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Karri et al.

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(54) **ADAPTIVE FILTERING OF CELL MEASUREMENTS**

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H04W 48/16 (2009.01)

(52) **U.S. Cl.**
CPC ***H04W 48/16*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 1/0026; H04L 1/20; H04B 17/309; H04B 17/318; H04B 17/327; H04B 17/345; H04B 17/382; H04B 1/06; H04W 24/10; H04W 36/0083; H04W 52/22; H04W 52/242; H04W 24/02; H04W 48/16
See application file for complete search history.

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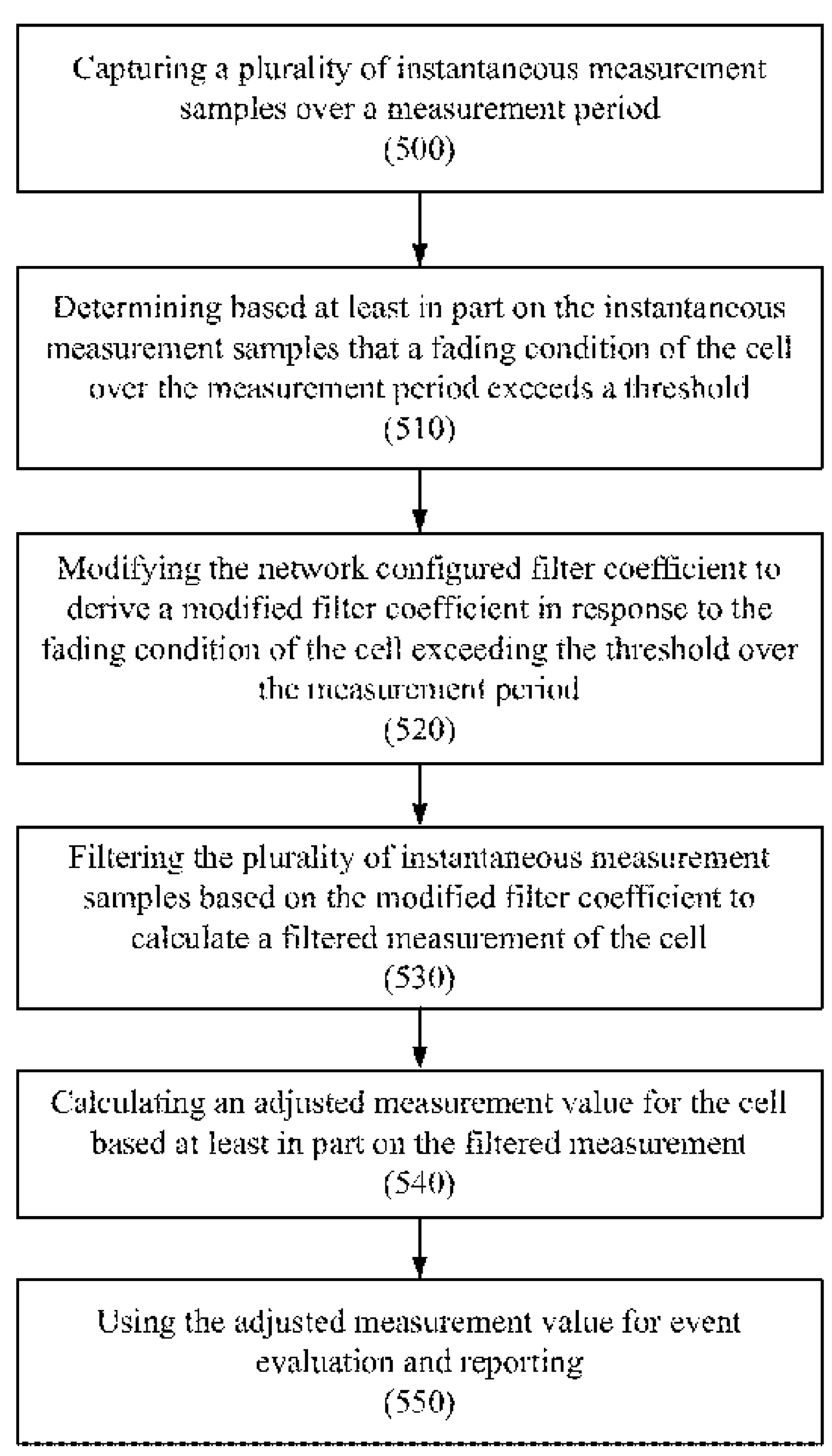
(57) **ABSTRACT**

A method for adaptive filtering of cell measurements is provided. The method can include a wireless communication device determining based on instantaneous measurement samples of a cell captured over a measurement period that a fading condition of the cell exceeds a threshold. The method can further include the wireless communication device modifying a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period. The method can additionally include the wireless communication device filtering the instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell. The method can also include the wireless communication device calculating an adjusted measurement value for the cell based on the filtered measurement. The method can further include the wireless communication device using the adjusted measurement value for event evaluation and reporting.

