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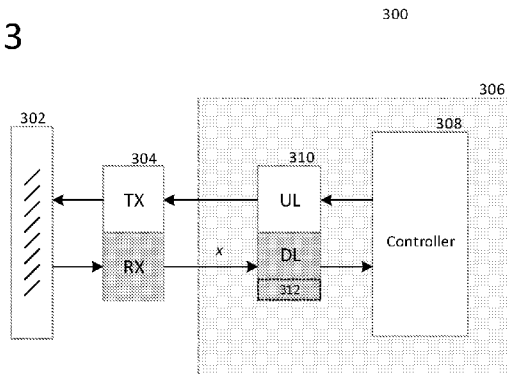
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FIG. 3



(57) Abstract: A communication circuit arrangement may include a synchronization burst detection circuit configured to process beacon carrier data to establish synchronization with a beacon carrier based on one or more synchronization bursts included in the beacon carrier data, a dummy burst detection circuit to identify one or more dummy bursts included in the beacon carrier data, and a signal measurement circuit configured to determine a signal level measurement using the one or more dummy bursts.

## METHODS AND DEVICES FOR SIGNAL LEVEL MEASUREMENT

### **Technical Field**

[1] Various embodiments relate generally to methods and devices for signal level measurement.

### **Background**

[2] Recent advances in mobile communication technologies have allowed a wide range of devices to enjoy network connectivity. This widespread connectivity enjoyed by devices ranging from portable devices to vehicles and buildings has been coined the Internet of Thing (IoT), and is expected to expand as wireless networks become more and more prevalent.

[3] In particular for Cellular IoT (CIoT) use cases, mobile devices may be expected to operate in relatively poor radio connectivity conditions. Accordingly, recent developments in communication standards such as the Global System for Mobile Communications (GSM) have focused on improving cellular coverage in order to address the unique requirements of cellular IoT device connectivity.

[4] Specifically, proposals such as Extended Coverage GSM (EC-GSM) have targeted improvements in cellular coverage to existing communication systems that may be better suited to IoT use cases. In the case of EC-GSM, cellular coverage increases of 20 dB have been targeted for the legacy General Packet Radio Service (GPRS). EC-GSM has proposed to meet such improvements through the use of blind repetition, which entails transmitting the same radio block multiple times. Mobile terminals may then be able to receive each of the repeated transmissions and subsequently accumulate the resulting data in order to obtain a substantial boost in reception performance.

### **Brief Description of the Drawings**

[5] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the invention are described with reference to the following drawings, in which:

FIG. 1 shows a timing diagram illustrating a blind repetition scheme;

FIG. 2 shows power density plot of a noisy data burst;

FIG. 3 shows a first internal configuration of a mobile terminal;

FIG. 4 shows a duplicate burst SNR estimation circuit;

FIG. 5 shows a method of performing SNR estimation;

FIG. 6 shows a second internal configuration of a mobile terminal;

FIG. 7 shows an FCCH/dummy burst SNR estimation circuit;

FIG. 8 shows a first method of performing radio measurements;

FIG. 9 shows a second method of performing radio measurements; and

FIG. 10 shows a third method of performing radio measurements.

### **Description**

[6] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced.

[7] The word “exemplary” is used herein to mean “serving as an example, instance, or illustration”. Any embodiment or design described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments or designs.

[8] The words “plural” and “multiple” in the description and the claims expressly refer to a quantity greater than one. Accordingly, any phrases explicitly invoking the aforementioned words (e.g. “a plurality of [objects]”, “multiple [objects]”) referring to a

quantity of objects expressly refers more than one of the said objects. The terms “group (of)”, “set [of]”, “collection (of)”, “series (of)”, “sequence (of)”, “grouping (of)”, etc., and the like in the description and in the claims, if any, refer to a quantity equal to or greater than one, i.e. one or more.

[9] It is appreciated that any vector and/or matrix notation utilized herein is exemplary in nature and is employed solely for purposes of explanation. Accordingly, it is understood that the approaches detailed in this disclosure are not limited to being implemented solely using vectors and/or matrices, and that the associated processes and computations may be equivalently performed with respect to sets, sequences, groups, etc., of data, observations, information, signals, etc. Furthermore, it is appreciated that references to a “vector” may refer to a vector of any size or orientation, e.g. including a  $1 \times 1$  vector (e.g. a scalar), a  $1 \times M$  vector (e.g. a row vector), and an  $M \times 1$  vector (e.g. a column vector). Similarly, it is appreciated that references to a “matrix” may refer to matrix of any size or orientation, e.g. including a  $1 \times 1$  matrix (e.g. a scalar), a  $1 \times M$  matrix (e.g. a row vector), and an  $M \times 1$  matrix (e.g. a column vector).

