

DESCRIPTION**TITLE****CHANNEL QUALITY INDICATOR REPORTING****TECHNICAL FIELD:**

The exemplary and non-limiting embodiments of this invention relate generally to wireless communication systems, methods, devices and computer programs and, more specifically, relate to the reporting of channel quality indicator information from a mobile node to a network access node.

BACKGROUND:

This section is intended to provide a background or context to the invention that is recited in the claims. The description herein may include concepts that could be pursued, but are not necessarily ones that have been previously conceived, implemented or described. Therefore, unless otherwise indicated herein, what is described in this section is not prior art to the description and claims in this application and is not admitted to be prior art by inclusion in this section.

The following abbreviations that may be found in the specification and/or the drawing figures are defined as follows:

3GPP	third generation partnership project
BS	base station
CA	carrier aggregation
CC	component carrier
CE	control element
CQI	channel quality indication
CSI RS	channel state information reference signal
DL	downlink (eNB towards UE)
eNB	E-UTRAN Node B (evolved Node B)

EPC	evolved packet core
E-UTRAN	evolved UTRAN (LTE)
FDMA	frequency division multiple access
GNSS	global navigation satellite system
ICO	in-device coexistence interference avoidance
IMTA	international mobile telecommunications association
ITU-R	international telecommunication union-radiocommunication sector
LTE	long term evolution of UTRAN (E-UTRAN)
LTE-A	LTE advanced
MAC	medium access control (layer 2, L2)
SU-MIMO	single user multiple input multiple output
MM/MME	mobility management/mobility management entity
NodeB	base station
OFDMA	orthogonal frequency division multiple access
O&M	operations and maintenance
OOR	out of range
PDCP	packet data convergence protocol
PHY	physical (layer 1, L1)
Rel	release
RLC	radio link control
RRC	radio resource control
RRM	radio resource management
SCell	serving cell
SGW	serving gateway
SC-FDMA	single carrier, frequency division multiple access
TM	transmission mode
UE	user equipment, such as a mobile station, mobile node or mobile terminal
UL	uplink (UE towards eNB)
UPE	user plane entity
UTRAN	universal terrestrial radio access network

One modern communication system is known as evolved UTRAN (E-UTRAN, also

referred to as UTRAN-LTE or as E-UTRA). In this system the DL access technique is OFDMA, and the UL access technique is SC-FDMA.

One specification of interest is 3GPP TS 36.300, V8.11.0 (2009-12), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Access Network (EUTRAN); Overall description; Stage 2 (Release 8), incorporated by reference herein in its entirety. This system may be referred to for convenience as LTE Rel-8. In general, the set of specifications given generally as 3GPP TS 36.xyz (e.g., 36.211, 36.311, 36.312, etc.) may be seen as describing the Release 8 LTE system. More recently, Release 9 versions of at least some of these specifications have been published.

Figure 1 reproduces Figure 4.1 of 3GPP TS 36.300 V8.11.0, and shows the overall architecture of the EUTRAN system (Rel-8). The E-UTRAN system includes eNBs, providing the E-UTRAN user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UEs. The eNBs are interconnected with each other by means of an X2 interface. The eNBs are also connected by means of an S1 interface to an EPC, more specifically to a MME by means of a S1 MME interface and to a S-GW by means of a S1 interface (MME/S-GW 4). The S1 interface supports a many-to-many relationship between MMEs / S-GWs / UPEs and eNBs.

The eNB hosts the following functions:

functions for RRM: RRC, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both UL and DL (scheduling);
IP header compression and encryption of the user data stream;
selection of a MME at UE attachment;
routing of User Plane data towards the EPC (MME/S-GW);
scheduling and transmission of paging messages (originated from the MME);
scheduling and transmission of broadcast information (originated from the MME or O&M); and
a measurement and measurement reporting configuration for mobility and scheduling.

Of particular interest herein are the further releases of 3GPP LTE (e.g., LTE Rel-10) targeted towards future IMTA systems, referred to herein for convenience simply as LTE-Advanced (LTE-A). Reference in this regard may be made to 3GPP TR 36.913, V9.0.0 (2009-12), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Requirements for Further Advancements for E-UTRA (LTE-Advanced) (Release 9). Reference can also be made to 3GPP TR 36.912 V9.2.0 (2010-03) Technical Report 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Feasibility study for Further Advancements for E-UTRA (LTE-Advanced) (Release 9).

A goal of LTE-A is to provide significantly enhanced services by means of higher data rates and lower latency with reduced cost. LTE-A is directed toward extending and optimizing the 3GPP LTE Rel-8 radio access technologies to provide higher data rates at lower cost. LTE-A will be a more optimized radio system fulfilling the ITU-R requirements for IMT-Advanced while keeping the backward compatibility with LTE Rel-8.

As is specified in 3GPP TR 36.913, LTE-A should operate in spectrum allocations of different sizes, including wider spectrum allocations than those of LTE Rel-8 (e.g., up to 100MHz) to achieve the peak data rate of 100Mbit/s for high mobility and 1 Gbit/s for low mobility. It has been agreed that carrier aggregation (CA) is to be considered for LTE-A in order to support bandwidths larger than 20 MHz. Carrier aggregation, where two or more component carriers (CCs) are aggregated, is considered for LTE-A in order to support transmission bandwidths larger than 20MHz. The carrier aggregation could be contiguous or non-contiguous. This technique, as a bandwidth extension, can provide significant gains in terms of peak data rate and cell throughput as compared to non-aggregated operation as in LTE Rel-8.