24 Claims, 9 Drawing Sheets



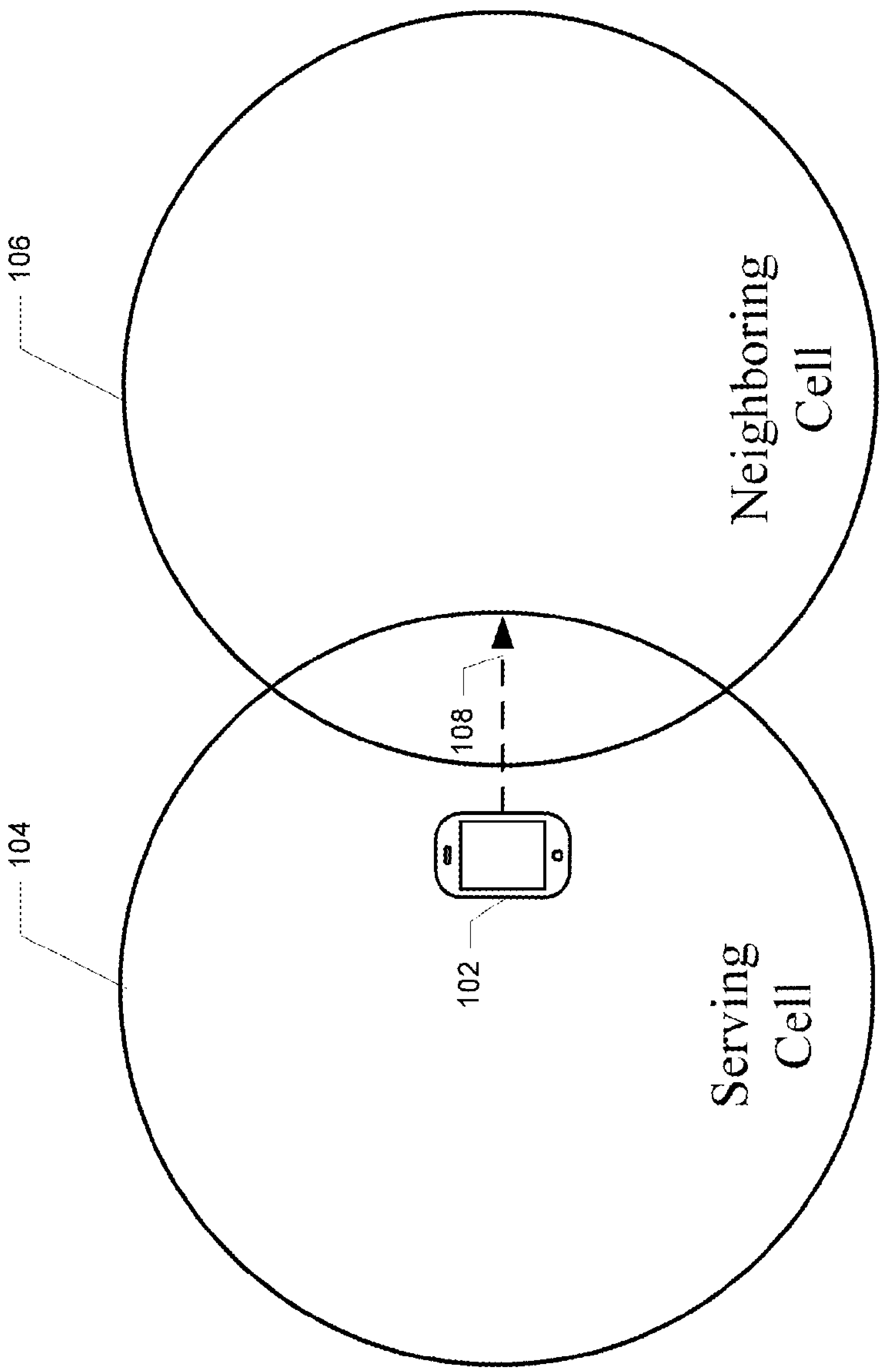


FIG. 1

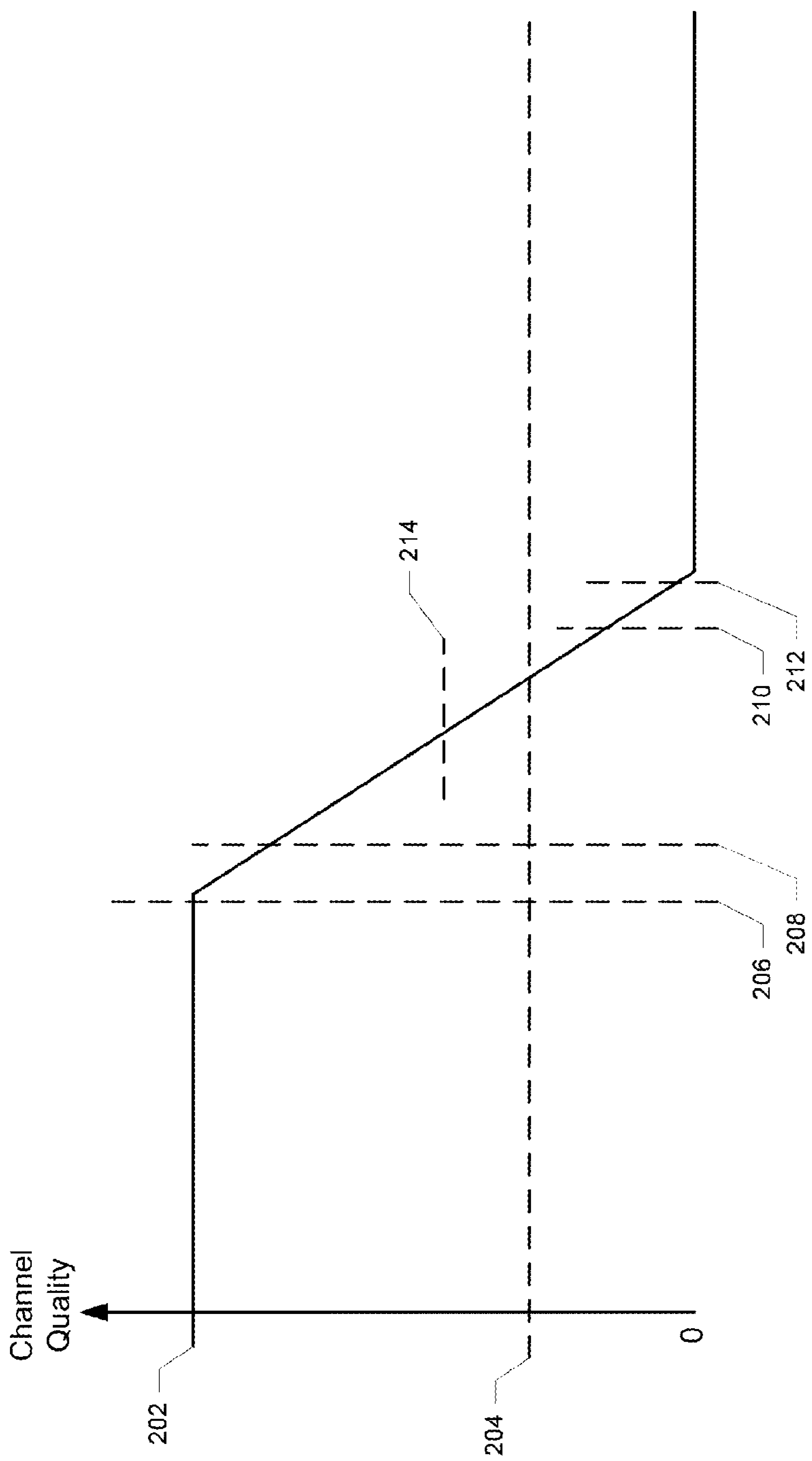


FIG. 2

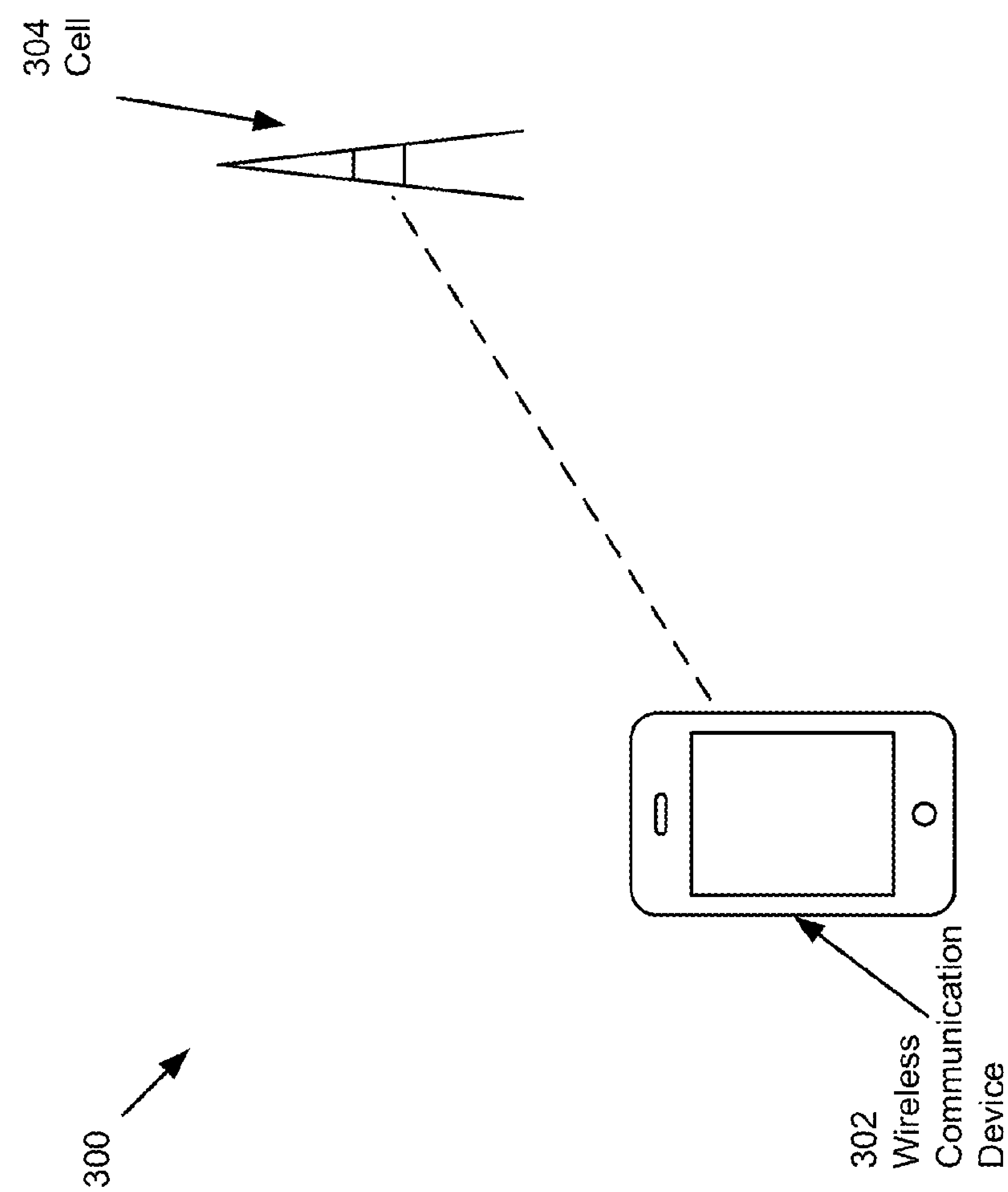


FIG. 3

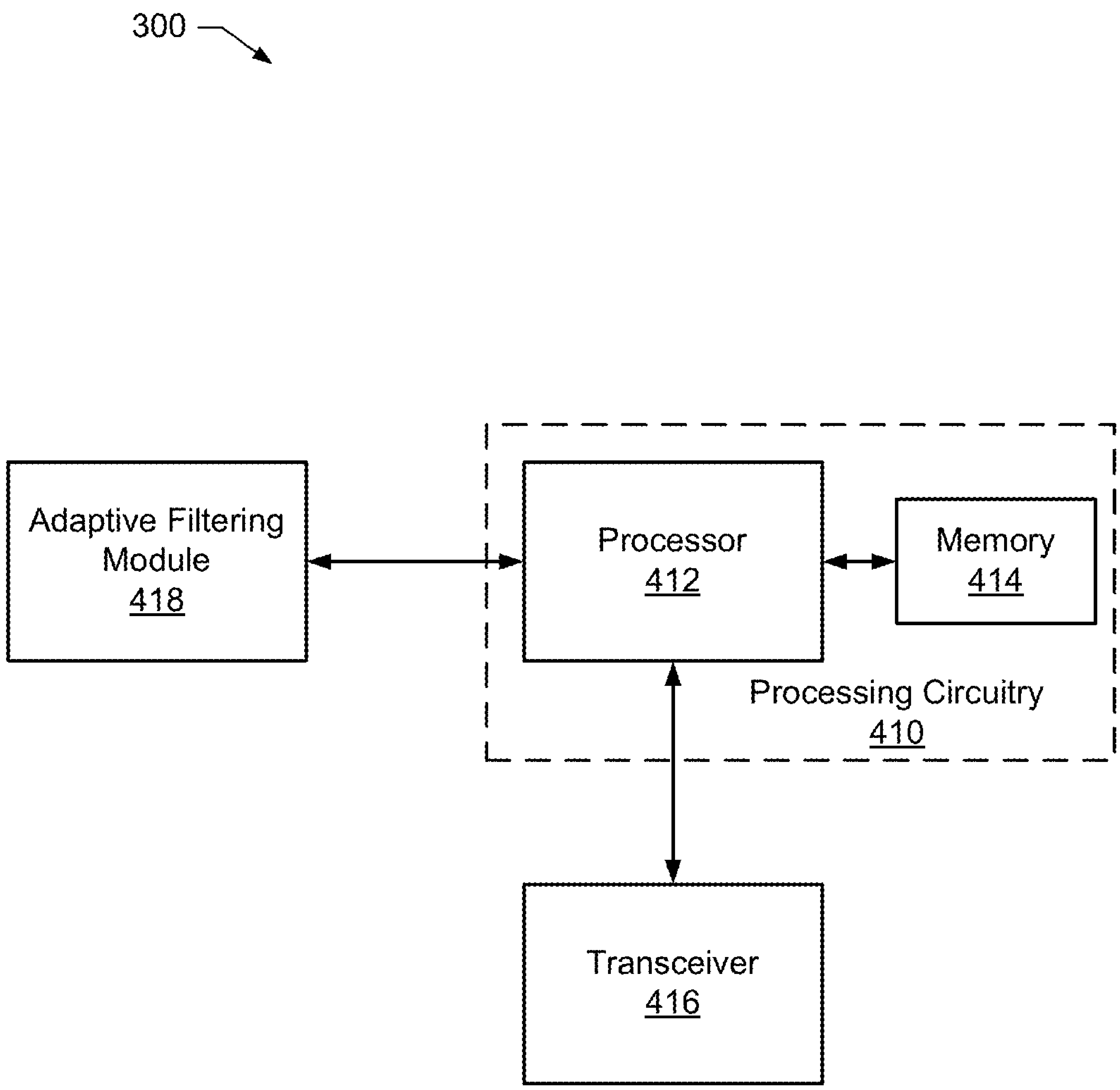

300
Adaptive Filtering Module 418
Processor 412
Memory 414
Processing Circuitry 410
Transceiver 416

FIG. 4

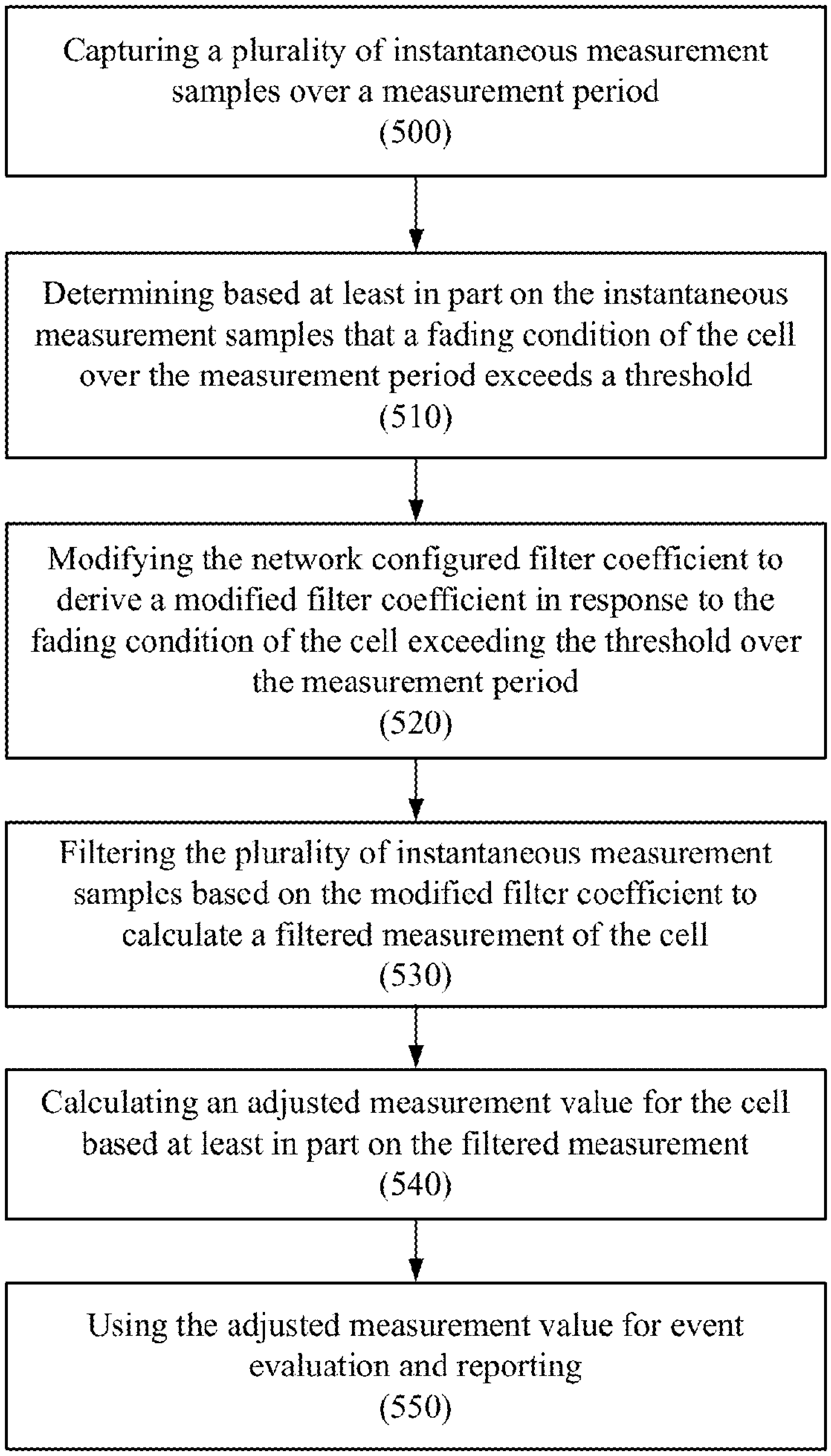
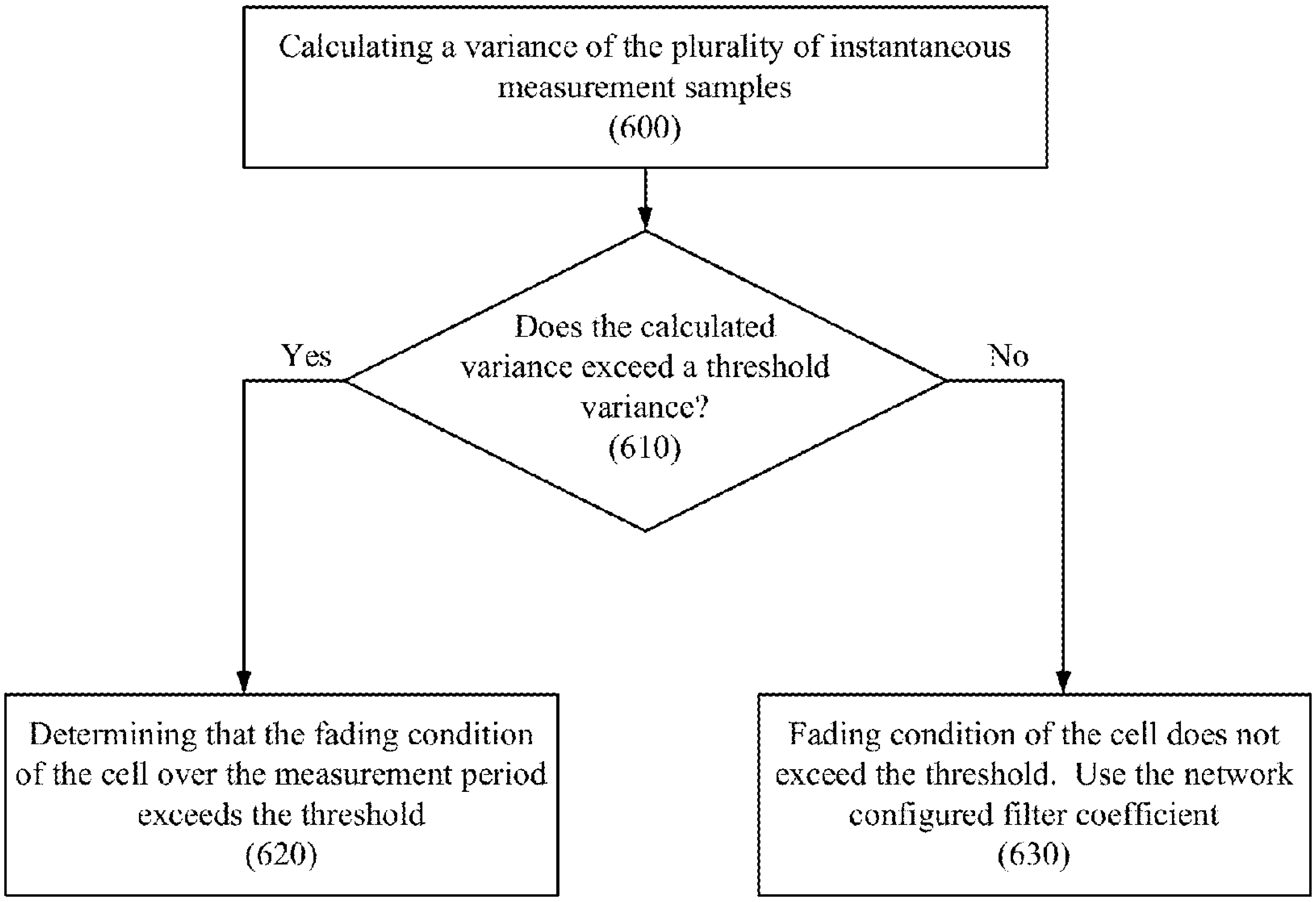

Capturing a plurality of instantaneous measurement samples over a measurement period
(500)
Determining based at least in part on the instantaneous measurement samples that a fading condition of the cell over the measurement period exceeds a threshold
(510)
Modifying the network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period
(520)
Filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell
(530)
Calculating an adjusted measurement value for the cell based at least in part on the filtered measurement
(540)
Using the adjusted measurement value for event evaluation and reporting
(550)

FIG. 5



Calculating a variance of the plurality of instantaneous measurement samples (600)
Does the calculated variance exceed a threshold variance? (610)
Yes
No
Determining that the fading condition of the cell over the measurement period exceeds the threshold (620)
Fading condition of the cell does not exceed the threshold. Use the network configured filter coefficient (630)