[10] A “circuit” as user herein is understood as any kind of logic-implementing entity, which may include special-purpose hardware or a processor executing software. A circuit may thus be an analog circuit, digital circuit, mixed-signal circuit, logic circuit, processor, microprocessor, Central Processing Unit (CPU), Graphics Processing Unit (GPU), Digital Signal Processor (DSP), Field Programmable Gate Array (FPGA), integrated circuit, Application Specific Integrated Circuit (ASIC), etc., or any combination thereof. Any other kind of implementation of the respective functions which will be described below in further detail may also be understood as a “circuit”. It is understood that any two (or more) of the circuits detailed herein may be realized as a single circuit with substantially equivalent functionality, and conversely that any single circuit detailed herein may be realized as two (or

more) separate circuits with substantially equivalent functionality. Additionally, references to a “circuit” may refer to two or more circuits that collectively form a single circuit.

**[11]** As used herein, “memory” may be understood as a non-transitory computer-readable medium in which data or information can be stored for retrieval. References to “memory” included herein may thus be understood as referring to volatile or non-volatile memory, including random access memory (RAM), read-only memory (ROM), flash memory, solid-state storage, magnetic tape, hard disk drive, optical drive, etc., or any combination thereof. Furthermore, it is appreciated that registers, shift registers, processor registers, data buffers, etc., are also embraced herein by the term memory. It is appreciated that a single component referred to as “memory” or “a memory” may be composed of more than one different type of memory, and thus may refer to a collective component comprising one or more types of memory. It is readily understood that any single memory component may be separated into multiple collectively equivalent memory components, and vice versa. Furthermore, while memory may be depicted as separate from one or more other components (such as in the drawings), it is understood that memory may be integrated within another component, such as on a common integrated chip.

**[12]** The term “base station” used in reference to an access point of a mobile communication network may be understood as a macro base station, micro base station, Node B, evolved NodeBs (eNB), Home eNodeB, Remote Radio Head (RRH), relay point, etc. As used herein, a “cell” in the context of telecommunications may be understood as a sector served by a base station. Accordingly, a cell may be a set of geographically co-located antennas that correspond to a particular sectorization of a base station. A base station may thus serve one or more cells (or sectors), where each cell is characterized by a distinct communication channel. Furthermore, the term “cell” may be utilized to refer to any of a macrocell, microcell, femtocell, picocell, etc.

**[13]** For purposes of this disclosure, radio communication technologies may be classified as one of a Short Range radio communication technology, Metropolitan Area System radio communication technology, or Cellular Wide Area radio communication technology. Short Range radio communication technologies include Bluetooth, WLAN (e.g. according to any IEEE 802.11 standard), and other similar radio communication technologies. Metropolitan Area System radio communication technologies include Worldwide Interoperability for Microwave Access (WiMax) (e.g. according to an IEEE 802.16 radio communication standard, e.g. WiMax fixed or WiMax mobile) and other similar radio communication technologies. Cellular Wide Area radio communication technologies include GSM, UMTS, LTE, General Packet Radio Service (GPRS), Enhanced Data Rates for GSM Evolution (EDGE), High Speed Packet Access (HSPA), HSPA Plus (HSPA+), and other similar radio communication technologies. Cellular Wide Area radio communication technologies also include “small cells” of such technologies, such as microcells, femtocells, and picocells. Cellular Wide Area radio communication technologies may be generally referred to herein as “cellular” communication technologies. It is understood that exemplary scenarios detailed herein are demonstrative in nature, and accordingly may be similarly applied to various other mobile communication technologies, both existing and not yet formulated, particularly in cases where such mobile communication technologies share similar features as disclosed regarding the following examples.