A terminal may simultaneously receive one or multiple component carriers depending on its capabilities. A LTE-A terminal with reception capability beyond 20 MHz can simultaneously receive transmissions on multiple component carriers. A LTE Rel-8 terminal can receive transmissions on a single component carrier only, provided that the structure of the component carrier follows the Rel-8 specifications. Moreover, it is required that LTE-A should be backwards compatible with Rel-8 LTE in the sense

that a Rel-8 LTE terminal should be operable in the LTE-A system, and that a LTE-A terminal should be operable in a Rel-8 LTE system.

Of some relevance to the discussion herein is 3GPP TR 36.816 v1.0.0 (2010-11) Technical Report 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; Evolved Universal Terrestrial Radio Access (E-UTRA); Study on signalling and procedure for interference avoidance for in-device coexistence; (Release 10), incorporated by reference herein.

As is stated in Section 4 of 3GPP TR 36.816 v1.0.0, in order to allow users to access various networks and services ubiquitously an increasing number of UEs are equipped with multiple radio transceivers. For example, a UE may be equipped with LTE, WiFi, and Bluetooth transceivers, and GNSS receivers. One resulting challenge lies in trying to avoid coexistence interference between those collocated radio transceivers. Figure 3, which reproduces Figure 4-1 of 3GPP TR 36.816 v1.0.0, shows an example of coexistence interference.

Due to extreme proximity of multiple radio transceivers within the same UE, the transmit power of one transmitter may be much higher than the received power level of another receiver. By means of filter technologies and sufficient frequency separation, the transmit signal may not result in significant interference. But for some coexistence scenarios, e.g., different radio technologies within the same UE operating on adjacent frequencies, current state-of-the-art filter technology may not provide sufficient rejection. Therefore, solving the interference problem by single generic RF design may not always be possible and alternative methods need to be considered.

SUMMARY:

The below summary section is intended to be merely exemplary and non-limiting.

The foregoing and other problems are overcome, and other advantages are realized, by the use of the exemplary embodiments of this invention.

In one exemplary embodiment of the invention, an apparatus is disclosed which is

configured to operate upon resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap. In operation the apparatus determines whether to report to a network access node an in-device coexistence interference indicator value. Thereafter, the apparatus sends the in-device coexistence interference indicator value to the network access node. The apparatus reports the in-device coexistence interference indicator value to the network access node for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.

In another exemplary embodiment of the invention there is provided a method which includes method steps which occur when resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap. The method includes a step of determining whether to report to a network access node an in-device coexistence interference indicator value. Thereafter, the method provides for sending the in-device coexistence interference indicator value to the network access node. The method reports the in-device coexistence interference indicator value to the network access node for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.

In another exemplary embodiment of the invention there is provided a non-transitory computer readable medium storing a program of machine-readable instructions executable by a digital processing apparatus of a computer system to perform operations for controlling computer system actions. The operations comprising operation which are preformed when resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap, determining whether to report to a network access node an in-device coexistence interference indicator value. Thereafter, the non-transitory computer readable medium performs an operation of sending the in-device coexistence interference indicator value to the network access node. The non-transitory computer readable medium reports the in-device coexistence interference indicator value to the network access node for a certain period if any periodic channel quality

indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.

In another exemplary embodiment of the invention there is provided an apparatus which includes means responsive to resuming data transmission/reception upon activation of a serving cell, or after an in-device coexistence interference avoidance gap. To determine whether to report to a network access node an in-device coexistence interference indicator value. A means for sending the in-device coexistence interference indicator value to the network access node, wherein the apparatus reports the in-device coexistence interference indicator value to the network access node for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.

BRIEF DESCRIPTION OF THE DRAWINGS

In the attached Drawing Figures:

Figure 1(a) reproduces Figure 4.1 of 3GPP TS 36.300, and shows the overall architecture of the EUTRAN system.

Figure 1(b) reproduces Tables 6.10.5.2-1 of 3GPP TS 36.211 and shows a mapping from CSI reference signal configured to (k', l') for normal cyclic prefix.

Figure 1(c) reproduces Tables 6.10.5.2-2 of 3GPP TS 36.211 and shows a mapping from CSI reference signal configured to (k', l') for extended cyclic prefix.

Figure 1(d) reproduces Table 6.10.5.3-1 of 3GPP TS 36.211 and shows CSI reference signal subframe configuration.

Figure 1(e) reproduces Table 6.11.1.1-1 of 3GPP TS 36.211 and shows root indices for the primary synchronization signal.

Figure 1(f) reproduces Table 7.2.3-0 of 3GPP TS 36.213 and shows PDSCH

transmission scheme assumed for CQI reference resource.

Figure 1(g) reproduces Table 7.2.3-1 of 3GPP TS 36.213 and shows a 4-bit CQI Table.

Figure 2 shows a simplified block diagram of various electronic devices that are suitable for use in practicing the exemplary embodiments of this invention.

Figure 3 reproduces Figure 4-1 of 3GPP TR 36.816 v1.0.0 and shows an example of coexistence interference.

Figure 4A reproduces Figure 1 from R2-106507 and shows an example of processing time for a CQI measurement.

Figure 4B reproduces Figure 2 from R2-106507 and shows an example of where the UE is not able to report CQI for a SCell immediately after the SCell is activated.

Figure 4C shows a case of a possible no valid CQI period for transmission modes other than TM9.

Figure 5 shows an example of a considerable period of time after activation/end of a gap where there may not be a CSI RS subframe available when using TM9.

Figure 6 is a logic flow diagram that illustrates the operation of a method, and a result of execution of computer program instructions embodied on a computer readable memory, in accordance with the exemplary embodiments of this invention.