FIG. 6

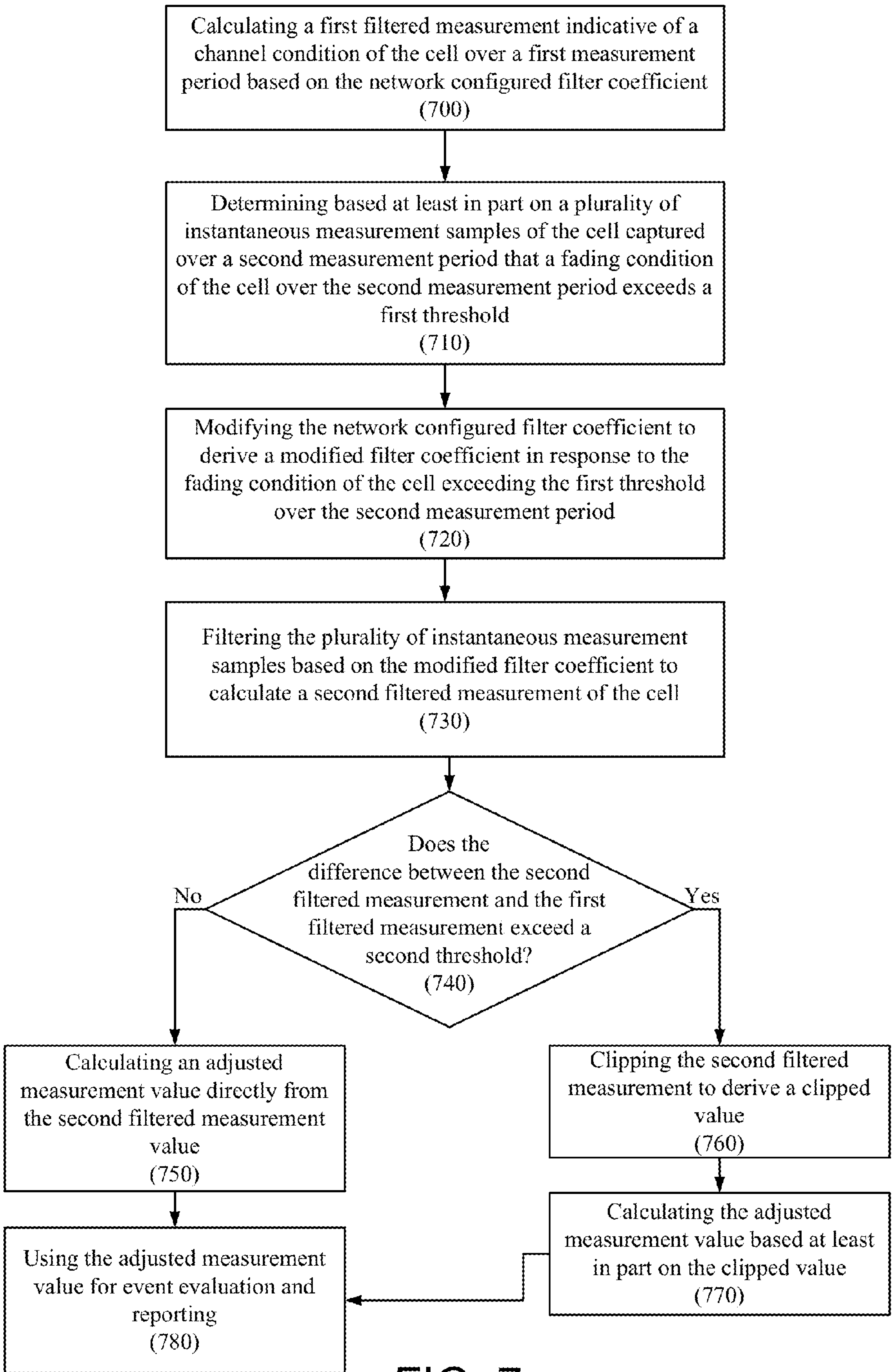

Calculating a first filtered measurement indicative of a channel condition of the cell over a first measurement period based on the network configured filter coefficient (700)
Determining based at least in part on a plurality of instantaneous measurement samples of the cell captured over a second measurement period that a fading condition of the cell over the second measurement period exceeds a first threshold (710)
Modifying the network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the first threshold over the second measurement period (720)
Filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a second filtered measurement of the cell (730)
Does the difference between the second filtered measurement and the first filtered measurement exceed a second threshold? (740)
No
Yes
Calculating an adjusted measurement value directly from the second filtered measurement value (750)
Clipping the second filtered measurement to derive a clipped value (760)
Calculating the adjusted measurement value based at least in part on the clipped value (770)
Using the adjusted measurement value for event evaluation and reporting (780)

FIG. 7

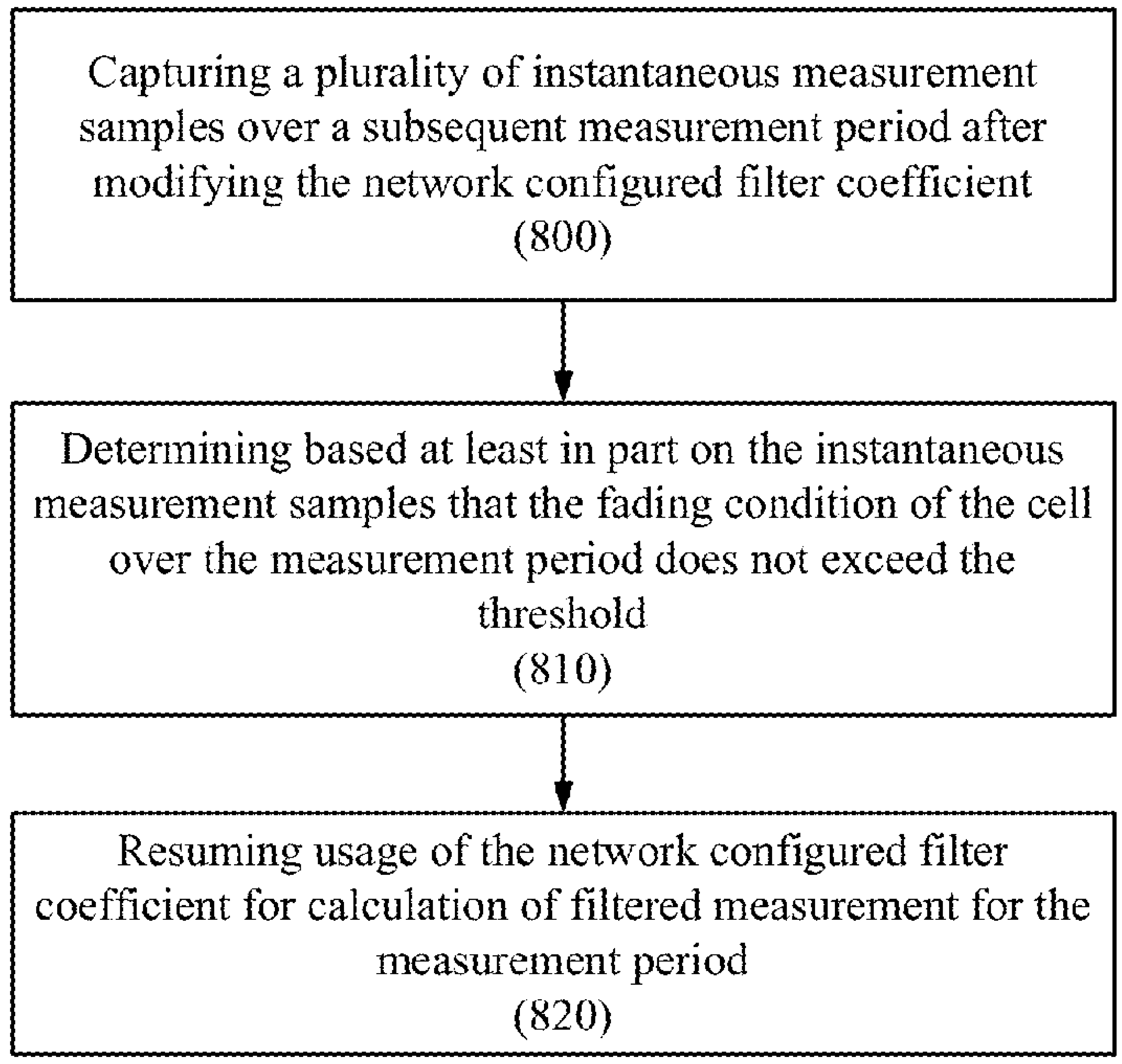
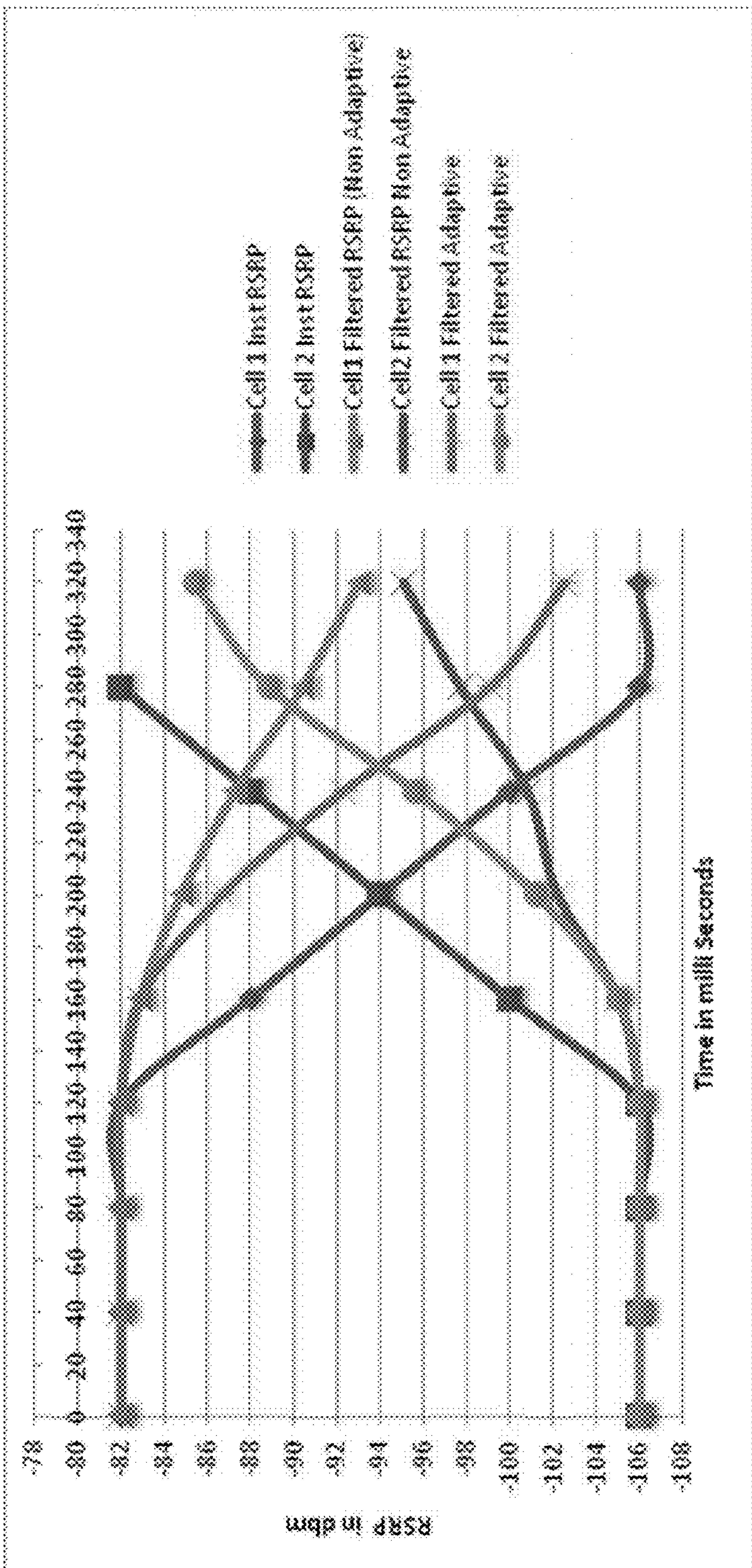

Capturing a plurality of instantaneous measurement samples over a subsequent measurement period after modifying the network configured filter coefficient
(800)
Determining based at least in part on the instantaneous measurement samples that the fading condition of the cell over the measurement period does not exceed the threshold
(810)
Resuming usage of the network configured filter coefficient for calculation of filtered measurement for the measurement period
(820)

FIG. 8



Cell 1 Inst RSRP
Cell 2 Inst RSRP
Cell1 Filtered RSRP (Non Adaptive)
Cell2 Filtered RSRP Non Adaptive
Cell 1 Filtered Adaptive
Cell 2 Filtered Adaptive
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
Time in milli Seconds
-78 -80 -82 -84 -86 -88 -90 -92 -94 -96 -98 -100 -102 -104 -106 -108
RSRP in dbm

FIG. 9

ADAPTIVE FILTERING OF CELL MEASUREMENTS

FIELD OF THE DESCRIBED EMBODIMENTS

The described embodiments relate generally to wireless communications and more particularly to adaptive filtering of cell measurements.