**[14]** The term “network” as utilized herein, e.g. in reference to a communication network such as a mobile communication network, encompasses both an access section of a network (e.g. a radio access network (RAN) section) and a core section of a network (e.g. a core network section). The term “radio idle mode” or “radio idle state” used herein in reference to a mobile terminal refers to a radio control state in which the mobile terminal is not allocated at least one dedicated communication channel of a mobile communication network. The term “radio connected mode” or “radio connected state” used in reference to a mobile terminal

refers to a radio control state in which the mobile terminal is allocated at least one dedicated uplink communication channel of a mobile communication network. Unless explicitly specified, the term “transmit” encompasses both direct and indirect transmission. Similarly, the term “receive” encompasses both direct and indirect reception unless explicitly specified.

**[15]** Extended Coverage GSM (EC-GSM) has proposed blind repetition as an approach to improve cellular coverage, in particular for mobile devices located in high noise environments. In blind repetition schemes, a base station may transmit the same radio burst multiple times, which may each be subsequently received by nearby mobile terminals. In order to improve receiver performance, a mobile terminal may receive each of the duplicate bursts and accumulate the resulting received data, thus realizing a substantial boost in Signal-to-Noise ratio (SNR) and allowing mobile terminals to maintain sufficient cellular connectivity even in considerably poor radio conditions.

**[16]** The number of blind repetitions, or “repetition count”, for a given radio burst (where the duplicate transmissions of a given burst collectively compose a repetition group) may vary depending on the radio conditions of the intended mobile terminals. For example, a base station transmitting a traffic burst to a mobile terminal that is currently experiencing relatively strong radio conditions may only need to use a small repetition count (e.g. two total duplicate bursts, i.e. a repetition count of two), while conversely a base station transmitting a traffic radio block to a mobile terminal in poor radio conditions may need to use a higher repetition count (e.g. eightduplicate bursts, sixteenduplicate bursts, etc.).

**[17]** In recognition of such, an EC-GSM network may quantify the current radio conditions of the associated mobile terminals in the form of a Coverage Class (CC), where large CC values may dictate a large repetition count and small CC values may dictate small repetition counts. The CC for each mobile terminal may depend on the downlink signal level seen at each mobile terminal. A mobile terminal may thus measure a signal level of a downlink signal received from a base station, calculate the CC based on the measured

downlink signal level, and report the calculated CC to the base station. The base station may then employ the reported CC to select a repetition count for the blind repetition scheme employed for the mobile terminal.

**[18]** Each served mobile terminal of a given base station may be in a different radio environment at any point in time, and accordingly a base station may receive differing CC reports from each of a plurality of served mobile terminals. A base station may thus employ a different repetition count for each mobile terminal according to the varying reported CCs. Additionally, a base station may select a separate repetition count for each logical channel of each mobile terminal according to the CC reported by each mobile terminal. For example, a base station may receive a CC report from a given mobile terminal and select a first repetition count for EC Access Grant Channel (EC-AGCH) bursts for the mobile terminal, a second repetition count for EC Paging Channel (EC-PCH) bursts for the mobile terminal, a third repetition count for EC Packet Data Traffic Channel (EC-PDTCH) bursts for the mobile terminal, a fourth repetition count for EC Broadcast Control Channel (EC-BCCH) bursts for the mobile terminal, etc. FIG. 1 depicts the associated CC mappings for Coverage Class 1 (CC1, top) to Coverage Class 6 (CC6, bottom) over a 51 multi-frame for the EC-PCH, where shaded blocks indicate the GSM frames that may contain a repetition burst and  $N$  denotes the TDMA timeslot (from 0-7 in a given GSM frame) at which a repetition burst may appear.

**[19]** Given the considerable effect of CC on repetition counts for multiple logical channels of each reporting mobile terminal, CC reporting may have a substantial impact on downlink transmissions. The ability of a mobile terminal to accurately calculate CC values may thus be critical, as underestimated CC values may cause high decoding errors due to insufficient repetition counts (potentially requiring further retransmissions and increased power consumption) and overestimated CC values may result in a waste of radio resources due to excessive repetition counts. However, as EC-GSM specifically targets CIoT devices operating at low SNR (given the 20 dB coverage extension), received downlink bursts may be

deeply embedded in noise which may as a result render it exceedingly difficult for such mobile terminals to obtain accurate signal level measurements. FIG. 2 shows an exemplary scenario in which a normal burst is buried within white noise. In such scenarios, straightforward measurement solutions (such as e.g. simply measuring the received signal power) may suffer from high inaccuracy as a result of the large noise presence. Mobile terminals may thus need to employ more robust signal measurement techniques in order to both measure downlink signal levels and report CC values with a high degree of accuracy.

