies on pre-compensation of the frequency offset difference among TRPs relative to the reference TRP (also denoted as anchor TRP). The reference TRP may be any TRP in SFN area, e.g., TRP closest to a given UE.

The following three steps for TRP-based frequency offset pre-compensation scheme.

*1st step: Transmission of the TRS resource(s) from TRP(s) without pre-compensation.

2nd step: Transmission of the uplink signal(s)/channel(s) with carrier frequency determined based on the received TRS signals in the 1st step

3rd step: Transmission of the PDCCH/PDSCH from TRP (s) with frequency offset pre-compensation determined based on the received signal/channel in the 2nd step

Note: A second set of TRS resource(s) may be transmitted at 3rd step.

FIG. **4** illustrates a high-level flow of TRP-based frequency offset compensation in accordance with some embodiments.

Assuming the first TRP as reference, the carrier frequency for UL signal transmission at the UE can be defined as follows

$$\hat{f}_{1,DL} = f_c + \Delta f_d^1 + \Delta f_o,$$

where, f_c is carrier frequency, $\Delta f_d^{\,1}$ is Doppler shift from the first TRP and Δf_o is UE frequency offset due to RF impairments. If the UL signal is transmitted using carrier frequency $\hat{f}_{1,DL}$, the carrier frequency estimated by each TRP from the UL signal can be obtained as follows

$$\hat{f}_{1,UL} = \hat{f}_{DL} + \Delta f_d^1 = f_c + \Delta f_d^1 + \Delta f_o + \Delta f_d^1,$$

$$\hat{f}_{2,UL} = \hat{f}_{DL} + \Delta f_d^2 = f_c + \Delta f_d^1 + \Delta f_0 + \Delta f_d^2,$$

Then, the non-reference TRP calculates frequency pre-compensation value $f_{2,c}$ by taking the difference between the carrier frequencies estimated on the reference and non-reference TRPs as follows

$$f_{2,c} = \hat{f}_{1,UL} - \hat{f}_{2,UL} = \Delta f_d^1 - \Delta f_d^2$$

After pre-compensation the carrier frequency of the DL signal from the non-reference TRP received at the UE would be defined as follows

$$\hat{f}_{2,DL} = f_c + f_{2,c} + \Delta f_d^2 + \Delta f_o = f_c + \Delta f_d^1 + \Delta f_o = \hat{f}_{1,DL}$$

The above value is the same as the carrier frequency of the DL signal from the reference TRP. It can be seen that the above procedure doesn't compensate the frequency offset of the DL signal, but rather trying to align the frequency offset value of the non-reference TRP to the frequency offset of the reference TRP.

TRP based pre-compensation is not supported in NR. This results in complex UE receiver for frequency offset estimation in HST-SFN deployment.

Embodiments herein include methods facilitating frequency offset pre-compensation at TRP for downlink transmissions. Embodiments may provide lower UE complexity and better performance.

Various embodiments may include quasi co-location (QCL) enhancements to support TPR based pre-compensation. In particular, single TRS transmission as in the existing Rel-16 NR would not be sufficient to provide all QCL parameters for PDSCH/PDCCH demodulation.

More specifically, SFN-ed TRS (which is also transmitted for the backward compatibility purpose) can be used by the UE for estimation of all QCL parameters except {Doppler shift, Doppler spread}, e.g., {average delay, delay spread, average gain}. Due to frequency offset alignment among TRP, {Doppler shift} component becomes the same across TRPs and, therefore, can be derived from the TRS transmitted by the reference TRP. The {Doppler spread} component of QCL depending on the embodiment can be estimated either from the SFN-ed TRS or reference TRS. Two TRS configurations can be provide to the UE using one or multiple TCI states, which include DL RS and corresponding QCL parameters. It is also proposed to support MAC CE signalling supporting sumptuous activation of the multiple TCI states across component carriers.

FIG. **5** illustrates the signalling rate for TRS reconfiguration in accordance with some embodiments.

In addition to QCL enhancement, association between UL reference signal and DL reference signal is proposed. More specifically, for determination of the carrier frequency for UL signal transmission, TRS of the reference TRP should be indicated to the UE. At the same time, since the actual UL transmission targets non-reference TRP, the Tx power control in UL should be selected according to TRS (or other DL reference signal) of the non-reference TRP. Similarly, the UL spatial filter should be also determined based on the DL reference signal transmitted by non-reference TRP.

