(54) Title: TERMINAL MEASUREMENTS OF INTERFERENCE IN WIRELESS COMMUNICATION

(57) Abstract: A new measurement report and/or reporting trigger for an LTE-based wireless communication network, in order to identify the occurrence of interference which is non-uniform in the frequency domain. The new report/trigger may be a modification of existing RSSI, RSRP and/or RSRQ to focus on specific sub-bands, sub-frames and/or sub-intervals of sub-frames within the available bandwidth and frame structure. A UE in the network monitors a measurement object such as received signal strength for each of a plurality of cells (S10) to obtain measured values, computes a difference or ratio between two such measured values (S20) and once a trigger event has occurred (S30), which may be a novel trigger based on said difference/ratio, send a report (S40) to its serving station. The report may indicate the computed difference/ratio and/or the measured values themselves.

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Terminal Measurements of Interference in Wireless Communication

Field of the Invention

The present invention relates to wireless communication systems, for example systems compliant with the 3GPP Long Term Evolution (LTE) and 3GPP LTE-A groups of standards.

Background of the Invention

Wireless communication systems are widely known in which base stations (BSs) communicate with user equipments (UEs) (also called subscriber or mobile stations) within range of the BSs.

The geographical area covered by one or more base stations is generally referred to as a cell, and typically many BSs are provided in appropriate locations so as to form a network covering a wide geographical area more or less seamlessly with adjacent and/or overlapping cells. (In this specification, the terms "system" and "network" are used synonymously). Each BS divides its available bandwidth, i.e. frequency and time resources, into individual resource allocations for the user equipments which it serves. The user equipments are generally mobile and therefore may move among the cells, prompting a need for handovers between the base stations of adjacent cells. A user equipment may be in range of (i.e. able to detect signals from) several cells at the same time, but in the simplest case it communicates with one "serving" cell.

Modern wireless communication systems such as LTE and LTE-A are hugely complex and a full description of their operation is beyond the scope of this specification. However, for assisting understanding of the inventive concepts to be described later, some outline will be given for some of the features of LTE which are of particular relevance in the present invention.

OFDM and OFDMA

OFDM (Orthogonal Frequency Division Multiplexing) is one known technique for transmitting data in a wireless communication system. An OFDM-based communications scheme divides data symbols to be transmitted among a large number of subcarriers, hence the term frequency division multiplexing. Data is modulated onto a subcarrier by adjusting its phase, amplitude, or both phase and amplitude. The "orthogonal" part of the name OFDM refers to the fact that the spacings of the subcarriers in the frequency domain are specially chosen so as to be orthogonal, in a mathematical sense, to the other subcarriers. In other words, they are arranged along the frequency axis such that the sidebands of adjacent subcarriers are allowed to overlap but can still be received without inter-subcarrier interference. In addition, each
OFDM symbol is preceded by a cyclic prefix (CP), which is used to effectively eliminate inter-symbol interference. Further, OFDM enables broadcast services on a synchronized single frequency network with appropriate cyclic prefix design. This allows broadcast signals from different cells to combine over the air, thus significantly increasing the received signal power and supportable data rates for broadcast services.

When individual subcarriers or sets of subcarriers are assigned to different user equipments, the result is a multi-access system referred to as OFDMA (Orthogonal Frequency Division Multiple Access), as used in LTE and LTE-A for the downlink - in other words for communication from base stations to user equipments. By assigning distinct frequency/time resources to each user equipment in a cell, OFDMA can substantially avoid interference among the users served within a given cell.

In OFDMA, users (called UEs in LTE) are allocated a specific number of subcarriers for a predetermined amount of time. These are referred to as resource blocks (RBs) in LTE. RBs thus have both a time and frequency dimension. Allocation of RBs is handled by a scheduling function at the base station (an eNodeB in an LTE-based system). Incidentally, the network is referred to as the E-UTRAN” (Evolved UMTS Terrestrial Radio Access Network) in LTE.

Frame Structure, Resource Blocks, Physical Channels

In a wireless communication system such as LTE, data for transmission on the downlink is organised in OFDMA frames each divided into a number of subframes. Various frame types are possible and differ between FDD and TDD for example. Frames follow successively one immediately after the other, and each is given a system frame number (SFN).

Figure 1 shows a generic frame structure for LTE, applicable to the downlink, in which the 10 ms frame is divided into 20 equally sized slots of 0.5 ms. A sub-frame consists of two consecutive slots, so one radio frame contains 10 sub-frames.

Figure 2 shows a so-called downlink resource grid for the duration of one downlink slot. The available downlink bandwidth consists of $N_{sw}$ sub-carriers with a spacing of $f = 15 \ kHz$. In case of multi cell MBMS transmission (see later), a sub-carrier spacing of $f = 7.5 \ kHz$ is also possible. $N_{sw}$ can vary in order to allow for scalable bandwidth operation up to 20 MHz. One downlink slot consists of $N_{symb}$ OFDM symbols in general. To each symbol, the above-mentioned cyclic prefix (CP) is appended as a guard time, as shown in Figure 1.
Nsymb depends on the cyclic prefix length. The generic frame structure with normal cyclic prefix length contains \( N_{\text{symb}} = 7 \) symbols as illustrated in Figure 2. Additionally, an extended CP is defined in order to cover large cell scenarios with higher delay spread and MBMS transmission (see below).

The transmitted signal in each slot is described by a resource grid of sub-carriers and available OFDM symbols, as shown in Figure 3. Each element in the resource grid is called a resource element and each resource element corresponds to one symbol.

OFDMA allows the access from multiple UEs the available bandwidth as already mentioned. Each UE is assigned a specific time-frequency resource. The data channels are shared channels, i.e. for each transmission time interval of 1 ms, a new scheduling decision is taken regarding which UEs are assigned to which time/frequency resources during this transmission time interval. The basic scheduling unit for allocation of resources to the UEs is called a resource block (RB). A resource block is defined as 7 or 6 consecutive OFDM symbols in the time domain depending on the cyclic prefix length and 12 consecutive sub-carriers (180 kHz) in the frequency domain.

However, the number of OFDM symbols and the number of subcarriers within a resource block are not limited to the 7x12 resource elements shown in Figure 3. The number of OFDM symbols and the number of subcarriers can be variously changed depending on the length of a CP, frequency spacing, and so on. For example, in the normal CP, the number of OFDM symbols can be 7, and in the extended CP, the number of OFDM symbols can be 6. In one OFDM symbol, the number of subcarriers can be one of 128, 256, 512, 1024, 1536, and 2048. The resource block size is the same for all bandwidths, therefore the number of available physical resource blocks depends on the bandwidth.

Several resource blocks may be allocated to the same UE, and these resource blocks do not have to be adjacent to each other. Scheduling decisions are taken at the base station (eNodeB). The scheduling algorithm has to take into account the radio link quality situation of different UEs, the overall interference situation, Quality of Service requirements, service priorities, etc.

Several "channels" for data and signalling are defined at various levels of abstraction within the network. Figure 4 shows some of the channels defined in LTE at each of a logical level, transport layer level and physical layer level, and the mappings between them. For present purposes, the channels at the physical layer level are of particular interest.

On the downlink, user data is carried on the Physical Downlink Shared Channel (PDSCH). There are various control channels on the downlink, which carry signalling for various purposes including so-called
Radio Resource Control (RRC), a protocol used as part of the above-mentioned RRM. In particular the Physical Downlink Control Channel, PDCCH, is used to carry scheduling information from base stations (called eNodeBs in LTE) to individual UEs. The PDCCH is located in the first OFDM symbols of a slot.

Meanwhile, on the uplink, user data and also some signalling data is carried on the Physical Uplink Shared Channel (PUSCH), and control channels include a Physical Uplink Control Channel, PUCCH, used to carry signalling from UEs including channel quality indication (CQI) reports, precoding matrix information (PMI), a rank indication for MIMO (see below), and scheduling requests.