DETAILED DESCRIPTION

By way of an introduction, it was agreed in RAN4 (R4-104930, Response LS on Timing Requirements for Activation and Deactivation of SCells, 3GPP TSG-RAN WG4 meeting #57, Jacksonville, United States of America, 15-19 November 2010, incorporated by reference) that when the eNB sends an activation/deactivation MAC CE activating an SCell in sub-frame n , the UE must have the SCell activated by

subframe $n+8$, and there is no need to start measuring the SCell before subframe $n+8$. Thus it is possible for some certain period that the UE does not have a valid CQI result immediately after activation of the SCell.

A similar period exists upon resuming data transmission/reception from a long gap of TDM for in-device coexistence interference avoidance (ICO).

One agreement in RAN2 to aid in solving the problems discussed above with reference to 3GPP TR 36.816 v1.0.0 and shown in Figure 3 is for the UE to inform the E-UTRAN when transmission/reception of LTE or some other radio signal would benefit, or no longer benefit, from the LTE system not using certain carriers or frequency resources. The UE judgment is therefore taken as a baseline approach for a Frequency Domain Multiplexing (FDM) solution where the UE indicates which frequencies are (not) useable due to in-device coexistence. In response to such signaling from the UE the eNB would typically order the UE to perform a handover to a frequency that has not been reported by the UE as suffering from in-device coexistence interference. This approach may be referred to as an FDM solution. However, when this is not possible a Time Domain Multiplexing (TDM) solution could be used. The TDM solution could involve alternating scheduled and unscheduled periods on problematic frequencies.

However, the period could be 4 ms of UE processing time for measurement if the RS for measurement is available every TTI. Reference in this regard can be made to Figure 4A herein, which reproduces Figure 1 from 3GPP TSG-RAN2 #72 meeting Tdoc R2-106507 Jacksonville, U.S., 15 - 19 November 2010 Agenda Item: 7.1.1.4, Source: Samsung, Title: SCell activation and CQI reporting (incorporated by reference). Reference can also be made to Figure 4B herein, which reproduces Figure 2 from R2-106507 and shows an example of where the UE is not able to report CQI for a SCell immediately after the SCell is activated. As is stated in R2-106507, the issue is whether the UE transmits CQI even if it does not have a valid measurement. It is assumed in R2-106507 that if the UE is required to transmit the CQI even if it has no measurement result the only logical CQI value to be reported is CQI = 0 (i.e., out of range or OOR). Thus it would be the choice between "no CQI transmission" and "OOR reporting".

Transmission Mode 9 (TM9) has been defined for Rel-10 DL MIMO for supporting SU-MIMO up to rank-8 and SU/MU dynamic switching (see, for example, 3GPP TSG RAN WG1 Meeting #62bis R1-105534 Xi'an, China, October 11 - 15, 2010 Source: Nokia Siemens Networks, Nokia, Title: Remaining Details of Transmission Mode 9 and DCI 2C, incorporated by reference). Reference with regard to TM9 can also be made to 3GPP TS 36.211 V10.0.0 (2010-12) Technical Specification 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (Release 10), Section 6.10.5 "CSI reference signals", incorporated by reference herein. As disclosed in ETSI TS 136 211, CSI reference signals are transmitted on one, two, four or eight antenna ports using $p = 15$, $p = 15, 16$, $p = 15, \dots, 18$ and $p = 15, \dots, 22$, respectively. CSI reference signals are defined for $\Delta f = 15$ kHz only. With respect to sequence generation, the reference-signal sequence $r_{l,n_s}(m)$ is defined by $r_{l,n_s}(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m + 1))$, where $m = 0, 1, \dots, N_{RB}^{max,DL} - 1$ where n_s is the slot number within a radio frame and l is the OFDM symbol number within the slot. The pseudorandom sequence $c(i)$. The pseudo-random sequence generator is initialized with $c_{init} = 2^{10} \cdot (7 \cdot (n_s + 1) + l + 1 \cdot 2 \cdot NID_{cell} + 1 + 2 \cdot NID_{cell} + NCP)$ at the start of each OFDM symbol where $NCP = 1$ for normal CP 0 for extended CP.

With respect to mapping to resource elements in subframes configured for CSI reference signal transmission, the reference signal sequence $r_{l,n_s}(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ used as reference symbols on antenna port p according to $a_{k,l}^{(p)} = w_{l^n} \cdot r_{l,n_s}(m')$ where

$$k = k' + 12m + \begin{cases} -0 & \text{for } p \in \{15, 16\}, \text{normal cyclic prefix} \\ -6 & \text{for } p \in \{17, 18\}, \text{normal cyclic prefix} \\ -1 & \text{for } p \in \{19, 20\}, \text{normal cyclic prefix} \\ -7 & \text{for } p \in \{21, 22\}, \text{normal cyclic prefix} \\ -0 & \text{for } p \in \{15, 16\}, \text{extended cyclic prefix} \\ -3 & \text{for } p \in \{17, 18\}, \text{extended cyclic prefix} \\ -6 & \text{for } p \in \{19, 20\}, \text{extended cyclic prefix} \\ -9 & \text{for } p \in \{21, 22\}, \text{extended cyclic prefix} \end{cases}$$

$$l = l' + \begin{cases} l'' & \text{CSI reference signal configurations 0 – 19, normal cyclic prefix} \\ 2l'' & \text{CSI reference signal configurations 20 – 31, normal cyclic prefix,} \\ l'' & \text{CSI reference signal configurations 0 – 27, extended cyclic prefix} \end{cases}$$

$$w_{l^n} = \begin{cases} 1 & p \in \{15, 17, 19, 21\} \\ (-1)^{l^n} & p \in \{16, 18, 20, 22\} \end{cases},$$

$$l'' = 0, 1,$$

$$m = 0, 1, \dots, N_{RB}^{DL} - 1, \text{ and}$$

$$m' = m + \left\lfloor \frac{N_{RB}^{max, DL} - N_{RB}^{DL}}{2} \right\rfloor.$$

The quantity (k', l') and the necessary conditions on n_s are given by Tables 6.10.5.2-1 and 6.10.5.2-2 for normal cyclic prefix reproduced in Figure 1(b) and extended cyclic prefix reproduced in Figure 1(c). Multiple CSI reference signal configurations according to TM 9 can be used in a given cell,

- one configuration for which the UE shall assume non-zero transmission power for the CSI-RS, and
- zero or more configurations for which the UE shall assume zero transmission power.