Such association can be supported by using UL transmission control indication (TCI), where the 1st field of UL TCI should contain the 1st reference signal (e.g., TRS of the reference TRP) and its usage (e.g., carrier frequency determination), while the 2nd field of UL TCI should contain the 2nd reference signal (e.g., TRS of the non-reference TRP) and its usage (power control, spatial Tx filter). The second field of UL TCI may be optional in case one DL signal is used for both purposes. Depending on the embodiment, DL RS can be SS/PBCH block, CSI-RS for beam management, CSI-RS for tracking, the disclosure is not limited on this aspect. The example of UL TCI structure is illustrated in FIG. **6** (Table 1).

FIG. **6** illustrates Table 1 showing an example UL TCI structure in accordance with some embodiments.

To support efficient switching of reference TRP due to train mobility, DCI and MAC CE signalling is proposed for UL TCI indication. More specifically, the reference signals of the reference and non-reference TRP can be dynamically updated for the UL reference signal transmission. This functionality can be accomplished by the following options

Supporting multiple UL TCI states configured by higher layers with DCI or MAC CE selection for UL reference signal.

DCI and MAC CE can support update of the reference signals ID and usage for the given TCI state.

For the UL reference signal, PUCCH and UL sounding reference signal (UL SRS) can be considered as reference for frequency offset estimation at TRP. Given flexibility of configuration and robustness of the transmission to the measurement errors, UL SRS is discussed below, but the principle can be also extended for other UL signals such as PUCCH.

In one embodiment special SRS resources with new usage are supported. This is controlled by RRC parameter 'usage' set to 'tracking'. This SRS may support single SRS antenna port and multiple SRS resources or SRS resource sets. Such SRS resource should not be connected to PUSCH or PUCCH transmission from the UE. More specifically, the uplink carrier frequency of that SRS may be different from carrier frequency of other SRS e.g., configured for codebook and non-codebook operation and PUSCH/PUCCH. In the other embodiment, SRS for antenna switching can be also used for frequency offset pre-compensation at TRP, e.g., can be configured with UL TCI.

FIG. **7** illustrates a functional block diagram of a wireless communication device, in accordance with some embodiments. Wireless communication device **700** may be suitable for use as a UE or gNB configured for operation in a 5G NR network. The communication device **700** may also be suitable for use as a handheld device, a mobile device, a cellular telephone, a smartphone, a tablet, a netbook, a wireless terminal, a laptop computer, a wearable computer device, a femtocell, a high data rate (HDR) subscriber device, an access point, an access terminal, or other personal communication system (PCS) device.

The communication device **700** may include communications circuitry **702** and a transceiver **710** for transmitting and receiving signals to and from other communication devices using one or more antennas **701**. The communications circuitry **702** may include circuitry that can operate the physical layer (PHY) communications and/or medium access control (MAC) communications for controlling access to the wireless medium, and/or any other communications layers for transmitting and receiving signals. The communication device **700** may also include processing circuitry **706** and memory **708** arranged to perform the operations described herein. In some embodiments, the communications circuitry **702** and the processing circuitry **706** may be configured to perform operations detailed in the above figures, diagrams, and flows.

In accordance with some embodiments, the communications circuitry **702** may be arranged to contend for a wireless medium and configure frames or packets for communicating over the wireless medium. The communications circuitry **702** may be arranged to transmit and receive signals. The communications circuitry **702** may also include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the processing circuitry **706** of the communication device **700** may include one or more processors. In other embodiments, two or more antennas **701** may be coupled to the communications circuitry **702** arranged for sending and receiving signals. The memory **708** may store information for configuring the processing circuitry **706** to perform operations for configuring and transmitting message frames and performing the various operations described herein. The memory **708** may include any type of memory, including non-transitory memory, for storing information in a form readable by a machine (e.g., a computer). For example, the memory **708** may include a computer-readable storage device, read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices and other storage devices and media.

In some embodiments, the communication device **700** may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), a wearable computer device, or another device that may receive and/or transmit information wirelessly.