BACKGROUND

Wireless communication devices operating on a cellular network, such as a Long Term Evolution (LTE) network, are generally configured to report cell measurements for a current serving cell and/or for one or more neighbor cells to support possible handovers. For example, in an LTE network a wireless communication device can be required to report reference signal received power (RSRP) and reference signal received quality (RSRQ) measurements for defined events. In many networks, a wireless communication device is configured to report a filtered measurement calculated in accordance with a network configured filter coefficient from a set of instantaneous measurement samples that can be captured over a measurement period that can be defined by the network.

The filtered measurements that are used for event evaluation and reporting can lag behind the instantaneous measurement samples. In this regard, in fast fading channel conditions, a measurement filtered using the network configured filter coefficient can weight samples captured earlier in the measurement period such that the filtered average of the measurement samples can mask fast fading channel conditions reflected by instantaneous measurement samples captured later in the measurement period. This lag can lead to a delay in the triggering of reporting events, and thus a delay in device handover. In some instances, this delay can result in call drops.

SUMMARY OF THE DESCRIBED EMBODIMENTS

Some example embodiments disclosed herein provide for adaptive filtering of cell measurements. In this regard, a wireless communication device in accordance with some example embodiments can be configured to modify a network configured filter coefficient and to use the resulting modified filter coefficient for calculating a filtered cell measurement in fading channel conditions. The filtered measurement calculated based on the modified filter coefficient may be more reflective of a more current instantaneous measurement sample so that event reporting and handover can be triggered more quickly in fast fading channel conditions. Users may accordingly benefit from reduced call drop frequency in fast fading channel conditions.

In a first embodiment, a method for adaptive filtering of cell measurements is provided. The method of the first embodiment can include a wireless communication device calculating a first filtered measurement of a cell based on a network configured filter coefficient. The first filtered measurement can be indicative of a channel condition of the cell over a first measurement period. The method of the first embodiment can further include the wireless communication device determining based at least in part on a plurality of instantaneous measurement samples of the cell captured over a second measurement period that a fading condition of the cell over the second measurement period exceeds a first threshold. The method of the first embodiment can additionally include the wireless communication device modifying the network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the first threshold over the second measurement period. The method of the first embodiment can also include the wireless communication device filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a second filtered measurement of the cell. The method of the first embodiment can further include the wireless communication device comparing the first filtered measurement and the second filtered measurement. In an instance in which a difference between the second filtered measurement and the first filtered measurement exceeds a second threshold, the method of the first embodiment can also include the wireless communication device clipping the second filtered measurement to derive a clipped value; and calculating an adjusted measurement value for the cell based at least in part on the clipped value. In an instance in which the difference between the second filtered measurement and the first filtered measurement does not exceed the second threshold, the method of the first embodiment can instead include the wireless communication device calculating the adjusted measurement value directly from the second filtered measurement value. The method of the first embodiment can additionally include the wireless communication device using the adjusted measurement value for event evaluation and reporting.

In a second embodiment, another method for adaptive filtering of cell measurements is provided. The method of the second embodiment can include a wireless communication device determining based at least in part on a plurality of instantaneous measurement samples of a cell captured over a measurement period that a fading condition of the cell over the measurement period exceeds a threshold. The method of the second embodiment can further include the wireless communication device modifying a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period. The method of the second embodiment can additionally include the wireless communication device filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell. The method of the second embodiment can also include the wireless communication device calculating an adjusted measurement value for the cell based at least in part on the filtered measurement. The method of the second embodiment can further include the wireless communication device using the adjusted measurement value for event evaluation and reporting.

In a third embodiment, a wireless communication device is provided. The wireless communication device of the third embodiment can include a transceiver and processing circuitry coupled to the transceiver. The transceiver can be configured to transmit data to and receive data from a cellular network. The processing circuitry can be configured to control the wireless communication device to at least determine based at least in part on a plurality of instantaneous measurement samples of a cell captured over a measurement period that a fading condition of the cell over the measurement period exceeds a threshold; modify a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period; filter the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell; calculate an adjusted measurement value for the cell based at least in part on the filtered measurement; and use the adjusted measurement value for event evaluation and reporting.

In a fourth embodiment, a computer program product for adaptive filtering of cell measurements is provided. The computer program product of the fourth embodiment can include at least one non-transitory computer readable storage medium having program code stored thereon. The program code of the fourth embodiment can include program code for determining based at least in part on a plurality of instantaneous measurement samples of a cell captured over a measurement period that a fading condition of the cell over the measurement period exceeds a threshold; program code for modifying a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period; program code for filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell; program code for calculating an adjusted measurement value for the cell based at least in part on the filtered measurement; and program code for using the adjusted measurement value for event evaluation and reporting.

In a fifth embodiment, an apparatus for adaptive filtering of cell measurements is provided. The apparatus of the fifth embodiment can include means for determining based at least in part on a plurality of instantaneous measurement samples of a cell captured over a measurement period that a fading condition of the cell over the measurement period exceeds a threshold; means for modifying a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period; means for filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell; means for calculating an adjusted measurement value for the cell based at least in part on the filtered measurement; and means for using the adjusted measurement value for event evaluation and reporting.

The above summary is provided merely for purposes of summarizing some example embodiments of the invention so as to provide a basic understanding of some aspects of the invention. Accordingly, it will be appreciated that the above described example embodiments are merely examples and should not be construed to narrow the scope or spirit of the invention in any way. Other embodiments, aspects, and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the described embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The described embodiments and the advantages thereof may best be understood by reference to the following description taken in conjunction with the accompanying drawings. These drawings are not necessarily drawn to scale, and in no way limit any changes in form and detail that may be made to the described embodiments by one skilled in the art without departing from the spirit and scope of the described embodiments.

FIG. **1** illustrates an example scenario in which a wireless communication device can encounter fast fading channel condition in accordance with some example embodiments.

FIG. **2** illustrates an example measurement scenario in a fast fading channel condition.

FIG. **3** illustrates an example wireless communication system in accordance with some example embodiments.

FIG. **4** illustrates a block diagram of an apparatus that can be implemented on a wireless communication device in accordance with some example embodiments.

FIG. **5** illustrates a flowchart according to an example method for adaptive filtering of cell measurements according to some example embodiments.

FIG. **6** illustrates a flowchart according to an example method for determining existence of a fading condition and initiating adaptive filtering according to some example embodiments.

FIG. **7** illustrates a flowchart according to another example method for adaptive filtering of cell measurements according to some example embodiments.

FIG. **8** illustrates a flowchart according to an example method for resuming usage of a network configured filter coefficient after initiation of adaptive filtering according to some example embodiments.

FIG. **9** illustrates a graph of instantaneous versus filtered measurements for a sample set of test data using both static filtering and adaptive filtering.

DETAILED DESCRIPTION OF SELECTED EMBODIMENTS

Representative applications of methods and apparatus according to the present specification are described in this section. These examples are being provided solely to add context and aid in the understanding of the described embodiments. It will thus be apparent to one skilled in the art that the described embodiments may be practiced without some or all of these specific details. In other instances, well known process steps have not been described in detail in order to avoid unnecessarily obscuring the described embodiments. Other applications are possible, such that the following examples should not be taken as limiting.

In the following detailed description, references are made to the accompanying drawings, which form a part of the description and in which are shown, by way of illustration, specific embodiments in accordance with the described embodiments. Although these embodiments are described in sufficient detail to enable one skilled in the art to practice the described embodiments, it is understood that these examples are not limiting; such that other embodiments may be used, and changes may be made without departing from the spirit and scope of the described embodiments.

In typical cellular network deployments, a wireless communication device can be configured to perform measurements for a current serving cell and/or for one or more neighbor cells to support potential handovers. For example, in LTE networks, a wireless communication device can be configured by a serving evolved Node B (eNB) to report RSRP and RSRQ measurements for events, such as A3 and A2, as defined in the Third Generation Partnership Project (3GPP) TS 36.331 specification. The wireless communication device can be configured to take measurements at least once in a measurement period that can be defined by the network and the wireless communication device can be configured to filter the measurements according to a network configured filter coefficient. The network configured filter coefficient can be signaled to the wireless communication device by the serving base station in radio resource control (RRC) reconfiguration signaling.

The sampling rate at which a wireless communication device captures instantaneous measurement samples can be left up to the device, and can vary by implementation. As an example, a wireless communication device operating on an LTE network can capture RSRP and/or RSRQ measurement samples every 40 milliseconds (ms) and can filter measurement samples over a measurement period, such as a 200 ms measurement period. While the network configured filter coefficient can provide stability in measurements and avoid unnecessarily triggering a handover due to a single instantaneous measurement sample that may be an aberration, a filtered measurement can lag behind instantaneous measurements in fast fading channel conditions to an extent to which event reporting and handover may be delayed to the detriment of an ongoing call, which may be dropped as a result of the delay.

Fast fading channel conditions can occur in a variety of scenarios. One such scenario is mobility of a device toward an edge of a serving cell, as illustrated in FIG. **1**. In this regard, a wireless communication device **102** can be served by serving cell **104**, which can be adjacent to neighboring cell **106**. The wireless communication device **102** can travel along a path **108** toward the boundary of the serving cell **104** and into range of the neighboring cell **106**. The wireless communication device **102** can encounter a fast fading channel condition due to mobility along the path **108** as it approaches the boundary of the serving cell **104**.

As an example, FIG. **2** illustrates example measurement scenario in a fast fading channel condition, such as may be encountered by the wireless communication device **102** as it approaches the edge of the serving cell **104** during mobility along the path **108**. As illustrated in FIG. **2**, the channel quality **202** of the serving cell **104** that can be experienced by the wireless communication device **102** can rapidly degrade as it approaches the boundary of the serving cell **104**. The threshold channel quality **204** is illustrative of an example threshold channel quality that can be configured to trigger event reporting and/or handover to another cell. Over the course of a measurement period, the wireless communication device **102** can capture the instantaneous measurement samples **206**, **208**, **210**, and **212**. The measurement samples **206** and **208** can reflect a high channel quality. The measurement samples **210** and **212**, which can be captured after the wireless communication device **102** begins to experience a fast fading channel condition, can reflect a poor channel quality that is below the threshold channel quality **204**. As such, the current channel conditions experienced by the wireless communication device **102** at the end of a measurement period in which the device is experiencing a fast fading channel condition can be sufficient to trigger event reporting and handover. However, calculation of the filtered measurement value in accordance with the network configured filter coefficient can result in a filtered average **214**, which does not satisfy the threshold channel quality **204**. As such, the wireless communication device **102** can remain on the serving cell **104** for at least another measurement period even though it can be experiencing channel conditions that can lead to call drops.