Reference Signals and Measurements

The above "channels" defined for various data and signalling purposes, should not be confused with the "channel" in the sense of the radio link between a UE and its serving base station(s), which is subject to interference as already mentioned. To facilitate measurements of the channel by UEs, reference signals are embedded in the resource blocks as shown in Figure 5. Figure 5 shows one subframe and two resource blocks with reference signals, denoted R, inserted at intervals within individual REs. Various kinds of reference signal (or symbol) are possible.

In LTE (as distinct from LTE-A), reference signals can be classified into a cell-specific (or common) reference signal (CRS), an MBSFN reference signal used in MBMS, and a user equipment-specific reference signal (UE-specific RS). The CRS is transmitted to all the UEs within a cell and used for channel estimation. The reference signal sequence carries the cell identity. Cell-specific frequency shifts are applied when mapping the reference signal sequence to the subcarriers.

The MBSFN reference signal can be transmitted in sub-frames allocated for MBSFN transmission (see below). A UE-specific reference signal is received by a specific UE or a specific UE group within a cell. UE-specific reference signals are chiefly used by a specific UE or a specific UE group for the purpose of data demodulation.

CRSs are transmitted in all downlink subframes in a cell supporting non-MBSFN transmission. If a subframe is used for transmission with MBSFN, only the first a few (0, 1 or 2) OFDM symbols in a subframe can be used for transmission of cell-specific reference symbols.

CRSs can be accessed by all the UEs within the cell covered by the eNodeB regardless of the specific time/frequency resource allocated to the UEs. They are used by UEs to measure properties of the radio channel - so-called channel state information or CSI - with respect to such parameters as CQI and PMI.
mentioned above. Meanwhile, DRSs are transmitted by the eNodeB only within certain resource blocks that only a subset of UEs in the cell are allocated to receive.

A new reference signal in LTE-A is a Channel State Information Reference Signal (CSI-RS). CSI-RS is inserted periodically by LTE-advanced eNodeB so that LTE-advanced UEs can estimate the channel state information, which is of assistance when configuring a UE for MIMO (see below).

As mentioned, UEs employ the reference signals in order to measure some property of the radio link with each cell which it can detect. Such measurements are reported to the network (to the base station of the serving cell) typically in response to some trigger criterion being met.

However, it should be noted that it is not always necessary to employ reference signals, depending on the situation. For example, a UE can detect interference in its serving cell from other cells if it detects the received signal strength at times when CRS is absent from the serving cell.

LTE uses the concept of a "measurement object" to define the quantity to be measured. Among other definitions given in 3GPP TS 36.331, the following abbreviated excerpts are worth mentioning here:

The measurement configuration includes, among other things, the following parameters:

1. Measurement objects: The objects on which the UE shall perform the measurements. For intra-frequency and inter-frequency measurements a measurement object is a single E-UTRA carrier frequency.

2. Reporting configurations: A list of reporting configurations where each reporting configuration consists of the following:
   - Reporting criterion: The criterion that triggers the UE to send a measurement report. This can either be periodical or a single event description.
   - Reporting format: The quantities that the UE includes in the measurement report and associated information (e.g. number of cells to report).

Only a single measurement object is configured for a given frequency, but multiple instances of the same event can be configured, e.g. by configuring two reporting configurations with different thresholds.

The UE maintains a single measurement object list, a single reporting configuration list, and a single measurement identities list. The measurement object list includes measurement objects, that are specified per RAT (Radio Access Technology) type, possibly including an intra-frequency object.
object corresponding to the serving frequency), inter-frequency object(s) and inter-RAT objects. The measurement procedures distinguish the following types of cells:

1. The serving cell.
2. Listed cells - these are cells listed within the measurement object(s).
3. Detected cells - these are cells that are not listed within the measurement object(s) but are detected by the UE on the carrier frequency(ies) indicated by the measurement object(s).

Thus, in LTE, the UE measures and reports on the serving cell, listed cells and detected cells.

Two measurement quantities used in LTE are Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). RSRP and/or RSRQ are employed by a UE to get and stay connected to the "serving cell", and to be handed over from one serving cell to another. In 3GPP TS 36.214 "Physical Layer Measurements", hereby incorporated by reference, these are defined as follows:

Reference signal received power (RSRP), is defined as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth. For RSRP determination, the above-mentioned cell-specific reference signals CRS are normally used (further details of reference signals are given in 3GPP TS 36.211, hereby incorporated by reference).

Reference Signal Received Quality (RSRQ) is defined as the ratio $N^*\text{RSRP}/(\text{E-UTRA carrier RSSI})$, where $N$ is the number of RB's of the E-UTRA carrier RSSI measurement bandwidth. The measurements of both quantities are made over the same set of resource blocks.

E-UTRA Carrier Received Signal Strength Indicator (RSSI) comprises the linear average of the total received power (in [W]) observed only in OFDM symbols containing reference symbols for a specified UE antenna, in the measurement bandwidth, over $N$ number of resource blocks by the UE from all sources, including co-channel serving and non-serving cells, adjacent channel interference, thermal noise etc.

As is apparent from the above definitions, RSRP and consequently also RSRQ measurement depends on detection of reference signals from the cell(s) concerned. By contrast, RSSI (which may be used as a signal strength indication in its own right) does not necessarily require detection of reference signals.

LTE also specifies so-called "layer 3 filtering" of measurement reports. In 3GPP TS 36.331 "Radio Resource Control (RRC) Protocol Specification", hereby incorporated by reference, this filtering is defined as follows.
The UE shall for each measurement quantity that the UE performs measurements, filter the measured result, before using for evaluation of reporting criteria or for measurement reporting, by the following formula:

\[ F_n = (1 - a) \cdot F_{n-1} + a \cdot M_n \]

where

- \( M_n \) is the latest received measurement result from the physical layer;
- \( F_n \) is the updated filtered measurement result, that is used for evaluation of reporting criteria or for measurement reporting;
- \( F_{n-1} \) is the old filtered measurement result, where \( F_0 \) is set to \( M_1 \) when the first measurement result from the physical layer is received; and
- \( a = \frac{1}{2^{(k+1)}} \), where \( k \) is the filterCoefficient for the corresponding measurement quantity received by the quantityConfig;

The effect of this is to provide a moving average of the measurement quantity (also called "measurement object").

A UE can be expected to take measurements at frequent intervals. However, the taking of a measurement is distinct from the act of reporting the measurement result (or any information derived therefrom) to the network.

In order to send a measurement report, a trigger criterion (trigger event) has to be fulfilled at the UE.

Various trigger events, for causing a UE to report a measurement to its serving eNodeB, are defined in LTE and specified in the above-mentioned 3GPP TS36.331. To give one example, there is an Event A1 (Serving becomes better than threshold). This is satisfied when:

\[ M_s - \text{Hys} > \text{Thresh} \]

where

- \( M_s \) is the measurement result of the serving cell, not taking into account any offsets.
- \( \text{Hys} \) is the hysteresis parameter for this event (i.e. hysteresis as defined within reportConfigEUTRA for this event).
- \( \text{Thresh} \) is the threshold parameter for this event (i.e. \( a_1 \)-Threshold as defined within reportConfigEUTRA for this event).
Signal strength is often used to determine whether to hand over to a neighbouring cell, as already mentioned. In this instance, a relevant event trigger in LTE is the so-called "A3" event, defined as follows:

5 Event A3 (Neighbour becomes offset better than serving)

\[ Mn + Ofn + Ocn - Hys > Ms + Ofs + Ocs + Off \]

where:

10 Mn is the measurement result of the neighbouring cell, not taking into account any offsets.

15 Ofn is the frequency specific offset of the frequency of the neighbour cell (i.e. offsetFreq as defined within measObjectEUTRA corresponding to the frequency of the neighbour cell).

20 Ocn is the cell specific offset of the neighbour cell (i.e. cellIndividualOffset as defined within measObjectEUTRA corresponding to the frequency of the neighbour cell), and set to zero if not configured for the neighbour cell.

25 Ms is the measurement result of the serving cell, not taking into account any offsets.

30 Ofs is the frequency specific offset of the serving frequency (i.e. offsetFreq as defined within measObjectEUTRA corresponding to the serving frequency).