For each bit set to one in the 16-bit bitmap ZeroPowerCSI-RS configured by higher layers, the UE shall assume zero transmission power for the resource elements corresponding to the four CSI reference signal column in Tables 6.10.5.2-1 and 6.10.5.2-2 for normal and extended cyclic prefix, respectively. The most significant bit corresponds to the lowest CSI reference signal configuration index and subsequent bits in the bitmap correspond to configurations with indices in increasing order.

CSI reference signals according to TM 9 can only occur in

- downlink slots where $n_s \bmod 2$ fulfils the condition in Tables 6.10.5.2-1 and 6.10.5.2-2 for normal and extended cyclic prefix, respectively, and
- where the subframe number fulfils the conditions set forth in Table 6.10.5.3-1

Moreover, CSI reference signals according to TM 9 cannot be transmitted

- in the special subframe(s) in case of frame structure type 2,
- when transmission of a CSI-RS would collide with transmission of synchronization signals, PBCH, or SystemInformationBlockType1 messages,
- in subframes configured for transmission of paging messages.

Resource elements (k, l) used for transmission of CSI reference signals on any of the antenna ports in the set S, where $S = \{15\}$, $S = \{15, 16\}$, $S = \{17, 18\}$, $S = \{19, 20\}$ or $S = \{21, 22\}$ shall

- not be used for transmission of PDSCH on any antenna port in the same slot, and
- not be used for CSI reference signals on any antenna port other than those in S in the same slot.

With respect to CSI reference signal subframe configuration TM 9, provides that the cell-specific subframe configuration period $T_{\text{CSI-RS}}$ and the cell-specific subframe offset $\Delta_{\text{CSI-RS}}$ for the occurrence of CSI reference signals are listed in Table 6.10.5.3-1 attached as Figure 1(d). The parameter $I_{\text{CSI-RS}}$ can be configured separately for CSI reference signals for which the UE shall assume non-zero and zero transmission power. Subframes containing CSI reference signals shall satisfy $\left(10n_f + \left\lfloor \frac{n_s}{2} \right\rfloor - \Delta_{\text{CSI-RS}}\right) \bmod T_{\text{CSI-RS}} = 0$.

With respect to synchronization signals in TM 9, LTE/LTE-A provides for 504 unique physical-layer cell identities. The physical-layer cell identities are grouped into 168 unique physical-layer cell-identity groups, each group containing three unique identities. The grouping is such that each physical-layer cell identity is part of one and only one physical-layer cell-identity group. A physical-layer cell identity $N_{\text{ID}}^{\text{cell}} = 3N_{\text{ID}}^{(1)} + N_{\text{ID}}^{(2)}$ is thus uniquely defined by a number $N_{\text{ID}}^{(1)}$ in the range of 0 to 167, representing the physical-layer cell-identity group, and a number $N_{\text{ID}}^{(2)}$ in the range of 0 to 2, representing the physical-layer identity within the physical-layer cell-identity group.

With respect to primary synchronization signal a sequence is generated according to TM 9 where the sequence $d(n)$ is used for the primary synchronization signal and generated from a frequency-domain Zadoff-Chu sequence according to

$$d_u(n) \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n=0,1,\dots,30 \\ e^{-j\frac{\pi u n(n+1)(n+2)}{63}} & n=31,32,\dots,61 \end{cases}$$

where the Zadoff-Chu root sequence index u is given by Table 6.11.1.1-1 reproduced

as Figure 1(e).

Channel quality indicator (CQI) according to TM 9 is defined in 3GPP TS 36.213 V10.0.1 (2010-12) Technical Specification 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 10), Section 7.2.3 "Channel quality indicator (CQI) definition", incorporated by reference herein.

According to TM 9, the CQI indices and their interpretations are given in Table 7.2.3-1 reproduced as Figure 1(f). Based on an unrestricted observation interval in time and frequency, the UE shall derive for each CQI value reported in uplink subframe n the highest CQI index between 1 and 15 in Table 7.2.3-1 which satisfies the following condition, or CQI index 0 if CQI index 1 does not satisfy the condition:

- A single PDSCH transport block with a combination of modulation scheme and transport block size corresponding to the CQI index, and occupying a group of downlink physical resource blocks termed the CQI reference resource, could be received with a transport block error probability not exceeding 0.1.

For TM 9 and feedback reporting modes the UE shall derive the channel measurements for computing the CQI value reported in uplink subframe n based on only the Channel-State Information (CSI) reference signals. For other transmission modes and their respective reporting modes the UE shall derive the channel measurements for computing CQI based on CRS.

A combination of modulation scheme and transport block size corresponds to a CQI index if:

- the combination could be signalled for transmission on the PDSCH in the CQI reference resource according to the relevant Transport Block Size table, and
- the modulation scheme is indicated by the CQI index, and
- the combination of transport block size and modulation scheme when applied to the reference resource results in the effective channel code rate which is the closest possible to the code rate indicated by the CQI index. If more than one combination of transport block size and modulation scheme

results in an effective channel code rate equally close to the code rate indicated by the CQI index, only the combination with the smallest of such transport block sizes is relevant.