Some example embodiments address the problem illustrated in FIG. **2** by applying adaptive filtering through usage of a modified filter coefficient, as will be described further herein below, in the event that a fast fading channel condition is detected. The resulting filtered measurement value can be more reflective of current channel conditions (e.g., of the more recent instantaneous measurement samples **210** and **212**) such that an event reporting threshold (e.g., the threshold channel quality **204**) can be satisfied more quickly and the wireless communication device can be handed over to a neighboring cell (e.g., the neighboring cell **106**) before a call drop occurs.

FIG. **3** illustrates an example wireless communication system **300** in accordance with some example embodiments. The system **300** can include a wireless communication device **302**, which can be embodied as any computing device that can be configured to connect to a cellular network. By way of non-limiting example, the wireless communication device **302** can be a cellular phone, such as a smart phone device; a tablet computing device; a laptop computing device; or other computing device that can be configured to connect to a cellular network.

The wireless communication device **302** can be within signaling range of a cell **304**, and can take measurements of the cell **304**. The cell **304** can be a serving cell for the wireless communication device **302**, or can be a neighboring cell of the device's serving cell. The cell **304** can be a cell of a network using any present or future developed cellular network technology. By way of non-limiting example, the cell **304** can be a cell of a network using an LTE technology, such as LTE, LTE-Advanced (LTE-A), or other present or future developed LTE technology. It will be appreciated, however, that embodiments described with respect to LTE networks and standards are provided by way of example, and not by way of limitation. In this regard, in some example embodiments, the cell **304** can be a cell of a non-LTE network, including, for example, a third generation (3G) network, such as a Wideband Code Division Multiple Access (WCDMA) or other Universal Mobile Telecommunications System (UMTS) network, such as a Time Division Synchronous Code Division Multiple Access (TD-SCDMA) network; a CDMA2000 network; 1xRTT network, or the like. As another example, cell **304** can be a cell of a second generation (2G) network such as a Global System for Mobile Communications (GSM) network.

FIG. **4** illustrates a block diagram of an apparatus **400** that can be implemented on a wireless communication device **302** in accordance with some example embodiments. In this regard, when implemented on a computing device, such as wireless communication device **302**, apparatus **400** can enable the computing device to operate within the system **300** in accordance with one or more example embodiments. It will be appreciated that the components, devices or elements illustrated in and described with respect to FIG. **4** below may not be mandatory and thus some may be omitted in certain embodiments. Additionally, some embodiments can include further or different components, devices or elements beyond those illustrated in and described with respect to FIG. **4**.

In some example embodiments, the apparatus **400** can include processing circuitry **410** that is configurable to perform actions in accordance with one or more example embodiments disclosed herein. In this regard, the processing circuitry **410** can be configured to perform and/or control performance of one or more functionalities of the apparatus **400** in accordance with various example embodiments, and thus can provide means for performing functionalities of the apparatus **400** in accordance with various example embodiments. The processing circuitry **410** can be configured to perform data processing, application execution and/or other processing and management services according to one or more example embodiments.

In some embodiments, the apparatus **400** or a portion(s) or component(s) thereof, such as the processing circuitry **410**, can include one or more chipsets, which can each include one or more chips. The processing circuitry **410** and/or one or more further components of the apparatus **400** can therefore, in some instances, be configured to implement an embodiment on a chipset(s). In some example embodiments in which one or more components of the apparatus **400** are embodied as a chipset, the chipset can be capable of enabling a computing device to operate in the system **300** when implemented on or otherwise operably coupled to the computing device. Thus, for example, one or more components of the apparatus **400** can provide a cellular baseband chipset, which can enable a computing device to operate within a cellular network.

In some example embodiments, the processing circuitry **410** can include a processor **412** and, in some embodiments, such as that illustrated in FIG. **4**, can further include memory **414**. The processing circuitry **410** can be in communication with or otherwise control a transceiver **416** and/or adaptive filtering module **418**.

The processor **412** can be embodied in a variety of forms. For example, the processor **412** can be embodied as various hardware-based processing means such as a microprocessor, a coprocessor, a controller or various other computing or processing devices including integrated circuits such as, for example, an ASIC (application specific integrated circuit), an FPGA (field programmable gate array), some combination thereof, or the like. Although illustrated as a single processor, it will be appreciated that the processor **412** can comprise a plurality of processors. The plurality of processors can be in operative communication with each other and can be collectively configured to perform one or more functionalities of the apparatus **400** as described herein. In some example embodiments, the processor **412** can be configured to execute instructions that can be stored in the memory **414** or that can be otherwise accessible to the processor **412**. As such, whether configured by hardware or by a combination of hardware and software, the processor **412** can be capable of performing operations according to various embodiments while configured accordingly.

In some example embodiments, the memory **414** can include one or more memory devices. Memory **414** can include fixed and/or removable memory devices. In some embodiments, the memory **414** can provide a non-transitory computer-readable storage medium that can store computer program instructions that can be executed by the processor **412**. In this regard, the memory **414** can be configured to store information, data, applications, instructions and/or the like for enabling the apparatus **400** to carry out various functions in accordance with one or more example embodiments. In some embodiments, the memory **414** can be in communication with one or more of the processor **412**, transceiver **416**, or adaptive filtering module **418** via a bus(es) for passing information among components of the apparatus **400**.

The apparatus **400** can further include transceiver **416**. The transceiver **416** can enable the apparatus **400** to send wireless signals to and receive signals from one or more cellular networks. As such, the transceiver **416** can be configured to support any type of cellular technology that can be implemented by the cell **304**, and can facilitate measurement of a channel quality of the cell **304**.

The apparatus **400** can further include adaptive filtering module **418**. The adaptive filtering module **418** can be embodied as various means, such as circuitry, hardware, a computer program product comprising a computer readable medium (for example, the memory **414**) storing computer readable program instructions executable by a processing device (for example, the processor **412**), or some combination thereof. In some embodiments, the processor **412** (or the processing circuitry **410**) can include, or otherwise control the adaptive filtering module **418**.

The adaptive filtering module **418** can be configured to perform adaptive filtering of cell measurements in accordance with one or more example embodiments, as described further herein below. In this regard, the adaptive filtering module **418** can be configured to calculate filtered measurements of a cell, such as the cell **304**, based on instantaneous measurement samples of the cell. In fast fading channel conditions, the adaptive filtering module **418** can be configured to modify a network configured filter coefficient to derive a modified filter coefficient and use the modified filter coefficient to calculate a filtered measurement. The adaptive filtering module **418** can be further configured to use a filtered measurement as a basis for event evaluation and reporting.

FIG. **5** illustrates a flowchart according to an example method for adaptive filtering of cell measurements according to some example embodiments. In this regard, FIG. **5** illustrates operations that can be performed by the wireless communication device **302** in accordance with some example embodiments. One or more of processing circuitry **410**, processor **412**, memory **414**, transceiver **416**, or adaptive filtering module **418** can, for example, provide means for performing the operations illustrated in and described with respect to FIG. **5**.

Operation **500** can include the wireless communication device **302** capturing a plurality of instantaneous measurement samples of the cell **304** over a measurement period. The measurement period can be a measurement period defined by the network, such as through RRC signaling. By way of non-limiting example, the measurement period can be 200 ms. The instantaneous measurement samples can be captured in accordance with a sampling rate that can be selected by the wireless communication device **302**. For example, in some embodiments, the wireless communication device **302** can use a 40 ms sampling rate, and can capture 5 samples per 200 ms measurement period. The instantaneous measurement samples can be maintained in a buffer. Thus, for example, in some embodiments, if five instantaneous measurement samples are captured in a measurement period, measurement samples x_1, x_2, x_3, x_4, and x_5 can be maintained in a buffer. Embodiments utilizing a buffer can, for example, implement a rolling buffer having a size that can be defined based at least in part on a sampling rate and measurement period length such that older instantaneous measurement samples can be replaced in the buffer by newly captured instantaneous measurement samples.

Operation **510** can include the wireless communication device **302** determining based at least in part on the instantaneous measurement samples captured during the measurement period that a fading condition of the cell **304** over the measurement period exceeds a threshold. In this regard, operation **510** can include the wireless communication device **302** comparing and/or otherwise evaluating the instantaneous measurement samples to detect whether channel degradation over the measurement period exceeds a threshold level of fading. For example, in some embodiments, operation **510** can include the wireless communication device **302** determining a statistical spread of two or more instantaneous measurements to determine whether the spread exceeds a threshold. In some example embodiments, such as that illustrated and described further with respect to FIG. **6**, operation **510** can include calculating a variance of the instantaneous measurement samples and determining whether the variance of the samples exceeds a threshold variance.

Operation **520** can include the wireless communication device **302** modifying the network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell **304** exceeding the threshold over the measurement period. In this regard, the network configured filter coefficient can be increased so that a resulting filtered measurement value will be more reflective of current channel conditions. In some example embodiments, the network configured filter coefficient can be increased by a factor,

k. In some example embodiments, k can be a static value, such as between 4 and 7. Alternatively, in some example embodiments, k can be selected based at least in part on an extent of the fading condition over the measurement period. In this regard, k can be proportional to an amount of observed fading. For example, a higher k value can be selected for conditions exhibiting faster fading and/or an otherwise greater magnitude in channel degradation than for conditions exhibiting a lesser degree of fading.

Operation **530** can include the wireless communication device **302** filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell **304**. Operation **540** can include the wireless communication device **302** calculating an adjusted measurement value for the cell **304** based at least in part on the filtered measurement. In this regard, the adjusted measurement value can reflect an adjustment that can result from usage of the modified filter coefficient such that the adjusted measurement value can be more reflective of current channel conditions than a measurement value calculated based on the network configured filter coefficient.

In some instances, the adjusted measurement value can be equivalent to the filtered measurement calculated in operation **530**. However, in other instances, one or more further measurement values can be calculated directly from the filtered measurement value and/or from a modified version of the filtered measurement value, such as a clipped version of the filtered measurement value, as discussed with respect to FIG. **7**. The adjusted measurement value can be any measurement metric that can be used for cell evaluation and/or handover purposes. For example, the adjusted measurement value can include an RSRP and/or RSRQ value for the cell **304**, such as in embodiments in which the cell **304** is a cell of an LTE network. It will be appreciated, however, that other measurement values that can be used to measure a channel quality can be calculated in addition to or in lieu of RSRP and/or RSRQ within the scope of various example embodiments, including, for example, received signal code power (RSCP), received signal strength indicator (RSSI), bit energy on the spectral noise density (Eb/No), Ec/Io, and/or the like.