35 Ocs is the cell specific offset of the serving cell (i.e. cellIndividualOffset as defined within measObjectEUTRA corresponding to the serving frequency), and is set to zero if not configured for the serving cell.

Hys is the hysteresis parameter for this event (i.e. hysteresis as defined within reportConfigEUTRA for this event).

Off is the offset parameter for this event (i.e. a3-Offset as defined within reportConfigEUTRA for this event).

The transmission of measurement reports by individual UEs is configured via Radio Resource Control (RRC), which as mentioned earlier is one aspect of the control signalling sent to the UE from its serving cell.

MIMO

A technique called MIMO, where MIMO stands for multiple-input multiple-output, has been adopted in LTE due to its spectral efficiency gain, spatial diversity gain and antenna gain. This type of scheme employs multiple antennas at the transmitter and/or at the receiver (often at both) to enhance the data capacity achievable between the transmitter and the receiver. Typically, this is used to achieve an enhanced data capacity between one or more BSs and the UEs served by the BSs.
The term channel is used to describe the frequency (or equivalently time delay) response of the radio link between a transmitter and a receiver. The so-called MIMO channel contains all the subcarriers, and covers the whole bandwidth of transmission. A MIMO channel contains many individual radio links (also called SISO channels for single-input single-output).

Heterogeneous Networks

Interference is a major factor limiting the performance of wireless communication systems. In cellular wireless communication systems the location and configuration of base stations is carefully planned to provide good coverage and low interference between cells/sectors. So-called Radio Resource Management (RRM) is used to control parameters such as transmit power, channel allocation, handover criteria, modulation scheme, and error coding schemes in order to reduce interference and thereby utilize the limited radio spectrum resources and radio network infrastructure as efficiently as possible.

However the advent of so-called "heterogeneous networks" has complicated the interference issue. Figure 6 schematically illustrates part of a heterogeneous network in which a macro base station covers a macro cell area MC, within which there are other, overlapping cells formed by a pico base station 12 (pico cell PC) and various femto base stations 14 (forming femto cells FC). As shown a UE 20 may be in communication with one or more cells simultaneously, in this example with the macro cell MC and the pico cell PC. The cells may not have the same bandwidth; typically, the macro cell will have a wider bandwidth than each femto cell.

Some definitions are as follows:

- Heterogeneous Network: A deployment that supports macro, pico, femto stations and/or relays in the same spectrum.

- Macro base station - conventional base stations that use dedicated backhaul and open to public access. Typical transmit power -43 dBm; antenna gain ~12-15 dBi.

- Pico base station - low power base station with dedicated backhaul connection and open to public access. Typical transmit power range from -23 dBm-30 dBm, 0-5 dBi antenna gain;

- Femto base station - consumer-deployable base stations that utilize consumer's broadband connection as backhaul; femto base stations may have restricted association. Typical transmit power < 23 dBm.
Relays - base stations using the same spectrum as backhaul and access. Similar power to a Pico base station.

In LTE, an example of a femto base station is the so-called Home eNodeB or Home eNodeB.

The installation by network customers of base stations with a localised network coverage cell, such as femto base stations (Home eNodeBs) is expected to become widespread in future LTE deployments. A femto base station or other local cover base station can be installed in, for example, a building within which network subscriber stations experience high path loss in transmissions with a macro cell. Femto base stations can be installed by a customer in his own premises. These femto base stations can improve network coverage, particularly within the femto cell, and can also improve spectral efficiency. However, since the deployment of these femto base stations is unplanned, they can also cause significant interference between the macro cell and the femto cell if they operate in the same frequency band.

Interference, CoMP and MBMS

Inter-cell interference may arise, for example, because the frequency resources (i.e. the carriers and subcarriers) utilised for transmitting data to UEs in one cell are identical to the frequency resources in use in an adjacent cell. In other words, in the kinds of wireless communication systems in which the present invention may find use, there is likely to be, using terminology common in the art, 1:1 frequency reuse between adjacent cells. Moreover the "adjacent" cells may in fact lie entirely one within another, as for example when a Home eNodeB is deployed within an existing macro cell (see Figure 6).

One method which has been proposed for addressing this difficulty is to coordinate the MIMO transmissions among multiple base stations (i.e. coordinating transmissions in adjacent or nearby cells) to eliminate or reduce this inter-cell interference. This coordination can reduce or eliminate inter-cell interference among coordinated cells (or coordinated portions of cells) and this can result in a significant improvement in the coverage of high data rates and overall system throughput. However, the trade-off for this improvement is that the coordination of transmissions in multi-cellular MIMO systems requires channel state information (CSI) and data information to be shared among the coordinated base stations.

Such coordinated multi-cell MIMO transmission/reception (also called coordinated multi-point transmission/reception or CoMP) may be used to improve the coverage of high data rates, cell-edge throughput and/or to increase system throughput. The downlink schemes used in CoMP include "Coordinated Scheduling and/or Coordinated Beamforming (CS/CB)" and "Joint Processing/Joint Transmission (JP/JT)". An additional technique which may be employed is aggregation of multiple carriers (CA) to increase the available peak data rate and allow more complete utilisation of available spectrum allocations.
In CS/CB, data to a single UE is transmitted from one transmission point, but decisions regarding user scheduling (i.e. the scheduling of timings for transmissions to respective user equipments) and/or beamforming decisions are made with coordination among the cooperating cells (or cell sectors). In other words, scheduling/beamforming decisions are made with coordination between the cells (or cell sectors) participating in the coordinated scheme so as to prevent, as far as possible, a single UE from receiving signals from more than one transmission point.

On the other hand, in JP/JT, data to a single UE is simultaneously transmitted from multiple transmission points to (coherently or non-coherently) improve the received signal quality and/or cancel interference for other UEs. In other words the UE actively communicates in multiple cells and with more than one transmission point at the same time. Further details of CoMP as applied to LTE can be found in the document 3GPP TR 36.814, also incorporated by reference.

In CA, discrete frequency bands are used at the same time (aggregated) to serve the same user equipment, allowing services with high bandwidth demands (up to 100MHz) to be provided. CA is a feature of LTE-A (LTE-Advanced) which allows LTE-A-capable terminals to access several frequency bands simultaneously whilst retaining compatibility with the existing LTE terminals and physical layer. CA may be considered as an complement to JP for achieving coordination among multiple cells, the difference being (loosely speaking) that CA requires coordination in the frequency domain and JP in the time domain.

Figures 7(a) and (b) schematically illustrates the working principles of the two above-mentioned categories of downlink transmission used in CoMP, although it should be noted that the Figure may not reflect the true distribution of base stations vis-a-vis cells in a practical wireless communication system. In particular, in a practical wireless communication system, the cells extend further than the hexagons shown in the Figure so as to overlap to some extent, allowing a UE to be within range of more than one base station at the same time. Furthermore, it is possible, in LTE for example, for the same base station (eNodeB) to provide multiple overlapping cells, normally using distinct carrier frequencies. Nevertheless, Figure 7 is sufficient for present purposes to illustrate the principles of CS/CB and JP downlink transmission schemes respectively, used in CoMP.

Joint Processing (JP) is represented in Figure 7(a) in which cells A, B and C actively transmit to the UE, while cell D is not transmitting during the transmission interval used by cells A, B and C.

Coordinated scheduling and/or coordinated beamforming (CS/CB) is represented in Figure 7(b) where only cell B actively transmits data to the UE, while the user scheduling/beamforming decisions are made
with coordination among cells A, B, C and D so that the co-channel inter-cell interference among the cooperating cells can be reduced or eliminated.

In the operation of CoMP, UEs feed back channel state information. The channel state information is often detailed, and often includes measurements of one or more of channel state/statistical information, narrow band Signal to Interference plus Noise Ratio (SINR), etc. The channel state information may also include measurements relating to channel spatial structure and other channel-related parameters including the UE’s preferred transmission rank and precoding matrix.