In some embodiments, the communication device **700** may include one or more antennas **701**. The antennas **701** may include one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas, or other types of antennas suitable for transmission of RF signals. In some embodiments, instead of two or more antennas, a single antenna with multiple apertures may be used. In these embodiments, each aperture may be considered a separate antenna. In some multiple-input multiple-output (MIMO) embodiments, the antennas may be effectively separated for spatial diversity and the different channel characteristics that may result between each of the antennas and the antennas of a transmitting device.

In some embodiments, the communication device **700** may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

Although the communication device **700** is illustrated as having several separate functional elements, two or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may include one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements of the communication device **700** may refer to one or more processes operating on one or more processing elements.

EXAMPLES

Example 1 may include a method of aperiodic CSI-RS transmission, wherein the aperiodic CSI-RS resource set is triggered by DCI. If there is no available downlink slot for CSI-RS transmission with the indicated slot offset, the aperiodic CSI-RS transmission should be postponed until there is available downlink slot for transmission.

Example 2 may include the method of example 1 or some other example herein, wherein if the aperiodic CSI-RS triggered by DCI in slot 'n' is configured with slot offset 'x', and the aperiodic CSI-RS can't be sent by the gNB in slot 'n+x', then the triggered aperiodic CSI-RS is viewed as pending CSI-RS. If the gNB has available resource for CSI-RS transmission within the time period of slot 'n+x' to slot 'n+x+y', then the pending CSI-RS could be delivered. If there is no available resource for aperiodic CSI-RS transmission within the time period of slot 'n+x' to slot 'n+x+y', then the pending CSI-RS should be cancelled. The value of 'y' could be pre-defined or up to UE capability. After the CSI-RS is delivered or cancelled, the pending status is stopped.

Example 3 may include the method of example 1 or some other example herein, wherein if the aperiodic CSI-RS can't be sent in the indicated slot, the aperiodic CSI-RS will be postponed to the next available downlink slot.

Example 4 may include the method of example 1 or some other example herein, wherein for aperiodic CSI-RS, the RRC parameter aperiodic TriggeringOffset with value 'i' could be defined as the i-th available slot for aperiodic CSI-RS transmission.

Example 5 may include the method of example 1 or some other example herein, wherein for aperiodic CSI-RS, the slot offset could be updated via a new MAC-CE.

Example 6 may include the method of example 1 or some other example herein, wherein for aperiodic CSI-RS, the slot offset could be indicated by RRC and DCI. In addition to the RRC parameter aperiodic TriggeringOffset, additional slot offset could be indicated by DCI. For aperiodic CSI-RS triggered by DCI in slot 'n' which is configured with RRC slot offset of 'x', and additional offset of 'm' is indicated by DCI, the aperiodic CSI-RS is transmitted in slot 'n+x+m'. The additional slot offset in DCI could be explicitly indicated by a new DCI field, e.g., CSI-RS Offset. Alternatively, the additional slot offset in DCI could be implicitly indicated by DCI codepoint. For example, the additional offset indicated by DCI could be defined by RRC as 2, 4, 6, 8 slots. In the DCI, the codepoint (of the new field or the existing CSI request field) indicates corresponding additional slot offset.

Example 7 may include the method of example 1 or some other example herein, wherein only a subset of the pending CSI-RS resource sets is considered as valid. If the number of the pending aperiodic CSI-RS resource sets exceeds certain value, then some CSI-RS resource sets are dropped. For example, the first CSI-RS resource set is dropped by the latest triggered CSI-RS resource set. Once the gNB has resource for CSI-RS transmission, the gNB only transmit the first CSI-RS resource set in the pending CSI-RS resource set list.

Example 8 may include the method of example 7 or some other example herein, wherein only one CSI-RS resource set which is the latest one triggered within K slots is considered to be valid. In this case every new CSI-RS resource set triggering by DCI always overrides the pending CSI-RS resource set.

Example 9 may include the method of example 1 or some other example herein, wherein when delivering the pending CSI-RS, there might be collision with other downlink signals, such as PDSCH. Thus, some priority rules should be defined for the transmission. In an example, the CSI-RS transmission is de-prioritized, e.g., if collision happens between aperiodic CSI-RS and other downlink signals, then the CSI-RS is not transmitted but considered as pending for the next transmission opportunity. In another example, the CSI-RS transmission is prioritized, e.g., if collision happens between aperiodic CSI-RS and other downlink signals, then the postponed CSI-RS should be delivered.