The CQI reference resource is defined as follows:

- In the frequency domain, the CQI reference resource is defined by the group of downlink physical resource blocks corresponding to the band to which the derived CQI value relates.
- In the time domain, the CQI reference resource is defined by a single downlink subframe $n - n_{\text{CQI_ref}}$,

where for periodic CQI reporting $n - n_{\text{CQI_ref}}$ is the smallest value greater than or equal to 4, such that it corresponds to a valid downlink subframe;

where for aperiodic CQI reporting $n_{\text{CQI_ref}}$ is such that the reference resource is in the same valid downlink subframe as the corresponding CQI request in an uplink DCI format.

where for aperiodic CQI reporting $n_{\text{CQI_ref}}$ is equal to 4 and downlink subframe $n - n_{\text{CQI_ref}}$ corresponds to a valid downlink subframe, where downlink subframe $n - n_{\text{CQI_ref}}$ is received after the subframe with the corresponding CQI request in a Random Access Response Grant.

A downlink subframe shall be considered to be valid if:

- it is configured as a downlink subframe for that UE, and
- except for transmission mode 9, it is not an MBSFN subframe, and
- it does not contain a DwPTS field in case the length of DwPTS is $7680 \cdot T_s$ and less, and
- it does not fall within a configured measurement gap for that UE.

If there is no valid downlink subframe for the CQI reference resource, CQI reporting is omitted in uplink subframe n .

- In the layer domain, the CQI reference resource is defined by any RI and PMI on which the CQI is conditioned.

In the CQI reference resource, the UE shall assume the following for the purpose of deriving the CQI index:

- The first 3 OFDM symbols are occupied by control signalling

- No resource elements used by primary or secondary synchronisation signals or PBCH
- CP length of the non-MBSFN subframes
- Redundancy Version 0
- If CSI-RS is used for channel measurements, the ratio of PDSCH EPRE to CSI-RS EPRE is as given in Section 7.2.5
- The PDSCH transmission scheme given by Table 7.2.3-0 reproduced as Figure 1(f) depending on the transmission mode currently configured for the UE (which may be the default mode).
- If CRS is used for channel measurements, the ratio of PDSCH EPRE to cell-specific RS EPRE is as given in Section 5.2 with the exception of p_A which shall be assumed to be
 - o $p_A = p_A + \Delta_{\text{offset}} + 10\log(2)$ [dB] for any modulation scheme, if the UE is configured with transmission mode 2 with 4 cell-specific antenna ports, or transmission mode 3 with 4 cell-specific antenna ports and the associated RI is equal to one;
 - o $p_A = p_A + \Delta_{\text{offset}}$ [dB] for any modulation scheme and any number of layers, otherwise.

The shift Δ_{offset} is given by the parameter `nomPDSCH-RS-EPRE-Offset` which is configured by higher-layer signaling.

In TM9 the CQI measurement is based on CSI RS with a configurable periodicity of 5ms to about 80ms. Referring to Figure 5 it can be seen that it thus is possible that for a considerable period of time after activation/end of a gap there is no CSI RS subframe available, but some periodic CQI resource is configured or aperiodic CQI is requested. The total period could be much longer than 4ms depending on the CSI RS periodicity and its occurrence after activation.

Several options were suggested in R2-106507 to permit the UE to not transmit CQI or to report OOR (out of range) for 4ms after activation. However, R2-106507 did not address the case of TM9 and the resumption of operation after a long ICO gap.

Before describing in further detail the exemplary embodiments of this invention, reference is made to Figure 2 for illustrating a simplified block diagram of various

electronic devices and apparatus that are suitable for use in practicing the exemplary embodiments of this invention. In Figure 2 a wireless network 1 is adapted for communication over a wireless link 11 with an apparatus, such as a mobile communication device which may be referred to as a UE 10, via a network access node, such as a Node B (base station), and more specifically an eNB 12. The network 1 may include a network control element (NCE) 14 that may include the MME/SGW functionality shown in Figure 1(a), and which provides connectivity with a further network, such as a telephone network and/or a data communications network (e.g., the internet). The UE 10 includes a controller, such as at least one computer or a data processor (DP) 10A, at least one non-transitory computer-readable memory medium embodied as a memory (MEM) 10B that stores a program of computer instructions (PROG) 10C, and at least one suitable radio frequency (RF) transceiver 10D for bidirectional wireless communications with the eNB 12 via one or more antennas. The eNB 12 also includes a controller, such as at least one computer or a data processor (DP) 12A, at least one computer-readable memory medium embodied as a memory (MEM) 12B that stores a program of computer instructions (PROG) 12C, and at least one suitable RF transceiver 12D for communication with the UE 10 via one or more antennas (typically several when multiple input / multiple output (MIMO) operation is in use). The eNB 12 is coupled via a data / control path 13 to the NCE 14. The path 13 may be implemented as the S1 interface shown in Figure 1. The eNB 12 may also be coupled to another eNB via data / control path 15, which may be implemented as the X2 interface shown in Figure 1.

For the purposes of describing the exemplary embodiments of this invention the UE 10 may be assumed to also include a CQI measurement and reporting unit or function or module (CQI) 10E, and the eNB 12 may include a complementary CQI unit or function or module 12E for receiving and interpreting CQI information received from the UE 10. Note also that the transceiver 10D (and related baseband circuitry and antenna) can represent the LTE RF and LTE baseband blocks (and antenna #1) shown in Figure 3. In addition, the UE 10 can include one or both of the global positioning system (GPS) RF and baseband blocks (and associated antenna #2) and the Bluetooth (BT)/WiFi RF and baseband blocks (and associated antenna #3) of Figure 3.