As another example of co-operative transmission among base stations, MBMS (Multimedia Broadcast Multicast Services) may be performed via multi-cell transmission. In case of multi-cell transmission the cells and content are synchronized to enable for the terminal to combine the received signal from multiple transmissions. This concept is also known as a Single Frequency Network. The E-UTRAN can configure which cells are part of an Single Frequency Network for transmission of an MBMS service, so-called MBSFN operation. The MBMS traffic can share the same carrier with the unicast traffic or be sent on a separate carrier. For MBMS traffic, the above-mentioned extended CP is provided, and in the case of subframes carrying MBSFN data, specific reference signals are used.

**Interference in the Context of Heterogeneous Networks and CoMP**

Various radio RRM (Radio Resource Management) measurements are defined in LTE whereby, for example, the UE can report the DL radio channel quality for a number of cells. This enables the UE to identify a suitable cell with which to attempt a connection and also enables network to determine whether a handover to a different serving cell is appropriate. The configuration of these measurements is by RRC signalling. Currently these measurements have limitations in the flexibility in characterising the quality of a given cell. For example they are not capable of identifying interference variations in the frequency domain (e.g. being based on frequency domain averaging). Furthermore, the mechanisms for timing and filtering measurements are not well adapted to indentifying interference variations in the time domain.

A further limitation on the RRM measurement scheme adopted in LTE is that it relies on the identification of at least one cell at a particular carrier frequency before any measurement can be reported for that part of the radio spectrum.

Some deployments of LTE (or more likely, LTE-A) where these limitations may be significant are as follows:

Frequency domain interference variations are envisaged where carriers with different bandwidths may be
present in the same part of the radio spectrum. One important example may be heterogeneous networks as mentioned earlier, where the macro cell bandwidth is larger than the home base station bandwidth (e.g. 20MHz vs. 10MHz). Such heterogeneous deployments can lead to situations where the interference is much greater in one part of the system bandwidth than another (e.g. transmissions in the lower half of the macro cell bandwidth of 20MHz are subject to strong interference from a Home eNodeB, while transmissions in the upper half are not).

Interference may also vary in the time domain. For example, some subframes may be configured for MBSFN operation as already mentioned, or may be used for relay operation, and this is likely to lead to higher average interference levels in those subframes. In addition, different interference levels may be present in different parts of a subframe depending on the presence of Common Reference Symbols (CRS), control channel (PDCCH) or data (PDSCH).

This can lead to some problems. For example, if the characterisation of the quality of a cell is based on an average of the interference across the frequency and/or time domain(s), this may lead to a pessimistic view in the case that the interference is non-uniform. This is because although the quality may be low at some frequencies and/or time periods, this can be more than offset by better quality at others. This effect may lead to inappropriate or unnecessary handovers.

Furthermore, interference may vary in the spatial domain. For UEs having multiple receive antennas, with the knowledge of the interfering radio links from the neighbouring cells (for example, a so-called interference co-variance matrix), it is possible to apply different antenna weights to the transmitter and/or receiver antennas, to reduce the effects of interference.

Co-operative multi-point (CoMP) operation, as above-mentioned, is envisaged for future Releases of LTE, where different cells at the same frequency co-operate to serve a UE. Because of the limitations mentioned above the currently available RRM measurements may prevent the network optimally selecting and configuring cells for CoMP operation.

It is therefore desirable to improve the RRM measurement scheme to address the above problems.

**Summary of the Invention**

According to a first aspect of the present invention, there is provided a user equipment for a cellular wireless communication network in which transmission is arranged to occur over radio links within an available bandwidth in the frequency domain and in units of frames in the time domain, the user
equipment arranged to measure one or more radio link properties and send to the network at least one
measurement report comprising at least one measurement made in relation to at least one of:
   at least two different sub-bands within the available bandwidth; and
   at least two different sub-periods within a frame.

According to a second aspect of the present invention, there is provided a user equipment for a cellular
wireless communication network in which transmission is arranged to occur within an available bandwidth
in the frequency domain and in units of frames in the time domain, the user equipment arranged to send
to the network at least one measurement report triggered by the result of comparing a measurement
made in relation to at least one of:
   at least two different sub-bands within the available bandwidth; and
   at least two different sub-periods within a frame,
with one of:
   a measurement of radio link properties; and a predetermined threshold.

These two aspects may be combined. That is, the user equipment may, in addition to sending a
measurement report in relation to at least two different sub-bands within the available bandwidth and/or in
relation to at least two different sub-periods within a frame, have regard to the at least two or more
different sub-bands/sub-periods as a trigger criterion for sending the report. The measurement of radio
link properties may be an existing measurement.

In both cases, the user equipment being "arranged" may refer to a selectable configuration of the user
equipment set by RRC signalling for example. Alternatively the network specifications may fix this
arrangement such that the user equipment will always be operable in the above manner.

In either aspect as defined above, where the frames are subdivided into subframes, each sub-period may
be a sub-interval within a subframe. The user equipment may send at least one measurement report in
relation to at least two different sub-intervals within a subframe. The at least one measurement may
also relate to different subframes within a frame. In the latter case, the user equipment may have a filter
for selecting measurements in relation to specific subframes.

The measurement report, and/or the trigger for sending the report, may involve a difference between the
measurements for two different sub-bands and/or sub-periods. Alternatively it may involve a ratio
between the measurements for two different sub-bands and/or sub-periods.
Preferably, the measurement report includes a report indicative of received signal strength at the user equipment. Such a report indicative of signal strength may provide information on each of a plurality of cells detected by the user equipment.

A preferred embodiment of the user equipment is employed in an LTE-based network, wherein the at least one measurement report includes a report corresponding to RSSI (Carrier Received Signal Strength Indicator) or RSRQ (Reference Signal Received Quality) as defined in LTE, but modified to apply to said at least two different sub-bands within the available bandwidth and/or in relation to at least two different sub-periods within a frame.

In any case, the user equipment may be further arranged to detect reference signals for measuring at least one radio link property and to select at least two different sub-bands within the available bandwidth, and/or in said at least two different sub-periods within a frame, on the basis of presence or absence of reference signals.

According to a third aspect of the present invention, there is provided a user equipment for a wireless communication network in which transmission is arranged to occur between the user equipment and base station, the user equipment arranged to assign plural sets of receiver weights, each set corresponding to a respective receiver beam pattern, and further arranged to report to the network at least one measurement in relation to one set of receiver weights.

Thus, the third aspect extends the same inventive concept as that of the first aspect to the spatial domain. A modification of this aspect is to use the at least one measurement report as a trigger for sending a report, thus extending the same inventive concept as the second aspect to the spatial domain.

According to a fourth aspect of the present invention, there is provided a base station for use with a user equipment according to any preceding claim and adapted to receive said at least one measurement report sent by the user equipment.

According to a fifth aspect of the present invention, there is provided a wireless communication network including user equipments according to any preceding claim.

According to a sixth aspect of the present invention, there is provided a wireless communication method comprising:

- arranging transmission to occur over radio links within an available bandwidth in the frequency domain and in units of frames in the time domain;
- measuring, at a user equipment, one or more radio link properties; and
the user equipment performing at least one of:

- sending, from the user equipment to the network, at least one measurement report in
  relation to at least two different sub-bands within the available bandwidth and/or in relation to at least two
  different sub-periods within a frame, and

- triggering sending of at least one measurement report by comparing measurements in
  relation to at least two different sub-bands within the available bandwidth and/or in relation to at least two
  different sub-periods within a frame.

Further aspects of the present invention may provide a RRM entity in a wireless communication network
for configuring user equipments in any manner as defined above, as well as controlling a base station to
provide control signalling to a user equipment for configuring it as above defined. A further aspect relates
to software for allowing transceiver equipment equipped with a processor to provide any user equipment
as defined above. Such software may be recorded on a computer-readable medium.

Throughout this section and the claims, the term "cell" is intended also to include sub-cells.

The sub-bands may be defined to be within a "configured measurement bandwidth". Another possibility
may be that a sub-band is an additional band, defined in relation to the configured measurement
bandwidth (e.g. an adjacent band).