Operation **550** can include the wireless communication device **302** using the adjusted measurement value for event evaluation and reporting. For example, in LTE networks, the adjusted measurement value can be used for evaluation and reporting of events such as A2 and A3 events.

In instances in which the fading condition of the cell **304** over a measurement period did not exceed the threshold, then the network configured filter coefficient can be used to calculate the filtered measurement for use in reporting and evaluation in lieu of performance of operations **520-550**.

Referring now to FIG. **6**, FIG. **6** illustrates a flowchart according to an example method for determining existence of a fading condition and initiating adaptive filtering according to some example embodiments. In this regard, FIG. **6** illustrates operations that can be performed by the wireless communication device **302** attendant to performance of operation **510** in some example embodiments. One or more of processing circuitry **410**, processor **412**, memory **414**, transceiver **416**, or adaptive filtering module **418** can, for example, provide means for performing the operations illustrated in and described with respect to FIG. **6**.

Operation **600** can include the wireless communication device **302** calculating a variance of the instantaneous measurement samples captured over a measurement period. For example, given n measurement samples, the variance can be calculated as follows in some example embodiments:

$$\text{Mean} = \frac{\sum_{k=1}^{n} x_k}{n} \quad [1]$$

$$\text{Variance} = \frac{\sum_{k=1}^{n} (x_k - \text{Mean})^2}{n} \quad [2]$$

Operation **610** can include comparing the variance calculated in operation **600** to a threshold variance to determine if the calculated variance exceeds the threshold variance. In an instance in which it is determined at operation **610** that the calculated variance exceeds the threshold variance, the method can proceed to operation **620**, which can include determining that the facing condition of the cell **304** over the measurement period exceeds the threshold. Operations **520-550**, as illustrated in and described with respect to FIG. **5** can accordingly be performed in response to operation **620**. If, however, it is determined at operation **610** that the calculated variance does not exceed the threshold variance, the method can instead proceed to operation **630**, which can include determining that the fading condition of the cell **304** does not exceed the threshold and using the network configured filter coefficient for calculating the filtered cell measurement.

In some example embodiments, a second threshold can be applied in instances in which a fading condition of the cell **304** exceeds a threshold over a measurement period and a modified filter coefficient is used. In this regard, a filtered measurement value calculated using a modified filter coefficient can be clipped if a difference between a filtered measurement value calculated in a previous measurement period and the filtered measurement value calculated using the modified filter coefficient exceeds a second threshold, the filtered measurement value calculated based on the modified filter coefficient can be clipped, such as by a constant, ϵ, to reduce an amount of fluctuation between filtered measurement values. FIG. **7** illustrates a flowchart according to an example method for adaptive filtering of cell measurements in accordance with such embodiments applying a second threshold. In this regard, FIG. **7** illustrates operations that can be performed by the wireless communication device **302**. One or more of processing circuitry **410**, processor **412**, memory **414**, transceiver **416**, or adaptive filtering module **418** can, for example, provide means for performing the operations illustrated in and described with respect to FIG. **7**.

With reference to FIG. **7**, operation **700** can include the wireless communication device **302** calculating a first filtered measurement (F_1) indicative of a channel condition of the cell **304** over a first measurement period based on the network configured filter coefficient. The wireless communication device can maintain F_1 for later use, such as in a buffer. Operation **710** can include the wireless communication device **302** determining based at least in part on a plurality of instantaneous measurement samples of the cell **304** over a second measurement period that a fading condition of the cell **304** over the second measurement period exceeds a first threshold. In this regard, operation **710** can correspond to operation **510**.

Operation **720** can include the wireless communication device **302** modifying the network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the first threshold over the second measurement period. Operation **720** can correspond to operation **520**. Operation **730** can, in turn include the wireless communication device **302** filtering the plurality of instantaneous measurement samples captured over the second measurement period based on the modified filter coefficient to calculate a second filtered measurement of the cell (F_2). In this regard, operation **730** can correspond to operation **530**.

Operation **740** can include the wireless communication device **302** comparing F_1 and F_2 to determine if the difference between F_2 and F_1 exceeds the second threshold. In an instance in which it is determined at operation **740** that the difference between the filtered measurements does not exceed the second threshold, the method can proceed to operation **750**, which can include calculating an adjusted measurement value directly from F_2. If, however, it is determined at operation **740** that the difference between the filtered measurements does exceed the second threshold, the method can proceed to operations **760** and **770** in lieu of operation **750**. Operation **760** can include the wireless communication device **302** clipping F_2 by ϵ to derive a clipped value, $F_2+/-\epsilon$. Operation **770** can include the wireless communication device **302** calculating the adjusted measurement value from the clipped value.

The method can proceed to operation **780** after performance of either operation **750** or operation **770**. Operation **780** can include the wireless communication device **302** using the adjusted measurement value for event evaluation and reporting. In this regard, operation **780** can correspond to operation **550**.

In some example embodiments instantaneous measurement samples can be monitored by the wireless communication device **302** on a rolling basis. Thus, if the wireless communication device **302** determines for a measurement period subsequent to using a modified filter coefficient that a fading condition of the cell for that measurement period does not exceed a threshold, then the wireless communication device **302** can return to using the network configured filter coefficient for filtered measurement calculation. FIG. **8** illustrates a flowchart according to an example method for resuming usage of a network configured filter coefficient after initiation of adaptive filtering according to some such example embodiments. One or more of processing circuitry **410**, processor **412**, memory **414**, transceiver **416**, or adaptive filtering module **418** can, for example, provide means for performing the operations illustrated in and described with respect to FIG. **8**. Operation **800** can include the wireless communication device **302** capturing a plurality of instantaneous measurement samples over a subsequent measurement period. Operation **810** can include the wireless communication device **302** determining based at least in part on the instantaneous measurement samples that the fading condition of the cell over the measurement period does not exceed the threshold. For example, operation **810** can include determining that a statistical spread or variance of the samples does not exceed a threshold spread or variance. In some example embodiments, the method illustrated in and described with respect to FIG. **6** can be used for performance of operation **810**. Operation **820** can include the wireless communication device **302** resuming usage of the network configured filter coefficient for calculation of filtered measurements in response to the determination of operation **810**.

Example Calculation of Modified Filter Coefficient and Sample Test Results

Having now described several example embodiments, example derivations of modified filter coefficients will now be described in accordance with some example embodiments. It will be appreciated that these example techniques for deriving modified filter coefficients can be applied in accordance with various example embodiments described herein. Thus, for example, these techniques for derivation of a modified filter coefficient can be used to facilitate performance of operation **520** and/or operation **720** in accordance with some example embodiments.

Calculation of a filtered measurement value can be defined as follows in accordance with some example embodiments:

$$y[n]=(1-\alpha)y[n-1]+\alpha x[n], \quad [3]$$

where:

x[n] is the last received instantaneous measurement from physical layer;

y[n] is the updated filtered measurement result that can be used for event evaluation and/or measurement reporting;

y[n−1] is the old filtered measurement value used for measurement report with y[0] set to x[0]; and

$$\alpha = 2^{-\frac{k}{4}}$$

where 'k' is the network configured filter coefficient, such as can be defined by "quantity config" in an RRC message.

Taking the Z-transform of equation [3] can yield the filter transfer function H[z], as follows:

$$H[z] = \frac{\alpha}{1-(1-\alpha)z^{-1}} \quad [4]$$

A filter can accordingly be designed having a pole at (1−α) based on equation [4]. Comparing the filter with the Z-transform of an exponential decay function with time constant 'Ts' can yield:

$$e^{-\frac{nTs}{\tau}}u[n] \leftrightarrow \frac{1}{1-\left(e^{\frac{-Ts}{\tau}}\right)z^{-1}} \quad [5]$$

The measurement period can be defined as Ts, and the wireless communication device **302** can capture measurement samples at a sampling rate of its choice. For purposes of non-limiting example, let Ts=200 ms and Ts' be the selected sampling rate. It will be appreciated, however, that other measurement periods can be used in accordance with various example embodiments. Given the hypothetical measurement period and sampling rates, it can be inferred from equations [4] and [5] that:

$$e^{\frac{-Ts}{\tau}} = 1-\alpha \quad [6]$$

The time constant of the filter that can be defined for use in a network with measurement periodicity Ts and the filter that can be used by the wireless communication device **302** with a different sampling rate can be defined to be equivalent. As such, the filter coefficient α' can be derived in accordance with equations [7] and [8] as set forth below:

$$\frac{Ts}{\ln(1-\alpha)} = \frac{Ts'}{\ln(1-\alpha')} \quad [7]$$

From equation [7], the filter coefficient α' can be defined as:

$$\alpha' = 1-(1-\alpha)^{\frac{Ts'}{Ts}} \quad [8]$$

However in fading channel conditions and/or other high mobility conditions, the wireless communication device **302** can move between one base station and another, which can lead to a sudden degradation of pilot channel power with a simultaneous increase of neighboring cell pilot channel power. In such conditions, the network specification defined measurement periodicity and time constant can be too long for the filtered values to converge and track the instantaneous measurement samples. The wireless communication device **302** can be configured to temporarily modify the filter coefficient (e.g., for a short period of time) so that the filter converges to the instantaneous measurement samples more quickly when such conditions are encountered.

For example, let $\{x_1, x_2, x_3, x_4, \ldots x_n\}$ be the last n measured instantaneous values (over a measurement period, such as a 200 ms period). The weighted variance, σ, of the samples can be defined as follows:

$$\sigma = \frac{\sum_{i=1}^{n} w_i (x_i - \mu)^2}{n}, \quad [9]$$

where,

$$\mu = \frac{\sum_{i=1}^{n} w_i x_i}{n} \quad [10]$$

w_i, as used in equations [9] and [10] denote weights that can be selected by the wireless communication device **302** based at least in part on channel conditions. The wireless communication device **302** can increase α' by factor 'm' depending on σ. Similarly, the wireless communication device **302** can decrease α' by m if σ is determined to be below a threshold. The resulting filtering equation using the modified filter coefficient can accordingly be defined as:

$$y[n]=(1-\alpha^{1/m})y[n-1]+\alpha^{1/m}x[n] \quad [11]$$

The convergence of a filter in accordance with equation [11] can be implicitly guaranteed by the convergence of the network defined filter. In some example embodiments, if the newly filtered value due to filter coefficient $y_{\alpha'}[n]$ is greater than $y_{\alpha}[n-1]$ by a threshold, then the newly $y_{\alpha'}[n]$ can be set to $y_{\alpha}[n]$.