[20] As presented herein, a GSM mobile terminal may obtain accurate signal level measurements for CC reporting by calculating downlink signal levels with repeated bursts received as part of a blind repetition scheme or with dummy bursts received during Frequency Correction Channel (FCCH) detection. Although the following disclosure may utilize a GSM framework to detail such approaches, the solutions detailed herein are demonstrative in nature and thus may be analogously applied to other radio access technologies in a parallel manner.

[21] FIG. 3 shows an internal configuration of mobile terminal 300, which may be configured to measure received downlink signals and report the resulting measurements to a base station (not explicitly shown). As shown in FIG. 3, mobile terminal 300 may include antenna system 302, radio frequency (RF) transceiver 304, and baseband modem 306. Although not explicitly shown in FIG. 3, mobile terminal 300 may include one or more additional components such as additional hardware, software, or firmware elements including processors/microprocessors, controllers/microcontrollers, memory, other specialty or generic hardware/processors/circuits, etc., in order to support a variety of additional operations. In particular, mobile terminal 300 may include a mobile application processor configured to execute various applications and/or programs of mobile terminal 300, such as e.g. an Operating System (OS), a User Interface (UI) for supporting user interaction with mobile terminal 300, and/or various user applications. The mobile application processor may interface with baseband modem 306 to transmit and receive user data such as voice data,

video data, messaging data, application data, basic Internet/web access data, etc., over a radio network connection provided by baseband modem **306**. Mobile terminal **300** may also include a variety of user input/output devices (display(s), keypad(s), touchscreen(s), speaker(s), external button(s), camera(s), microphone(s), etc.), peripheral device(s), memory, power supply, external device interface(s), subscriber identify module(s) (SIM) etc.

**[22]** In abridged operational overview, mobile terminal **300** may transmit and receive radio signals on one or more cellular communication networks according to the associated communications protocol of each cellular communication network, which may be directed by controller **308** of baseband modem **306**. Controller **308** may thus manage the wireless communication operations of mobile terminal **300** via control of antenna system **302**, RF transceiver **304**, and the various processing components of baseband modem **306**. Controller **308** may be structurally realized as a protocol processor configured to execute program code that defines the control logic of each associated communications protocol and subsequently control the aforementioned other components of mobile terminal **300** under the direction of the protocol control logic.

**[23]** Mobile terminal **300** may transmit and receive radio signals with antenna system **302**, which may be implemented as a single antenna or an antenna array composed of multiple antennas. In the downlink direction (RX), RF transceiver **304**/RX may receive analog radio frequency signals from antenna system **302** and perform various preprocessing operations on the analog radio frequency signals to produce digital baseband signals (IQ samples) to provide to baseband modem **306**. RF transceiver **304**/RX may thus include reception circuitry components including amplification circuitry (e.g. a Low Noise Amplifier (LNA)), filtering circuitry, mixing circuitry, and analog-to-digital conversion (ADC) circuitry to convert the received analog radio frequency signals to digital baseband signals. In the uplink direction (TX), RF transceiver **304**/TX may receive digital baseband signals from baseband modem **306** and perform various processing operations on the digital baseband signals to produce

analog radio frequency signals to provide to antenna system **302** for wireless transmission. RF transceiver **304/TX** may thus include transmission circuitry components including digital-to-analog conversion (DAC) circuitry, mixing circuitry, filtering circuitry, and amplification circuitry (e.g. a Power Amplifier (PA)) to mix the digital baseband signals (IQ samples) received from baseband modem **306** to radio frequencies to produce the analog radio frequency signals for wireless transmission by antenna system **302**.

[24] Baseband modem **306** may include uplink/downlink processing circuit **310**, which may perform physical layer uplink and physical layer downlink processing in order to prepare outgoing uplink baseband (In-phase/Quadrature (IQ)) samples provided by controller **308** (which may encompass physical layer control (e.g. a PHY/L1 controller) in addition to upper protocol stack layers (L2/L3) and other uplink data sinks and sources) for transmission via RF transceiver **304/TX** and prepare incoming downlink samples provided by RF transceiver **304/RX** for processing by controller **308**. Uplink/downlink processing circuit **310** may thus perform one or more of error detection, forward error correction encoding/decoding, channel coding and interleaving, physical channel modulation/demodulation, physical channel mapping, radio measurement and search, frequency and time synchronization, antenna diversity processing, power control and weighting, rate matching, retransmission processing, etc., according to the relevant physical layer communications protocol. Uplink/downlink processing circuit **310** may be structurally realized as hardware logic, e.g. as an integrated circuit or FPGA, as software logic, e.g. as program code defining arithmetic, control, and I/O instructions stored in a non-transitory computer-readable storage medium and executed on a processor, or as a combination of hardware and software logic.