Thus, an embodiment of the present invention may provide a new measurement report and/or reporting
trigger for an LTE-based wireless communication network, in order to identify the occurrence of
interference which is non-uniform in the frequency domain. The new report/trigger may be based on
existing RSSI, RSRP and/or RSRQ as defined in LTE, but modified to focus on specific sub-bands, sub-
frames and/or sub-intervals of sub-frames within the available bandwidth and frame structure. A user
equipment in the network monitors a measurement object such as received signal strength for each of a
plurality of cells or sub-cells to obtain measured values, computes a difference or ratio between two such
measured values and once a trigger event has occurred, which may be a novel trigger based on said
difference/ratio, send a report to its serving station. The report may indicate the computed difference/ratio
and/or the measured values themselves.

In general, and unless there is a clear intention to the contrary, features described with respect to one
aspect of the invention may be applied equally and in any combination to any other aspect, even if such a
combination is not explicitly mentioned or described herein.

As is evident from the foregoing, the present invention involves signal transmissions between base
stations and user equipments in a wireless communication system. A base station may take any form
suitable for transmitting and receiving such signals. It is envisaged that the base stations will typically
take the form proposed for implementation in the 3GPP LTE and 3GPP LTE-A groups of standards, and
may therefore be described as an eNodeB (eNB) (which term also embraces Home eNodeB or Home
eNodeB) as appropriate in different situations. However, subject to the functional requirements of the
invention, some or all base stations may take any other form suitable for transmitting and receiving signals
from user equipments, and for adapting signals for transmission to user equipments based on fed back
channel state information.

Similarly, in the present invention, each user equipment may take any form suitable for transmitting and
receiving signals from base stations. For example, the user equipment may take the form of a subscriber
station (SS), or a mobile station (MS), or any other suitable fixed-position or movable form. For the
purpose of visualising the invention, it may be convenient to imagine the user equipment as a mobile
handset (and in many instances at least some of the user equipments will comprise mobile handsets),
however no limitation whatsoever is to be implied from this.

**Brief Description of the Drawings**

Reference is made, by way of example only, to the accompanying drawings in which:

Figure 1 illustrates a generic frame structure used in LTE;

Figures 2 and 3 illustrate resource blocks (RBs) and resource elements (REs) in a downlink subframe;

Figure 4 shows the mapping between logical channels, transport channels and physical channels in LTE;

Figure 5 shows an example of reference signal transmission within resource blocks;

Figure 6 schematically illustrates a heterogeneous network in which a macro cell, pico and femto cells are
overlapping;

Figure 7(a) schematically illustrates joint processing (JP) downlink transmission used in CoMP;

Figure 7(b) schematically illustrates coordinated scheduling and/or beamforming (CS/CB) downlink
transmission used in CoMP; and

Figure 8 is a flowchart of the main steps involved in a method embodying the invention.
Detailed Description

The RRM measurements for LTE are specified in 3GPP TS 36.214 and configured by RRC signalling according to 3GPP TS36.331, both of which are incorporated by reference as already mentioned.

The relevant measurements in 3GPP TS 36.214 are made for a defined cell and defined measurement bandwidth around the defined carrier centre frequency, and the definitions of these quantities were given in the introduction. Note that reporting of RSRP and RSRQ require that a cell is actually detected at the defined carrier frequency (in order that the CRS locations are known). In other types of wireless communication network such as UMTS (with which many LTE-capable UEs may be compatible), RSSI may also be reported.

As indicated in the introduction, in LTE channel state information (CSI) may also be reported by means of physical layer signalling. The most relevant metric is a channel quality indication (CQI), which is expressed in terms of an achievable data rate. Some CQI reporting modes provide for CQI reports relating to different parts of the frequency domain. However, the use of CQI reports has significant limitations:

- CQI measurements are designed to support efficient scheduling of transmissions, not handover
- CQI reports are only available in connected mode,
- Only some CQI reporting modes provide for different CQI in different parts of the frequency domain.
- CQI does not directly distinguish between limitations on data rate arising from the channel transfer function and those arising from interference. Other information (such as PMI) will be needed to make a good estimate of SIR based on CQI.

Conventionally, in LTE, RSRP (and RSRQ) is derived by a direct measurement of power in particular REs containing a CRS. However, since the CRS sequence (i.e. the values in different locations in the time/frequency domain) is known at the UE, more accurate methods are possible. Typically, such methods assume that the radio channel does not change significantly (e.g. over a resource block).
The present invention is described mainly with respect to using modified versions of existing measurements, in particular RSSI and RSRQ. However, it will also be generally applicable to new measurements.

For example, a new measurement can be based on RSRP, but where the power of a given reference signal sequence (for the cell in question) is measured over defined intervals in the time and frequency domains (e.g. one Resource Block) and this is averaged over a defined bandwidth. This has the advantage of being more robust to interference than the current definition of RSRP.

Following this invention, modified versions of RSSI and/or RSRQ with different definitions may be considered. Further, RSSI may be explicitly reported as an RRM measurement.

**Frequency Domain Measurements.**

It is desirable for the UE to be able to report measurements which can identify situations where interference is non-uniform in the frequency domain. It is further desirable that the existing measurement report triggers and filters can be used. Therefore the inventors have devised the following options:

(a) Define one or more new measurement quantities based on splitting a carrier into two or more sub-bands for measurement purposes, such as RSSI for two or more sub-bands. This may be within the conventionally-configured measurement bandwidth (or possibly outside it - that is, an additional band, defined in relation to the configured measurement bandwidth (e.g. an adjacent band). The definition of the sub-bands may be part of the configuration.

(i) This new measurement quantity may be reported as the difference, or magnitude of the difference, between RSSI for different sub-bands (e.g. one or more difference values). In the case of two bands, there is little more to be considered, except that the magnitude of the difference (i.e. its absolute value) is likely to be of more interest than which of the two sub-bands has the higher measurement value.

In the case of three or more sub-bands there are various possibilities, including:

- Difference between largest and smallest sub-band RSSI
- Difference between largest (or smallest) sub-band RSSI and the an average RSSI over the other sub-bands (or measurement bandwidth)
- Difference between the RSSIs for a specific pair of sub bands
- Difference between the RSSI for a specific sub band and an average RSSI
- Magnitude of an absolute RSSI difference (e.g. one or more magnitudes)
- Smallest (or possibly largest) RSSI over the sub-bands
A function of the RSSI values for each sub-band (for example, "the difference between the RSSI value and another value", where the "another value" may be, for example, the "mean RSSI over the sub-bands", "previous mean RSSI", "previous RSSI for the same sub-band").

According to an embodiment of the invention, the RSSI (or differential RSSI) for each sub-band will be treated as distinct measurement quantities.

(ii) This new measurement quantity may be reported as RSRQ for two or more sub-bands (similar to RSSI). These sub-bands may be within the configured measurement bandwidth (or possibly outside it). Possible ways to report this RSRQ-like quantity include:

- Difference between RSRQ for different sub-bands
- Largest (or possibly smallest) RSRQ over the sub-intervals
- A function of the RSRQ values for each sub-interval a generic function where the input variables will be at least the RSSI values for each band. Possible examples may be mean, variance max, min, or the difference between max and min.

In several of the cases of interest, it is relevant if there is a difference (e.g. sub-bands have different RSRQ), but the sign of the difference is not important (e.g. which sub-band has the higher RSRQ). The RSRQ (or differential RSRQ) for each sub-band will be treated as a different measurement quantities.

(b) An alternative option devised by the inventors is to define a new measurement quantity based on RSSI, for example, including only REs without CRS (for the serving cell), denoted by RSSI_{nocRS}.

Excluding REs containing CRS from the wanted cell will lead to RSSI giving a better estimate of interference from other cells, particularly if the wanted cell was not actively transmitting data. Options here include:

- Report RSSI_{nocRS} as an RRM measurement
- Report RSRQ_{mod} derived from the ratio of RSRP and RSSI_{nocRS}
- Derive RSSI_{nocRS} and RSRQ_{mod} in two or more sub-bands (as above).