Example 10 may include the method of example 1 or some other example herein, wherein in FR2 different Rx beamforming are used for reception of aperiodic CSI-RS. In particular, if transmission interval between PDCCH and CSI-RS is less than threshold, e.g., corresponding to UE capability value, UE should use default Rx beamforming, where default Rx beamforming could be QCL type D reference signal corresponding to CORESET with lowest ID. Otherwise if the CSI-RS transmission interval is above the threshold the Rx beamforming should be determined according to TCI indication provided in DCI. For postponed CSI-RS transmission, the transmission time interval could be the actual interval between scheduling PDCCH and CSI-RS transmission. In the other example, the time interval is the time interval is interval indicated by scheduling DCI.

Example 11 includes a method comprising:

determining a slot offset for a channel state information-reference signal (CSI-RS) transmission to a user equipment (UE);

encoding a radio resource control (RRC) message for transmission to the UE that includes an indication of the slot offset for an aperiodic CSI-RS transmission;

determining the slot offset for the aperiodic CSI-RS transmission is not available; and

in response to determining the slot offset for the aperiodic CSI-RS transmission is not available, postponing or cancelling the aperiodic CSI-RS transmission.

Example 12 includes the method of example 11 or some other example herein, wherein the aperiodic CSI-RS transmission includes a CSI-RS resource set and is triggered by downlink control information (DCI).

Example 13 includes the method of example 11 or some other example herein, wherein the aperiodic CSI-RS transmission is transmitted in a subsequent slot after postponement.

Example 13a includes the method of example 13 or some other example herein, wherein the subsequent slot is a next available downlink slot.

Example 14 includes the method of example 11 or some other example herein, wherein the aperiodic CSI-RS transmission is cancelled in response to determining no available resources are available within a predetermined time period.

Example 15 includes the method of example 14 or some other example herein, wherein the predetermined time period is pre-defined.

Example 16 includes the method of example 14 or some other example herein, wherein the predetermined time period is based on a capability of the UE.

Example 17 includes the method of example 11 or some other example herein, wherein the aperiodic CSI-RS transmission is marked with pending status until transmitted or cancelled.

Example 18 includes the method of example 11 or some other example herein, wherein the RRC message is further to indicate an available slot for aperiodic CSI-RS transmission.

Example 19 includes the method of example 11 or some other example herein, further comprising updating the slot offset for the aperiodic CSI-RS transmission using a medium access control (MAC) control element (CE).

Example 20 includes the method of example 11 or some other example herein, wherein the aperiodic CSI-RS transmission is cancelled based on a total number of pending or postponed CSI-RS transmissions.

Example 21 includes the method of example 11 or some other example herein, wherein the aperiodic CSI-RS transmission is cancelled or transmitted based on a priority level assigned to the aperiodic CSI-RS transmission.

Example 22 includes the method of any of examples 11-21 or some other example herein, wherein the method is performed by a next-generation NodeB (gNB) or portion thereof.

Example 23 includes a method of a user equipment (UE), comprising:

receiving, by the UE, a radio resource control (RRC) message for transmission to the UE that includes an indication of a slot offset for an aperiodic CSI-RS transmission;

determining, by the UE based on the RRC message, whether a transmission interval between a physical downlink control channel (PDCCH) and the aperiodic CSI-RS transmission is less than a predetermined time period; and

based on determining whether the transmission interval between the PDCCH and the aperiodic CSI-RS transmission is less than the predetermined time period, either:

utilizing a default reception (Rx) beamforming to receive the aperiodic CSI-RS transmission; or

utilizing an Rx beamforming to according to a transmission configuration indicator (TCI) provided in downlink control information (DCI) to receive the aperiodic CSI-RS transmission.

Example 24 includes the method of example 23 or some other example herein, wherein the aperiodic CSI-RS transmission includes a CSI-RS resource set and is triggered by downlink control information (DCI).

Example 25 includes the method of example 23 or some other example herein, wherein the aperiodic CSI-RS transmission is transmitted in a subsequent slot after postponement.