[25] Mobile terminal **300** may be configured to operate on EC-GSM cellular networks as introduced above. Controller **308** may thus be responsible for directing communication functions in accordance with the EC-GSM communication protocols, which as previously detailed may encompass receiving cellular data with a blind repetition scheme in addition to

calculating and transmitting CC reports to a base station. As mobile terminal **300** may need to operate in considerably poor radio conditions, mobile terminal **300** may need to be able to accurately calculate downlink signal levels in order to generate reliable CC reporting values.

[26] As shown in FIG. 3, uplink/downlink processing circuit **310** may include duplicate burst SNR estimation circuit **312**, which may be configured to perform SNR estimates based on received duplicate bursts. FIG. 4 shows an internal configuration of duplicate burst SNR estimation circuit **312**, which may include signal power estimation circuit **402**, total power estimation circuit **404**, and SNR estimation circuit **406**. As will be detailed, duplicate burst SNR estimation circuit may be configured to calculate downlink signal levels and provide the downlink signal levels to controller **308**. Controller **308** may receive the downlink signal levels provided by SNR estimation circuit **406** and determine a CC reporting value according to the downlink signal levels. Controller **308** may then generate a CC report to transmit via uplink/downlink processing circuit **310**, RF transceiver **304** and antenna system **302**. While each of signal power estimation circuit **402**, total power estimation circuit **404**, and SNR estimation circuit **406** may be described from an operational perspective, the disclosed functionality of each of signal power estimation circuit **402**, total power estimation circuit **404**, and SNR estimation circuit **406** may be structurally realized as hardware logic, e.g. as an integrated circuit or FPGA, as software logic, e.g. as program code defining arithmetic, control, and I/O instructions stored in a non-transitory computer-readable storage medium and executed on a processor, or as a combination of hardware and software logic.

[27] As previously shown in FIG. 2, the received downlink signal may be embedded in noise, thus making it exceedingly difficult for baseband modem **306** to employ conventional downlink signal level measurement techniques. Instead, duplicate burst SNR estimation circuit **312** may rely on the correlation between each received duplicate burst in a given repetition group in order to separate the received bursts from the surrounding noise and subsequently obtain reliable downlink signal level measurements for CC reporting.

[28] As previously indicated, a base station may transmit multiple duplicate bursts in repetition group according to a particular repetition count, where the repetition count is dependent on CC values reporting by the corresponding mobile terminal (in addition to the particular logical channel containing the relevant burst). While each duplicate burst may be identical at the transmitter side, the effects of wireless propagation introduced by the wireless channel and random noise may corrupt the duplicate bursts received at the receiver, e.g. at mobile terminal **300**.

[29] Accordingly, a corresponding base station may transmit a given burst  $s(n)$  a total of  $M$  times in a given repetition group, where each of the  $M$  bursts of the repetition group are composed of the same  $N_{iq}$  IQ samples, i.e.  $n = 0, 1, \dots, N_{iq} - 1$ . Following wireless propagation over a given wireless channel and reception by antenna system **302**, RF transceiver **304**/RX may receive the resulting analog radio frequency symbols and perform IQ demodulation to provide baseband IQ samples to baseband modem **306** at uplink/downlink processing circuit **310**/UL. Following any required preprocessing, duplicate burst SNR estimation circuit **312** may receive the baseband IQ samples as  $x(b, n)$  (which may be Gaussian minimum shift key (GMSK)-modulated in the context of GSM), with  $x(b, n)$  is defined as

$$x(b, n) = hs(n)e^{j(2\pi\Delta f n T_s + \Theta_b)} + w(b, n) \quad (1)$$

where  $b$  is the burst index within the repetition group and defined from  $b = 0, 1, \dots, M$ ,  $h$  is the channel impulse response (represented in Equation (1) as a single tap for brevity),  $s(n)$  is the  $n$ -th transmitted IQ sample of the burst,  $T_s$  is the sample period,  $\Delta f$  is the frequency offset,  $\Theta_b$  is the initial phase of the  $b$ -th burst,  $w(b, n)$  is the  $n$ -th noise sample of the  $B$ -th burst,

and  $N_{iq}$  and  $M$  are the number of IQ samples in each burst and  $M$  is the number of bursts of the repetition group, respectively, as previously indicated.