In the above, a suitable event trigger (trigger for sending a report to the network: see above) may be based on "magnitude of the difference" for RSSI or RSRQ, while the reported measurement may be the "difference" (the distinction being that "difference" includes the sign, plus or minus). For comparing different cells when considering the trigger conditions it may be argued (for most cases) that a larger value of the difference is "better" in terms of potential handover, since this means that at least part of the band has better than average quality. The expectation will be that the new cell will support more reliable communication and/or a higher bit rate. Alternatively, a trigger event could be based on comparison with
a fixed or configurable threshold.

Another possibility will be to define RSRQ with a measurement frequency which is offset with respect to the carrier centre frequency. For example, if the measurement bandwidth is half the carrier bandwidth, then a frequency offset of plus or minus 1/4 the carrier bandwidth may be used to indicate either the upper or lower half of the carrier. In this case the "frequency offset" will need to be a configured parameter of the measurement object. Unfortunately, this will imply the need for multiple measurement objects at the same carrier frequency, and new trigger conditions to be defined which are not cell based. Note that this is not in line with the existing framework for LTE, where it is stated in 3GPP 36.331, "For intra-frequency and inter-frequency measurements a measurement object is a single E-UTRA carrier frequency". This may then cover more than one cell.

Thus, an embodiment of the present invention can provide a new measurement report that can be used within the existing framework, in order to identify the occurrence of interference which is non-uniform in the frequency domain. In particular, taking the magnitude of a measurement difference may be particularly useful for triggering measurement reporting.

**Time Domain Measurements**

A similar principle can also be applied in the time-domain i.e. to identify scenarios where the interference is non-uniform in the time domain. For example, if neighbouring cells are transmitting with higher power level in the control channel region (PDCCH) than the data region (PDSCH), interference levels will vary between different parts of the subframe. A case of particular interest will be where the cells have synchronised timing such that the control channel regions of neighbouring cells overlap.

Therefore it is proposed to define one or more new measurement quantities by splitting a subframe into two or more sub-intervals for measurement purposes, such as:

(i) RSSI for two or more sub-intervals within a subframe. The definition of the intervals may be part of the configuration. This may be reported as:

* Difference between RSSI for different sub-intervals. A special case is two sub-intervals; other possibilities for more than two sub-intervals include:

- Difference between largest and smallest sub-interval RSSI
- Difference between largest (or smallest) sub-interval RSSI and an average RSSI over the other sub-intervals (or the subframe)

- Difference between the RSSIs for a specific pair of sub intervals
- Difference between the RSSI for a specific sub interval and an average RSSI
Magnitude of an RSSI difference
- Smallest (or possibly largest) RSSI over the sub-intervals
- A function of the RSSI values for each sub-interval

Here, the RSSI (or differential RSSI) for each sub-interval will be treated as different measurement quantities.

(ii) RSRQ for multiple sub-intervals (similar to RSSI). This can be reported as:
- Difference between RSRQ for different sub-intervals
- Magnitude of an RSRQ difference
- Largest (or possibly smallest) RSRQ over the sub-intervals
- A function of the RSRQ values for each sub-interval

The RSRQ (or differential RSRQ) for each sub-interval will be treated as different measurement quantities.

The sub-intervals mentioned above may correspond to at least one of: OFDM symbols containing/not containing control channel information; and OFDM symbols containing/not containing CRS.

To explain this further, RSSI measurements (aimed at quantifying interference) do not need any reference symbols. However, reference symbols may be needed to measure wanted signal power or quality. So measurements of RSSI may give different results depending on which symbols are used for the measurements. If the intention is to measure interference due to data transmission, then it may be preferable to use symbols without CRS or CSI-RS.

It is noted that the above approach may require a tighter definition of the measurement definition at physical layer to apply to one subframe. For example, the measurement definition may specify which OFDM symbols within a subframe are included for particular measurements.

In the above, a suitable event trigger may be based on "magnitude of the difference" for RSSI or RSRQ, while the reported measurement may be the "difference". For comparing different cells for handover purposes, when considering the trigger conditions it may be argued (for most cases) that a larger value of the difference is "better", since this means that at least part of the subframe has better than average quality.

An extension of the above idea is to identify scenarios where the interference level differs between subframes. This may occur if different subframes are configured for different purposes, such as broadcast services or relay transmissions. In particular in LTE, subframes for broadcast (or other) services may be configured as MBSFN subframes as already mentioned. The principle proposed for
measurements within a subframe may be extended to cover intervals longer than a subframe. An alternative approach will be to define suitable Layer 3 filters applying to RSSI and/or RSRQ.

Conventionally, Layer 3 filtering (if applied) is intended to give a moving average of the measurement. One filter may give a (moving) average of measurements restricted to a set of subframes meeting certain criteria (e.g. without CSI-RS). Another filter may include only subframes with CSI-RS.

In this case the following are possibilities:

(i) The filter selects only measurements taken in particular subframes, such as:
   - A given (configurable) subframe number within each radio frame
   - In radio frames where SFN mod N = M, where SFN is system frame number and N and M are configurable
   - Subframes which satisfy a (possibly configurable) criterion based on both SFN and subframe number within a radio frame
   - Subframes configured according to one (or more) of the following conditions:
     - MBSFN subframes
     - Non-MBSFN subframes
     - Subframes with CSI-RS
     - Subframes without CSI-RS
     - Subframes with positioning reference symbols
     - Subframes without positioning reference symbols
     - Subframes used for relaying
     - Subframes not used for relaying

(ii) The filter combines measurements taken in particular subframes (for example derived as above), to give results such as:
   - Difference between largest and smallest measurements for any sub-frame
   - Difference between largest (or smallest) measurements for any subframe and an average over the other subframes (or all subframes)
   - Difference between the measurements for a specific pair of subframes
   - Difference between the measurements for a specific subframe and an average measurement

The above scheme provides a new measurement report that can be used within the existing framework, in order to identify the occurrence of interference which is non-uniform in the time domain. In particular, taking the magnitude of a measurement difference may be particularly useful for triggering measurement reporting. A further feature is the introduction of Layer 3 filtering as mentioned, to characterize time
dependent interference levels and hence time dependent cell quality.

**Spatial Domain Measurements**

A similar principle can also be applied in the spatial domain i.e. to identify scenarios where the interference is spatially non-uniform. This will require definition of new measurements adapted to deriving spatial properties for signals received from neighbouring cells, or for characterising the spatial properties of interference. This characterisation may be based on the interference co-variance matrix mentioned earlier.

This will be applicable in the MIMO scenario outlined in the introduction, i.e. for terminals with multiple antennas. One possibility will be to define sets of receiver combining weights, where a given weight from a set is applied to the received signal from a given antenna at the terminal, each set corresponding to a different spatial signature.

For example, with two antennas, suitable receiver weights may be \([1,1], [1,-1], [-1,1], [-1,-1]\). Each set corresponds to a different receiver beam pattern. Different weights will lead to different measurements for the same cell: in this example, up to four instances of RSRQ for each measured cell. The receiver weights may be specified for each measurement, or perhaps modified measurements defined where the receiver weights are optimised e.g. chosen to give the maximum RSRQ for a given cell.

**First Embodiment**

In a first embodiment based on LTE-Advanced, the network operates using FDD and comprises one or more eNodeBs, each controlling at least one downlink cell, each with a corresponding uplink cell. Each cell may serve one or more terminals (UEs) which may receive and decode signals transmitted in that cell. In may be allocated a "serving cell" in the downlink (DL) by the network, with a corresponding uplink (UL) resource (which may be termed an UL cell). An eNodeB may control cells with different carrier frequencies.

The network configures the UE to report particular types of measurements made on a subset of the carrier frequencies, measurement bandwidth and, optionally, a subset of cells. The network also configures trigger conditions for measurement reporting. The cells for which the UE reports measurements depend at least on the configured subset of carrier frequencies and the cells that the UE can detect at each carrier frequency.