Example 25a includes the method of example 25 or some other example herein, wherein the subsequent slot is a next available downlink slot.

Example 26 includes the method of example 23 or some other example herein, wherein the predetermined time period is pre-defined.

Example 27 includes the method of example 23 or some other example herein, wherein the predetermined time period is based on a capability of the UE.

Example 28 includes the method of example 23 or some other example herein, wherein the RRC message is further to indicate an available slot for aperiodic CSI-RS transmission.

Example 29 includes the method of example 23 or some other example herein, further comprising receiving an update to the slot offset for the aperiodic CSI-RS transmission via medium access control (MAC) control element (CE).

Example 30 may include a method of DL TCI indication for PDSCH/PDCCH with two TRS configurations indicating 1^{st} TRS indicating QCL parameters {average gain, average delay, delay spread} 2^{nd} TRS indicating QCL parameter {Doppler shift} wherein 1^{st} or 2^{nd} TRS can be indicated for {Doppler spread} depending on the embodiment.

Example 31 may include the method of example 30 or some other example herein, wherein MAC CE signalling activates multiple DL TCI across component carriers configured by higher layers.

Example 32 may include the system and method of UL TCI indication to the UE, wherein UL TCI is configured by gNB for the UL reference signal UL TCI indication include up to two DL reference signals and up to two usages DL reference signal configuration includes type of RS and its reference signal identity. Usage may include carrier frequency, UL power control, spatial Tx filter for UL signal transmission that should be derived based on the DL measurements.

Example 33 may include the method of example 32 or some other example herein, wherein MAC CE or DCI support dynamic switching of UL TCI for UL reference signal.

Example 34 may include the method of example 33 or some other example herein, wherein UL reference signal is UL SRS with antenna switching.

Example 35 may include the method of example 34 or some other example herein, wherein UL reference signal is UL SRS with new usage "tracking" not connected to PUSCH or PUCCH transmission.

Example 36 may include a method comprising: receiving a first tracking reference signal (TRS) and a second TRS; and determining one or more first quasi co-location (QCL) parameters based on the first TRS and one or more second QCL parameters based on the second TRS.

Example 37 may include the method of some other example herein, wherein the one or more first QCL parameters include one or more of an average gain, an average delay, and/or a delay spread.

Example 38 may include the method of some other example herein, wherein the one or more second QCL parameters include a Doppler shift.

Example 39 may include the method of some other example herein, further comprising receiving a signal from a transmission-reception point (TRP) based on the first and/or second QCL parameters.

Example 40 may include the method of some other example herein, wherein the signal is a PDSCH or a PDCCH.

The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

What is claimed is:

1. An apparatus for user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) network, the apparatus comprising: processing circuitry; and memory, the processing circuitry configured to:

decode Radio Resource Control (RRC) signalling received from a gNB, the RRC signalling to indicate an aperiodic Triggering Offset (aperiodicTriggeringOffset) for aperiodic channel state information reference signal (CSI-RS) resources,

the aperiodic Triggering Offset indicating an offset comprising a value indicating a number of slots between a first slot containing a downlink control information (DCI) that triggers a set of aperiodic CSI-RS resources and a second slot in which the set is transmitted by the gNB; and

decode the DCI that triggers the set of aperiodic CSI-RS resources, the DCI received from the gNB, the processing circuitry is configured to:

determine, based on the offset and the first slot containing the DCI, a location of the second slot; and

configure the UE to receive the set of aperiodic CSI-RS resources in the second slot.

2. The apparatus of claim **1**, wherein for operating in frequency range 2 (FR2), the number of slots indicted by the value is at least as great as a beam switching time.

3. The apparatus of claim **2**, wherein in response to the DCI that triggers the set of aperiodic CSI-RS resources, the processing circuitry is to configure the UE to switch beams and perform beamforming to receive the set of aperiodic CSI-RS resources in the second slot.

4. The apparatus of claim **3**, wherein the UE is configured for multi-transmission reception point (mTRP) reception and the set of aperiodic CSI-RS resources is enabled with beam switching.

5. The apparatus of claim **4**, wherein when the aperiodic Triggering Offset is not included in the RRC signalling, the processing circuitry is configured to apply a value of zero for the offset.