Table 1 illustrates a comparison of instantaneous measurement samples and filtered measurement values using the static filter defined by equation [3] from a set of test measurements.

TABLE 2

	Instantaneous		Filtered		Filter	
Time in ms	RSRP-Cell 1	RSRP Cell 2	Filtered-Cell 1	Filtered Cell 2	Coeff K	Alpha'
0	−82	−106	−82	−106	3	0.1654
40	−82	−106	−82	−106	3	0.1654
80	−82	−106	−82	−106	3	0.1654
120	−82	−106	−82	−106	3	0.1654
160	−88	−100	−82.9	−105	0.75	0.3436
200	−94	−94	−86.7	−101.2	0.375	0.4249
240	−100	−88	−92.4	−95.6	0.1875	0.4977
280	−106	−82	−99.1	−88.8	0.1875	0.4977
320	−106	−82	−102.6	−85.4		

As can be seen from Table 1, the filtered values can diverge significantly from the instantaneous measurement samples over time when using the static filter. In contrast, Table 2 illustrates a comparison of instantaneous measurement samples and filtered measurement values when using the adaptive filter defined in equation [11] from the same set of test measurements.

TABLE 1

	Instantaneous		Filtered		Fileter	
Time in ms	RSRP-Cell 1	RSRP Cell 2	RSRP Cell 1	RSRP Cell 2	Coeff K	Alpha
0	−82	−106	−82	−106	3	0.1653
40	−82	−106	−82	−106	3	0.1653
80	−82	−106	−82	−106	3	0.1653
120	−82	−106	−82	−106	3	0.1653
160	−88	−100	−82.9	−105	3	0.1653
200	−94	−94	−84.8	−102.2	3	0.1653
240	−100	−88	−87.3	−100.8	3	0.1653
280	−106	−82	−90.4	−97.7	3	0.1653
320	−106	−82	−92.97	−95.11		

FIG. **9** illustrates a graph of instantaneous versus filtered measurements for the static filter and adaptive filter values set forth in Table 1 and Table 2.

CONCLUSION

The various aspects, embodiments, implementations or features of the described embodiments can be used separately or in any combination. Various aspects of the described embodiments can be implemented by software, hardware or a combination of hardware and software. The described embodiments can also be embodied as computer readable code on a computer readable medium for controlling manufacturing operations or as computer readable code on a computer readable medium for controlling a manufacturing line. The computer readable medium is any data storage device that can store data which can thereafter be read by a computer system. Examples of the computer readable medium include read-only memory, random-access memory, CD-ROMs, HDDs, DVDs, magnetic tape, and optical data storage devices. The computer readable medium can also be distributed over network-coupled computer systems so that the computer readable code is stored and executed in a distributed fashion.

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the described embodiments. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the described embodiments. Thus, the foregoing descriptions of specific embodiments are presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the described embodiments to the precise forms disclosed. It will be apparent to one of ordinary skill in the art that many modifications and variations are possible in view of the above teachings.

What is claimed is:

1. A method for adaptive filtering of cell measurements, the method comprising a wireless communication device:

calculating a first filtered measurement of a cell in a network, wherein the first filtered measurement is based on a network configured filter coefficient, the first filtered measurement indicative of a channel condition of the cell over a first measurement period;

determining, based at least in part on a plurality of instantaneous measurement samples of the cell captured over a second measurement period, that a fading condition of the cell over the second measurement period exceeds a first threshold;

modifying the network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the first threshold over the second measurement period;

filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a second filtered measurement of the cell;

comparing the first filtered measurement and the second filtered measurement;

in an instance in which a difference between the second filtered measurement and the first filtered measurement exceeds a second threshold:

clipping the second filtered measurement to derive a clipped value; and

calculating an adjusted measurement value for the cell based at least in part on the clipped value;

in an instance in which the difference between the second filtered measurement and the first filtered measurement does not exceed the second threshold, calculating the adjusted measurement value directly from the second filtered measurement; and

using the adjusted measurement value for event evaluation and reporting.

2. The method of claim **1**, wherein the cell comprises a cell of a network using a Long Term Evolution (LTE) technology, and wherein the plurality of instantaneous measurement samples comprises one or more of a reference signal received power (RSRP) value or a reference signal received quality (RSRQ) value.

3. The method of claim **1**, wherein determining that the fading condition of the cell exceeds the first threshold comprises:

calculating a variance of the plurality of instantaneous measurement samples of the cell captured over the second measurement period; and

determining that the variance exceeds the first threshold.

4. The method of claim **1**, wherein modifying the network configured filter coefficient comprises increasing the network configured filter coefficient by a factor k.

5. The method of claim **4**, wherein k is a static value.

6. The method of claim **4**, wherein k is a value selected based at least in part on an extent of the fading condition over the second measurement period.

7. The method of claim **1**, wherein the plurality of instantaneous measurement samples are filtered based on the network configured filter coefficient in an instance in which the fading condition of the cell does not exceed the first threshold over the second measurement period.

8. The method of claim **1**, further comprising the wireless communication device:

capturing a plurality of instantaneous measurement samples over a third measurement period;

determining based at least in part on the plurality of instantaneous measurement samples captured over the third measurement period that a fading condition over the third measurement period does not exceed the first threshold; and

resuming usage of the network configured filter coefficient in response to the fading condition over the third measurement period not exceeding the first threshold.

9. A method for adaptive filtering of cell measurements of a cell in a network, the method comprising a wireless communication device:

determining a weighted variance of a plurality of instantaneous measurement samples of the cell captured over a measurement period. wherein the weighted variance comprises a weighted sum of squared terms;

determining based at least in part on the weighted variance, that a fading condition of the cell over the measurement period exceeds a threshold;

modifying a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period;

filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell;

calculating an adjusted measurement value for the cell based at least in part on the filtered measurement; and

using the adjusted measurement value for event evaluation and reporting.

10. The method of claim **9**, further comprising:

obtaining a first sampling rate defined by the network;

selecting a second sampling rate; and

determining the plurality of instantaneous measurement samples based on the second sampling rate,

wherein the second sampling rate is based on the first sampling rate and the network configured filter coefficient.

11. The method of claim **1**, further comprising:

obtaining a first sampling rate defined by the network;

selecting a second sampling rate; and

determining the plurality of instantaneous measurement samples based on the second sampling rate,

wherein the second sampling rate is based on the first sampling rate and the network configured filter coefficient.

12. The method of claim **9**, further comprising:

comparing the filtered measurement and a second filtered measurement calculated for a previous measurement period based on the network configured filter coefficient; and

in an instance in which a difference between the filtered measurement and the second filtered measurement exceeds a second threshold, calculating the adjusted measurement value comprises:

clipping the filtered measurement to derive a clipped value; and

calculating the adjusted measurement value based at least in part on the clipped value.

13. The method of claim **9**, wherein the cell comprises a cell of a network using a Long Term Evolution (LTE) technology, and wherein calculating the adjusted measurement value comprises calculating one or more of a reference signal received power (RSRP) value or a reference signal received quality (RSRQ) value.

14. The method of claim **9**, wherein modifying the network configured filter coefficient comprises increasing the network configured filter coefficient by a factor k.

15. The method of claim **14**, wherein k is a static value.

16. A wireless communication device comprising:

a transceiver configured to transmit data to and receive data from a network; and

processing circuitry coupled to the transceiver, the processing circuitry configured to control the wireless communication device to at least:

determine based at least in part on a plurality of instantaneous measurement samples of a cell in the network that a fading condition of the cell over a measurement period exceeds a threshold;

modify a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period;

filter the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell;

derive a first value by clipping the filtered measurement when a difference of the filtered measurement and a second filtered measurement exceeds a second threshold;

set the first value equal to the filtered measurement when the difference does not exceed the second threshold;

calculate an adjusted measurement value for the cell based at least in part on the first value; and

use the adjusted measurement value for event evaluation and reporting.

17. The wireless communication device of claim **16**, wherein the cellular network is a network using a Long Term Evolution (LTE) technology, and wherein the plurality of instantaneous measurement samples comprises one or more of a reference signal received power (RSRP) value or a reference signal received quality (RSRQ) value for the cell.

18. The wireless communication device of claim **16**, wherein the processing circuitry is further configured to control the wireless communication device to determine that the fading condition of the cell exceeds the threshold at least in part by:

calculating a variance of the plurality of instantaneous measurement samples of the cell captured over the measurement period; and

determining that the variance exceeds the threshold.

19. The wireless communication device of claim **16**, wherein the processing circuitry is further configured to control the wireless communication device to modify the network configured filter coefficient at least in part by increasing the network configured filter coefficient by a factor k.

20. A computer program product for adaptive filtering of cell measurements, the computer program product comprising at least one non-transitory computer readable storage medium having computer program code stored thereon, the computer program code comprising:

program code for determining a weighted variance of a plurality of instantaneous measurement samples of a cell in a network, wherein the weighted variance comprises a weighted sum of squared terms;

program code for determining, based at least in part on the weighted variance, that a fading condition of the cell over a measurement period exceeds a threshold;

program code for modifying a network configured filter coefficient to derive a modified filter coefficient in response to the fading condition of the cell exceeding the threshold over the measurement period;

program code for filtering the plurality of instantaneous measurement samples based on the modified filter coefficient to calculate a filtered measurement of the cell;

program code for calculating an adjusted measurement value for the cell based at least in part on the filtered measurement; and

program code for using the adjusted measurement value for event evaluation and reporting.

21. The computer program product of claim **20**, further comprising:

program code for comparing the filtered measurement and a second filtered measurement calculated for a previous measurement period based on the network configured filter coefficient;

program code for clipping the filtered measurement to derive a clipped value in an instance in which a difference between the filtered measurement and the second filtered measurement exceeds a second threshold; and

program code for calculating the adjusted measurement value based at least in part on the clipped value in an instance in which the difference between the filtered measurement and the second filtered measurement exceeds a second threshold.

22. The computer program product of claim **20**, wherein the cell comprises a cell of a network using a Long Term Evolution (LTE) technology, and wherein the plurality of instantaneous measurement samples comprises one or more of a reference signal received power (RSRP) value or a reference signal received quality (RSRQ) value.

23. The computer program product of claim **20**, wherein the program code for modifying the network configured filter coefficient comprises program code for increasing the network configured filter coefficient by a factor k.

24. The computer program product of claim **20**, further comprising:

computer code for obtaining a first sampling rate defined by the network;

computer code for selecting a second sampling rate; and

computer code for determining the plurality of instantaneous measurement samples based on the second sampling rate,

wherein the second sampling rate is based on the first sampling rate and the network configured filter coefficient.

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