The particular feature of this embodiment is that for at least one carrier frequency the UE is configured to
report at least one type of measurement for which measurements are reported for at least two different sub-bands within the measurement bandwidth.

In variations of this embodiment, the UE reports at least one of the following:-

- Difference between measurements for two different sub-bands
- Difference between largest and smallest sub-band measurements
- Difference between largest (or smallest) sub-band measurement and the average measurement over the other sub-bands (or measurement bandwidth)
- Difference between the measurement for a specific sub band and an average measurement
- Magnitude of a difference between measurements
- Smallest (or possibly largest) measurement over the sub-bands
- A function of the measurement values for each sub-band.

The measurements reported by the UE are used by the network to determine whether to change the serving cell for that UE, and if so, to which cell.

**Second Embodiment**

A second embodiment is like the first embodiment except that for at least one carrier frequency, the UE is configured to report at least one type of measurement for which measurements are reported for at least two different sub-intervals within a subframe. In variations of this embodiment the UE reports at least one of the following:-

- Difference between measurements for two different sub-intervals
- Difference between largest and smallest sub-interval measurements
- Difference between largest (or smallest) sub-interval measurement and the average measurement over the other sub-intervals (or whole subframe)
- Difference between the measurement for a specific sub interval and an average measurement
- Magnitude of a difference between measurements
- Smallest (or possibly largest) measurement over the sub-intervals
- A function of the measurement values for each sub-interval.

Figure 8 is a flowchart outlining a method of the above embodiments.

In a first step (S10), the UE monitors a measurement object, that is one or more cells or frequency bands, similar to the routine measurement process specified in LTE but with the difference that sub-bands and/or sub-intervals are selected for consideration (that is, for measurement and/or for triggering a report) in accordance with the invention.
In step S20, the UE calculates a difference between the measurements for the sub-bands/sub-intervals along the lines already mentioned. As an alternative to a difference, a ratio of measurements may be found.

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The UE then determines (S30) whether a trigger criterion is fulfilled (in other words whether a trigger event has occurred). The trigger event may be based on the selected sub-bands and/or sub-bands. If yes (S30, "Y"), the UE sends (S40) a measurement report to the network - most usually, to the base station of the serving cell. If not (S30, "N") it returns to the beginning.

Third Embodiment

A third embodiment is like the first embodiment except a particular feature is that for at least one carrier frequency, the UE is configured with a measurement filter which selects measurements for at least one particular subframe. The measurement filter operates according to at least one of the following principles:

(i) The filter selects subframes according to at least one of the following criteria:

* A given (configurable) subframe number within each radio frame
* Subframes in radio frames where SFN mod N = M, where SFN is the system frame number and N and M are configurable
* Subframes which satisfy a (configurable) criterion based on both SFN and subframe number within a radio frame
* Subframes configured according to one (or more) of the following conditions:
  - MBSFN subframes
  - Non-MBSFN subframes
  - Subframes with CSI-RS
  - Subframes without CSI-RS (as mentioned previously, reference symbols are only needed for RSRP and RSRQ, not RSSI)
  - Subframes with positioning reference symbols
  - Subframes without positioning reference symbols
  - Subframes used for relaying
  - Subframes not used for relaying

(ii) The filter combines measurements taken in particular subframes to give at least one of the following:

* Difference between largest and smallest measurements for any sub-frame
Difference between largest (or smallest) measurements for any subframe and an average over the other subframes (or all subframes)
Difference between the measurements for a specific pair of subframes
Difference between the measurements for a specific subframe and an average measurement
Magnitude of a difference
Smallest (or possibly largest) measurement over the sub-frames
A function of the measurement values for each sub-frame (see above for examples of such a function).

The measurements may be used by the network to determine which cells should be configured for the UE as primary and secondary cells in carrier aggregation (CA).

The measurements can also be used by the network to determine which cells should be used for co-operative multi-point operation (CoMP). In general, it will be preferable to initiate CoMP operation with cells generating high interference, provided such cells are "CoMP capable" or that CoMP operation is possible in the frequency/time regions experiencing the interference.

In at least some cases, a similar effect to defining a new measurement may be achieved by modification to the Layer 3 filtering. Some examples are given below.

A filter taking inputs from two measurements (e.g. on different sub-bands), and computing the difference may be equivalent to a measurement defined as the difference between two measurements (e.g. in quality difference between sub-bands).

In at least some cases, a similar effect to defining a new measurement may be achieved by modification to reporting triggers. The trigger, which is proposed to treat the measurements on two sub-bands in the same way as measurements on different cells, may cause the UE to report both measurement values. Some examples are given below.

If measurements from a particular sub-bands of a cell are treated in an equivalent way to those from different cells, a trigger condition that compares measurements between cells may be equivalent to measurement defined in terms of the difference in quality between sub-bands. In other words, in this case the measurement is defined for one cell-equivalent as the difference between the values for two sub-bands.

If measurements from a particular sub-interval (or subframe) of a cell are treated in an equivalent way to those from different cells, a trigger condition that compares measurements between cells may be
equivalent to measurement defined in terms of the difference in quality between sub-intervals or subframes.

In general, it may be useful to treat measurements corresponding to parts of a cell (in time and/or frequency domains) as if they are from different cells (or possibly as sub-cells). This may require the cell ID to be extended to support additional "sub-cells".

In another embodiment an additional reporting trigger is defined as "Neighbour cell becomes offset better than neighbour cell". This allows the identification of the any neighbours which are significantly better than other neighbours, even if they do not trigger any of the other criteria. This may be useful for CoMP, where it will be desirable to identify good candidate cells for co-operation. If applied to "sub-cells" this may allow identification of the case where a sub-band (or sub-interval or subframe) becomes better than another sub-band (or sub-interval or subframe). This may require sub-cells of the serving cell to be considered as neighbour cells. It may beneficial to define a sub-cell specific offset for inclusion in the triggering conditions.

By analogy with the events (such as event A3, mentioned earlier) defined for cells in LTE, additional possible trigger conditions may be as follows:-

- Sub-cell becomes offset better than sub-cell
- Sub-cell becomes offset better than sub-cell of serving cell
- Sub-cell of serving cell becomes offset better than sub-cell of serving cell
- Sub-cell of neighbour cell becomes offset better than sub-cell of serving cell
- Sub-cell of neighbour cell becomes offset better than sub-cell of neighbour cell

Additional trigger Conditions may be obtained from the above list by replacing one or both occurrences of "sub-cell" by "cell". A "sub-cell" may be defined in terms of a subset or part of one or more of the frequency domain, time domain or spatial domain corresponding to a cell.

Thus, to summarise, an embodiment of the present invention may provide a new measurement report and/or reporting trigger for an LTE-based wireless communication network, in order to identify the occurrence of interference which is non-uniform in the frequency domain. The new report/trigger may be based on existing RSSI, RSRP and/or RSRQ as defined in LTE, but modified to focus on specific sub-bands, sub-frames and/or sub-intervals of sub-frames within the available bandwidth and frame structure. A UE in the network monitors a measurement object such as received signal strength for each of a plurality of cells or sub-cells (S10) to obtain measured values, computes a difference or ratio between two such measured values (S20) and once a trigger event has occurred (S30), which may be a novel trigger
based on said difference/ratio, send a report (S40) to its serving station. The report may indicate the computed difference/ratio and/or the measured values themselves.

Features of the present invention include the following:

- Definitions of new measurements for LTE (RSSI is known, but the modified versions of RSSI are not)
- Definition of new measurements relating to part of a cell (i.e. corresponding to a sub-cell)
- Reporting the magnitude of the difference between measurements
- Selection of particular sub-carriers for measurement (this is known, but not in combination with the other features)
- Selection of particular OFDM symbols for measurement (this is known, but not in combination with other features)
- Selection of particular subframes for measurement
- Definition of new measurement filters
- Definition of new measurement trigger conditions (e.g. including sub-cells).

The features in the different embodiments above may be combined in the same embodiment. Moreover, various modifications are possible within the scope of the present invention.