6. The apparatus of claim **4**, wherein the UE is configured to receive the CSI-RS from another TRP.

7. The apparatus of claim **4**, wherein the processing circuitry is further configured to decode a medium-access control layer control element (MAC-CE) to activate the set of aperiodic CSI-RS resources.

8. The apparatus of claim **4**, wherein the processing circuitry is to:

configure the UE to perform a channel measurement using the set of aperiodic CSI-RS resources received in the second slot; and

report the channel measurement to the gNB.

9. The apparatus of claim **8**, wherein the processing circuitry is to configure the UE to receive the set of aperiodic CSI-RS resources in the second slot when resource elements are available in the second slot.

10. The apparatus of claim **9**, wherein when the resource elements of the second slot are not available, the processing circuitry is to configure the UE to refrain from receiving the CSI-RS during the second slot.

11. A non-transitory computer-readable storage medium that stores instructions for execution by processing circuitry of a user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) network, the processing circuitry configured to:

decode Radio Resource Control (RRC) signalling received from a gNB, the RRC signalling to indicate an aperiodic Triggering Offset (aperiodicTriggeringOffset) for aperiodic channel state information reference signal (CSI-RS) resources,

the aperiodic Triggering Offset indicating an offset comprising a value indicating a number of slots between a first slot containing a downlink control information (DCI) that triggers a set of aperiodic CSI-RS resources and a second slot in which the set is transmitted by the gNB; and

decode the DCI that triggers the set of aperiodic CSI-RS resources, the DCI received from the gNB, the processing circuitry is configured to:

determine, based on the offset and the first slot containing the DCI, a location of the second slot; and

configure the UE to receive the set of aperiodic CSI-RS resources in the second slot.

12. The non-transitory computer-readable storage medium of claim **11**, wherein for operating in frequency range 2 (FR2), the number of slots indicted by the value is at least as great as a beam switching time.

13. The non-transitory computer-readable storage medium of claim **12**, wherein in response to the DCI that triggers the set of aperiodic CSI-RS resources, the processing circuitry is to configure the UE to switch beams and perform beamforming to receive the set of aperiodic CSI-RS resources in the second slot.

14. The non-transitory computer-readable storage medium of claim **13**, wherein the UE is configured for multi-transmission reception point (mTRP) reception and the set of aperiodic CSI-RS resources is enabled with beam switching.

15. The non-transitory computer-readable storage medium of claim **14**, wherein when the aperiodic Triggering Offset is not included in the RRC signalling, the processing circuitry is configured to apply a value of zero for the offset.

16. The non-transitory computer-readable storage medium of claim **14**, wherein the UE is configured to receive the CSI-RS from another TRP.

17. The non-transitory computer-readable storage medium of claim **14**, wherein the processing circuitry is further configured to decode a medium-access control layer control element (MAC-CE) to activate the set of aperiodic CSI-RS resources.

18. An apparatus of a generation node B (gNB) configured for operation in a fifth-generation new radio (5G NR) network, the apparatus comprising: processing circuitry; and memory, the processing circuitry configured to:

encode Radio Resource Control (RRC) signalling for transmission to a user equipment (UE), the RRC signalling to indicate an aperiodic Triggering Offset (aperiodicTriggeringOffset) for aperiodic channel state information reference signal (CSI-RS) resources,

the aperiodic Triggering Offset indicating an offset comprising a value indicating a number of slots between a first slot containing a downlink control information (DCI) that triggers a set of aperiodic CSI-RS resources and a second slot in which the set is transmitted by the gNB; and

encode the DCI triggering the set of aperiodic CSI-RS resources for transmission to the UE; and

configure transmission of the set of aperiodic CSI-RS resources in the second slot,

wherein the processing circuitry is configured to determine, based on the offset and the first slot containing the DCI, a location of the second slot.

19. The apparatus of claim **18**, wherein for operating in frequency range 2 (FR2), the number of slots indicted by the value is at least as great as a beam switching time of the UE.

20. The apparatus of claim **19**, wherein the processing circuitry is configured to switch transmission of the set of aperiodic CSI-RS resources in the second slot to another transmission reception point when the set of aperiodic CSI-RS resources is enabled with beam switching and the UE is configured for multi-transmission reception point (mTRP) reception.

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