At least one of the PROGs 10C and 12C is assumed to include program instructions that, when executed by the associated DP, enable the device to operate in accordance with the exemplary embodiments of this invention, as will be discussed below in greater detail. That is, the exemplary embodiments of this invention may be implemented at least in part by computer software executable by the DP 10A of the UE 10 and/or by the DP 12A of the eNB 12, or by hardware, or by a combination of software and hardware (and firmware). Further in this regard the CQI units 10E, 12E can be implemented entirely in circuitry, or entirely as software code, or as a combination of circuitry and software code (and firmware).

In general, the various embodiments of the UE 10 can include, but are not limited to, cellular telephones, personal digital assistants (PDAs) having wireless communication capabilities, portable computers having wireless communication capabilities, image capture devices such as digital cameras having wireless communication capabilities, gaming devices having wireless communication capabilities, music storage and playback appliances having wireless communication capabilities, Internet appliances permitting wireless Internet access and browsing, as well as portable units or terminals that incorporate combinations of such functions.

The computer-readable memories 10B and 12B may be of any type suitable to the local technical environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, random access memory, read only memory, programmable read only memory, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The data processors 10A and 12A may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on multi-core processor architectures, as non-limiting examples.

In accordance with the exemplary embodiments of this invention, when resuming data transmission/reception upon activation of an SCell, the UE 10 is allowed to report an OOR for the just activated SCell for a certain period if periodic CQI reporting for the cell is configured for the UE 10, or if an aperiodic CQI for the cell is

requested from the eNB 12 (normal CQI will be reported for other already activated cells). When resuming data transmission/reception after a long ICO gap, when carrier aggregation (CA) is not configured, the UE 10 is allowed to report an OOR for a certain period if periodic CQI reporting is configured for the UE, or if an aperiodic CQI is requested from the eNB 12. When CA is configured, it applies to all the configured or activated serving cells. That is, the UE 10 is enabled to report a valid CQI if available, otherwise, the UE 10 is enabled to report an OOR. Subsequently the UE 10 reports a valid CQI result.

It should be noted that a CQI report may also be referred to as a channel state information (CSI) report.

For the case of TM9 the certain period is from SCell activation/long ICO gap until the first available CSI RS subframe (potentially plus 4ms considering the UE 10 processing time for a CQI measurement). For other transmission modes (other than TM9) the period can be the UE processing time for the CQI measurement.

To reiterate, even though RAN4 has indicated that the UE 10 is not required to start measuring the activated SCell before subframe $n+8$, some UE implementations could re-tune the RF and start measuring earlier than $n+8$, even before $n+4$ when an acknowledge (ACK) is sent. If measurements are started before $n+4$, the UE 10 could have a valid CQI result at $n+8$, and would need no additional "gap" for CQI reporting. If measurements are started after $n+4$, the size of the "gap" is would depend on the implementation of the UE 10. The longest additional delay is 4 ms after $n+8$, as CRS for CQI measurement is available every TTI for transmission modes other than TM9, as shown in Figure 4C.

For TM9, where the CQI measurement is based on CSI RS (per 3GPP TS 36.213) with a configurable periodicity of 5~80 ms (per 3GPP TS 36.211), it is possible that the period without a valid CQI is much longer than 4ms in the case the UE 10 misses the CSI RS occasion, as shown in Figure 5. The period could be as long as until the first subframe has CSI RS available, +4 ms considering the UE 10 processing time for CQI measurement.

The time point when the UE 10 has a valid CQI result depends on the transmission mode and the CSI RS configuration. From the point of view of the eNB 12 it may be preferable to specify when the UE 10 should obtain a valid CQI result at the latest to capture the minimum requirement, at the same time allowing an improved UE 10 implementation to report a valid CQI earlier, which is similar to "ending DRX" (discontinuous reception).

It can thus be desirable to specify when the UE 10 should have a valid CQI result at the latest: (a) 4 ms after activation for TMs other than TM9; and (b) until the first subframe has CSI RS available after activation +4 ms for TM9.

Another exemplary embodiment is for the CQI unit 10E to avoid reporting anything before the first occurrence of a CSI RS. In that both the UE 10 and the eNB 12 are aware of the CSI RS pattern no decoding issue should arise at the eNB 12.

Another exemplary embodiment is for the CQI unit 10E to report an historic value before the first occurrence of a CSI RS. In that the eNB 12 is aware that no CSI RS has been transmitted yet, it can assume in this embodiment that the reported CQI is the historic CQI, and it can decide whether to use the reported value or to ignore it.

When the UE10 resumes transmission/reception upon SCell activation, or after a long ICO gap, this explicitly specifies the timing of when a valid CQI result should be reported to ensure scheduling performance. An improved UE 10 implementation can thus benefit if it can have an earlier valid CQI result.

It can be noted that it may be most preferable, with respect to CQI reporting for all configured cells or only for configured and activated cells, to report OOR until the UE 10 has a valid CQI result when a SCell is activated.

It can be further noted that there may be a question as to whether a gap is only for a real activation of a deactivated SCell or also for re-activation. In this regard a deactivation timer and PHR (power headroom report) trigger covers activation of activated or deactivated SCells. However, when considering the CQI reporting that is a subject of the exemplary embodiments of this invention it may be most preferable

that the UE 10 should not re-tune the RF for a case of SCell re-activation, and thus no gap for the CQI report should be created.