Wherever the context permits, a "difference" between measurements also includes a "ratio" of measurements.

Whilst the above description has been made with respect to LTE and LTE-A, the present invention may have application to other kinds of wireless communication system also. Accordingly, references in the claims to "user equipment" are intended to cover any kind of subscriber station, mobile terminal and the like and are not restricted to the UE of LTE.

As will be apparent, the features described above can be performed by a user equipment having a selector for selecting sub-bands and/or sub-periods on which to focus for interference measurement; as well as (in some embodiments) a filter for filtering measurements, such as measurements in specific sub-bands.

Although the above description has referred to a trigger event causing a UE to report to the network; there is no need for such a report to be immediate. The invention can also be applied to measurements which are stored in the UE and later signalled to the network.
Reference has been made above to CRS and CSI-RS reference signals where CRS refers to a cell-specific reference signal for estimating channel for an LTE Release 8 system, and CSI-RS refers to a Channel State Information (CSI) reference signal for estimating CSI in an LTE-A system. In any of the embodiments, measurements may be made on CSI-RS instead of CRS. In any case, the present invention is not limited to these, but can be applied to various reference signals.

In any of the aspects or embodiments of the invention described above, the various features may be implemented in hardware, or as software modules running on one or more processors. Features of one aspect may be applied to any of the other aspects.

The invention also provides a computer program or a computer program product for carrying out any of the methods described herein, and a computer readable medium having stored thereon a program for carrying out any of the methods described herein.

A computer program embodying the invention may be stored on a computer-readable medium, or it may, for example, be in the form of a signal such as a downloadable data signal provided from an Internet website, or it may be in any other form.

It is to be clearly understood that various changes and/or modifications may be made to the particular embodiment just described without departing from the scope of the claims.

**Industrial Applicability**

The invention proposes new radio measurements which provide information on frequency domain variations (within the carrier bandwidth) and time domain variations (within a subframe) in cell quality and interference levels. Additionally, new measurement filtering is proposed to allow cell quality and interference variations between subframes to be identified.

The invention improves the knowledge of the LTE network of the quality of the cells received by the UE, which will facilitate cell selection, handover, and configuration of carrier aggregation and CoMP, particularly for Heterogeneous Network scenarios.
CLAIMS

1. A user equipment for a cellular wireless communication network in which transmission is arranged to occur over radio links within an available bandwidth in the frequency domain and in units of frames in the time domain, the user equipment arranged to measure one or more radio link properties and send to the network at least one measurement report comprising at least one measurement made in relation to at least one of:
   - at least two different sub-bands within the available bandwidth; and
   - at least two different sub-periods within a frame.

2. A user equipment for a cellular wireless communication network in which transmission is arranged to occur within an available bandwidth in the frequency domain and in units of frames in the time domain, the user equipment arranged to send to the network at least one measurement report triggered by the result of comparing a measurement, made in relation to at least one of:
   - at least two different sub-bands within the available bandwidth; and
   - at least two different sub-periods within a frame,
   with one of:
   - a measurement of radio link properties; and a predetermined threshold.

3. The user equipment according to claim 1 and/or claim 2 wherein the frames are subdivided into subframes, and each sub-period is a sub-interval within a subframe.

4. The user equipment according to claim 1 and/or claim 2 wherein the frames are subdivided into subframes, the user equipment arranged to send at least one measurement report in relation to at least two different sub-intervals within a subframe.

5. The user equipment according to claim 4 further comprising a filter for selecting measurements in relation to specific subframes.

6. The user equipment according to any preceding claim arranged to determine a difference between the measurements for two different sub-bands and/or sub-periods.

7. The user equipment according to any preceding claim arranged to determine a ratio between the measurements for two different sub-bands and/or sub-periods.
8. The user equipment according to any preceding claim wherein the at least one measurement report includes a report indicative of received signal strength at the user equipment.

9. The user equipment according to claim 8 wherein the report indicative of signal strength provides information on a plurality of cells detected by the user equipment.

10. The user equipment according to claim 9 for use in an LTE-based network, wherein the at least one measurement report includes a report corresponding to at least one of RSSI and RSRQ as defined in LTE but modified to apply to said at least two different sub-bands within the available bandwidth and/or in relation to at least two different sub-periods within a frame.

11. The user equipment according to any preceding claim further arranged to detect reference signals for measuring at least one radio link property and to select at least two different sub-bands within the available bandwidth, and/or in said at least two different sub-periods within a frame, on the basis of presence or absence of reference signals.

12. A user equipment for a wireless communication network in which transmission is arranged to occur between the user equipment and base station, the user equipment arranged to assign plural sets of receiver weights, each set corresponding to a respective receiver beam pattern, and further arranged to report to the network at least one measurement in relation to a set of receiver weights.

13. A base station for use with a user equipment according to any preceding claim and adapted to receive said at least one measurement report sent by the user equipment.

14. A wireless communication network including user equipments according to any preceding claim.

15. A wireless communication method comprising:
arranging transmission to occur over radio links within an available bandwidth in the frequency domain and in units of frames in the time domain;
measuring, at a user equipment, one or more radio link properties; and
the user equipment performing at least one of:
sending, from the user equipment to the network, at least one measurement report in relation to at least two different sub-bands within the available bandwidth and/or in relation to at least two different sub-periods within a frame, and
triggering sending of at least one measurement report by comparing measurements in relation to at least two different sub-bands within the available bandwidth and/or in relation to at least two different sub-periods within a frame.
FIGURE 1
Resource Block:
7 symbols x 12 subcarriers (short CP), or:
6 symbols x 12 subcarriers (long CP)

FIGURE 2
1 subframe = 1 ms = 14 OFDM symbols
(normal cyclic prefix)

1 slot = 0.5 ms = 7 OFDM symbols
(normal cyclic prefix)

Resource Block
(12 subcarriers in frequency domain, 1 slot in time domain)

Subcarriers (numbered with index $k$)

$k = 0$

$l = 0$

OFDM symbols (numbered with index $l$)

FIGURE 3
3 - CoMP transmission points

1 - CoMP cooperating set

This cell is muting its downlink signals

2 - CoMP Measurement set

(a) CoMP JP

3 - CoMP transmission points

2 - CoMP Measurement set

1 - CoMP cooperating set

Scheduling/beamforming coordinated among A, B, C, and D

(b) CoMP CS/CB

FIGURE 7
START

S10
Monitor measurement object for sub-bands/sub-intervals

S20
Compute difference between sub-bands/intervals

S30
Trigger event occurred?

N

Y

S40
Transmit report to base station

FIGURE 8
A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W36/00

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>2-11</td>
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<td>X</td>
<td>wo 2004/004173 AI (KONINKL PHI LI PS ELECTRONICS NV [NL]; BAKER MATTHEW P J [GB]; MOULSLEY) 8 January 2004 (2004-01-08) page 9, line 15 - page 10, line 27</td>
<td>13, 15</td>
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</table>

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"M" member of the same patent family

Date of the actual completion of the international search: 23 September 2011

Date of mailing of the international search report: 30/09/2011

Name and mailing address of the ISA:

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer:

Harrysson, Andreas
\begin{table}
\centering
\begin{tabular}{|c|p{0.7\textwidth}|c|}
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Category | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. \\
\hline
X & MOTOROLA: "Reference signals for mobility related measurements" , 3GPP DRAFT; RI-071330 MEAS_REF, 3RD GENERATION PARTNERSHIP PROJECT (3GPP) , MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTI POLIS CEDEX ; FRANCE, vol. RAN WG1, no. St. Julian; 20070403 , 3 April 2007 (2007-04-03) , XP050105282 , page 2 , line 12 - line 16 & 2, 14, 15 \\
\hline
\end{tabular}
\end{table}
This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☑ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-11, 13-15

**Remark on Protest**

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.
This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

   sending or triggering the sending of measurement reports comprising temporally or spectrally different measurement results;
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2. Claims: 12-14
   setting sets of receiver weights corresponding to receiver beam patterns
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