Based on the foregoing it should be apparent that the exemplary embodiments of this invention provide a method, apparatus and computer program(s) to provide enhanced CQI reporting when TM9 is in use, and generally after a number of subframes have occurred without the UE 10 receiving a CSI RS.

Figure 6 is a logic flow diagram that illustrates the operation of a method, and a result of execution of computer program instructions, in accordance with the exemplary embodiments of this invention. In accordance with these exemplary embodiments a method performs, at Block 6A, a step of, when resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap, where a valid channel quality indication result is available at the latest: (a) 4 ms after activation for transmission modes other than transmission mode 9; and (b) until the first subframe that has a channel state information reference signal available after activation +4 ms for transmission mode 9, determining whether to report to a network access node no channel quality indication value, or to report an historic channel quality indication value, or to report an out of range channel quality indication value for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node. At Block 6B there is a step of reporting a valid channel quality indication if available, otherwise reporting no channel quality indication value, or reporting one of the historic channel quality indication value or the out of range channel quality indication value.

In the method of the preceding paragraph, where the certain period includes processing time for a channel quality indication measurement.

In the method of Figure 6 and the preceding paragraphs, where when resuming data transmission/reception after a long in-device coexistence interference avoidance gap, when carrier aggregation is not configured, reporting an out of range condition for a certain period if periodic channel quality indication reporting is configured or if an aperiodic channel quality indication is requested, while when carrier aggregation is

configured it applies to all configured or activated serving cells.

A non-transitory computer-readable medium that contains software program instructions, where execution of the software program instructions by at least one data processor results in performance of operations that comprise execution of the method of Figure 6 and the foregoing paragraphs descriptive of Figure 6.

The various blocks shown in Figure 6 may be viewed as method steps, and/or as operations that result from operation of computer program code, and/or as a plurality of coupled logic circuit elements constructed to carry out the associated function(s).

In general, the various exemplary embodiments may be implemented in hardware or special purpose circuits, software, logic or any combination thereof. For example, some aspects may be implemented in hardware, while other aspects may be implemented in firmware or software which may be executed by a controller, microprocessor or other computing device, although the invention is not limited thereto. While various aspects of the exemplary embodiments of this invention may be illustrated and described as block diagrams, flow charts, or using some other pictorial representation, it is well understood that these blocks, apparatus, systems, techniques or methods described herein may be implemented in, as non-limiting examples, hardware, software, firmware, special purpose circuits or logic, general purpose hardware or controller or other computing devices, or some combination thereof.

The exemplary embodiments thus also encompass an apparatus that comprises a processor and a memory that includes computer program code. The memory and computer program code are configured to, with the processor, cause the apparatus at least to, when resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap, where a valid channel quality indication result is available at the latest: (a) 4 ms after activation for transmission modes other than transmission mode 9; and (b) until the first subframe that has a channel state information reference signal available after activation +4 ms for transmission mode 9, determine whether to report to a network access node no channel quality indication value, or to report an historic channel quality indication

value, or to report an out of range channel quality indication value for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node. The memory and computer program code are further configured to, with the processor, cause the apparatus to report a valid channel quality indication if available, or to otherwise report no channel quality indication value, or to report one of the historic channel quality indication value or the out of range channel quality indication value.

It should thus be appreciated that at least some aspects of the exemplary embodiments of the inventions may be practiced in various components such as integrated circuit chips and modules, and that the exemplary embodiments of this invention may be realized in an apparatus that is embodied as an integrated circuit. The integrated circuit, or circuits, may comprise circuitry (as well as possibly firmware) for embodying at least one or more of a data processor or data processors, a digital signal processor or processors, baseband circuitry and radio frequency circuitry that are configurable so as to operate in accordance with the exemplary embodiments of this invention.

The exemplary embodiments also encompass an apparatus that comprises means, responsive to resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap, where a valid channel quality indication result is available at the latest: (a) 4 ms after activation for transmission modes other than transmission mode 9; and (b) until the first subframe that has a channel state information reference signal available after activation +4 ms for transmission mode 9, for determining (e.g., DP 10A, memory 10B, program 10C, CQI 10E) whether to report to a network access node no channel quality indication value, or to report an historic channel quality indication value, or to report an out of range channel quality indication value for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node. The apparatus further comprises means for reporting (e.g., DP 10A, memory 10B, program 10C, transceiver 10D, CQI 10E) a valid channel quality indication if available, otherwise reporting no channel quality indication value, or reporting one of the historic channel

quality indication value or the out of range channel quality indication value.

Various modifications and adaptations to the foregoing exemplary embodiments of this invention may become apparent to those skilled in the relevant arts in view of the foregoing description, when read in conjunction with the accompanying drawings. However, any and all modifications will still fall within the scope of the non-limiting and exemplary embodiments of this invention.

For example, while the exemplary embodiments have been described above in the context of the (UTRAN LTE-A) system, it should be appreciated that the exemplary embodiments of this invention are not limited for use with only this one particular type of wireless communication system, and that they may be used to advantage in other wireless communication systems, as well as in systems using different combination of technologies (e.g., other than or in addition to LTE cellular, LTE-A cellular, GNSS, Bluetooth and WiFi, which are discussed merely as examples and not in a limiting sense).

It should be noted that the terms "connected," "coupled," or any variant thereof, mean any connection or coupling, either direct or indirect, between two or more elements, and may encompass the presence of one or more intermediate elements between two elements that are "connected" or "coupled" together. The coupling or connection between the elements can be physical, logical, or a combination thereof. As employed herein two elements may be considered to be "connected" or "coupled" together by the use of one or more wires, cables and/or printed electrical connections, as well as by the use of electromagnetic energy, such as electromagnetic energy having wavelengths in the radio frequency region, the microwave region and the optical (both visible and invisible) region, as several non-limiting and non-exhaustive examples.

Further, the various names used for the described parameters, modes of operation, subframes, reports and the like (e.g., CQI report, CSI report, CSI RS, TM9, ICO, etc.) are not intended to be limiting in any respect, as these parameters, modes of operation, subframes, reports and the like may be identified by any suitable names. Further, any names assigned to various channels (e.g., PDCCH, etc.) are not

intended to be limiting in any respect, as these channels may be identified by any suitable names.

Furthermore, some of the features of the various non-limiting and exemplary embodiments of this invention may be used to advantage without the corresponding use of other features. As such, the foregoing description should be considered as merely illustrative of the principles, teachings and exemplary embodiments of this invention, and not in limitation thereof.

CLAIMS:

1. An apparatus, comprising:
at least one processor; and
at least one memory storing a computer program;
in which the at least one memory with the computer program is configured with the at least one processor to cause the apparatus to at least:
when resuming data transmission/reception upon activation of a serving cell, or after an in-device coexistence interference avoidance gap, determine whether to report to a network access node an in-device coexistence interference indicator value; and
send the in-device coexistence interference indicator value to the network access node,
wherein the apparatus reports the in-device coexistence interference indicator value to the network access node for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.
2. The apparatus according to claim 1, where the in-device coexistence interference indicator value comprises:
an indication of no channel quality indication value;
a historical channel quality indication value; or
an out of range channel quality indication value.
3. The apparatus according to claim 1, where the apparatus communicates with the network access node in accordance with transmission mode 9.
4. The apparatus according to claim 3, where a valid channel quality indication result is available at least 4 ms after activation for transmission modes other than transmission mode 9 and until the first subframe that has a channel state information reference signal available after activation +4 ms for transmission mode 9.
5. The apparatus according to claim 1, wherein the apparatus does not report to the network access node until the first occurrence of a channel state information

reference signal.

6. The apparatus according to claim 5, where a historic value is reported to the network access node before a first occurrence of the channel state information reference signal.

7. The apparatus according to claim 1, wherein when a serving cell is activated all configured cells, or only configured and activated cells, report out of range channel quality indication value to the network access node until the apparatus has a valid channel quality indication result.

8. The apparatus according to claim 1, further comprising:
a deactivation timer and a power headroom report trigger for determining whether a gap indicates a real activation of a deactivated serving cells or reactivation of the serving cell.

9. The apparatus according to claim 1, where the certain period includes processing time for a channel quality indication measurement.

10. The apparatus according to claim 1, where when resuming data transmission/reception after an in-device coexistence interference avoidance gap, when carrier aggregation is not configured, reporting an out of range condition for a certain period if periodic channel quality indication reporting is configured or if an aperiodic channel quality indication is requested, wherein carrier aggregation is configured to apply to all configured or activated serving cells.

11. A method comprising:
when resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap, determining whether to report to a network access node an in-device coexistence interference indicator value; and
sending the in-device coexistence interference indicator value to the network access node,
wherein the apparatus reports the in-device coexistence interference indicator

value to the network access node for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.

12. The method according to claim 11, where the in-device coexistence interference indicator value comprising:

- an indication of no channel quality indication value;
- a historical channel quality indication value; or
- an out of range channel quality indication value.

13. The method according to claim 11, where the step of sending the in-device coexistence interference indicator value to the network access node is in accordance with transmission mode 9.

14. The method according to claim 13, where a valid channel quality indication result is available at least 4 ms after activation for transmission modes other than transmission mode 9 and until the first subframe that has a channel state information reference signal available after activation +4 ms for transmission mode 9.

15. The method according to claim 11, wherein the step of reporting to the network access node does not occur until a first occurrence of a channel state information reference signal.

16. The apparatus according to claim 15, where a historic value is reported to the network access node before the first occurrence of the channel state information reference signal.

17. The method according to claim 11, wherein when a serving cell is activated all configured cells or only configured and activated cells report out of range channel quality indication value to the network access node until the user equipment has a valid channel quality indication result.

18. The method according to claim 11, further comprising a step of:
determining whether a gap indicates a real activation of a deactivated serving

cells or reactivation of the serving cell by employing a deactivation timer and a power headroom report trigger.

19. The method according to claim 11, where the certain period includes processing time for a channel quality indication measurement.

20. The method according to claim 11, where when resuming data transmission/reception after a long in-device coexistence interference avoidance gap, when carrier aggregation is not configured, reporting an out of range condition for a certain period if periodic channel quality indication reporting is configured or if an aperiodic channel quality indication is requested, wherein carrier aggregation is configured to apply to all configured or activated serving cells..

21. A non-transitory computer readable medium storing a program of machine-readable instructions executable by a digital processing apparatus of a computer system to perform operations for controlling computer system actions, the operations comprising:

when resuming data transmission/reception upon activation of a serving cell, or after a long in-device coexistence interference avoidance gap, determining whether to report to a network access node an in-device coexistence interference indicator value; and

sending the in-device coexistence interference indicator value to the network access node,

wherein the non-transitory computer readable medium reports the in-device coexistence interference indicator value to the network access node for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.

22. An apparatus, comprising:

means responsive to resuming data transmission/reception upon activation of a serving cell, or after an in-device coexistence interference avoidance gap, for determining whether to report to a network access node an in-device coexistence interference indicator value; and

means for sending the in-device coexistence interference indicator value to the network access node,

wherein the apparatus reports the in-device coexistence interference indicator value to the network access node for a certain period if any periodic channel quality indication resource is configured for the cell, or if an aperiodic channel quality indication for the cell is requested from the network access node.