[30] In a conventional downlink signal level measurement, mobile terminal **300** may simply receive a single burst transmission  $x(b, n)$  (for  $n = 1, \dots, N_{iq} - 1$ ) and perform a downlink signal level measurement on the single received burst. However, as previously detailed regarding FIG. 2, the actual transmitted burst signal  $s(n)$  may be deeply embedded in noise (by noise signal  $w(b, n)$ ), and accordingly the resulting downlink signal measurement may not be reliable.

[31] Instead, mobile terminal **300** may rely on the fact that the IQ samples of  $s(n)$  are identical for each  $b$ -th received burst  $x(b, n)$  in order to accumulate the samples of multiple duplicate bursts (thus emphasizing the received bursts relative to the random surrounding noise) before separating the received bursts from the noise by relying on the underlying correlation between each received duplicate burst.

[32] FIG. 5 shows method **500**, which duplicate burst SNR estimation circuit **312** may execute in order to accurately calculate a downlink Signal-to-Noise ratio (SNR) for subsequent use in CC reporting. As shown in FIG. 5, duplicate burst SNR estimation circuit **312** may first receive each of the  $M$  duplicate bursts in a given repetition group in **502**. Accordingly, duplicate burst SNR estimation circuit **312** may receive the baseband IQ samples of  $x(b, n)$  for each of the  $M$  duplicate bursts of the repetition group (which duplicate burst SNR estimation circuit **312** may receive via antenna system **302**, RF transceiver **304**/RX following IQ demodulation by RF transceiver **304**, and any preprocessing elements of uplink/downlink processing circuit **310**). Signal power estimation circuit **402** may then separate the  $M$  duplicate bursts of the repetition group into multiple accumulation groups in **504**. For example, signal power estimation circuit **402** may separate the  $M$  duplicate bursts into two accumulation groups, where the first accumulation group is composed of the first

$M/2$  duplicate bursts ( $x(b, n)$  for  $b = 0, 1, \dots, \frac{M}{2} - 1$ ) and the second accumulation group is composed of the remaining  $M/2$  duplicate bursts ( $x(b, n)$  for  $b = \frac{M}{2}, \dots, M - 1$ ). Alternate separation schemes are also possible; however, separation into first and second halves of the repetition group may ensure that the duplicate bursts of each accumulation group are proximate in time, thus allowing the simplification in which the channel  $h$  is assumed constant over time.

**[33]** As previously indicated, baseband modem **306** may employ IQ accumulation in order to combine the received burst samples  $x(b, n)$  to produce accumulated bursts, thus countering noise by emphasizing the burst samples over white noise. However, the received burst samples  $x(b, n)$  for the duplicate bursts of each accumulation group may not be phase-aligned, and accordingly directly accumulating the received burst samples  $x(b, n)$  may result in destructive accumulation. For example, given a phase offset of  $\pi$  between two burst samples  $x(b_1, n_1)$  and  $x(b_2, n_1)$  (i.e. the received sample of  $s(n_1)$  received at the  $b_1$ -th and  $b_2$ -th burst repetition), the IQ accumulation  $x(b_1, n_1) + x(b_2, n_1)$  will cancel out complete (complete destruction accumulation) even though the underlying sample  $s(n_1)$  was identical. Such phase offsets may be in particular caused by frequency offsets between the local oscillator of RF transceiver **304/RX** and the radio carrier frequency of received signals (e.g. as a result of Doppler shift, oscillator drift, etc.) or by phase mismatches caused by non-continuous phase transition, all of which may result in a phase difference between successively received bursts.

**[34]** In order to provide constructive accumulation of the duplicate bursts within each accumulation group, signal power estimation circuit **402** may phase align each of the duplicate bursts within each accumulation group in **506**. Signal power estimation circuit **402** may thus calculate a phase shift to apply to the received burst samples of the duplicate bursts of each accumulation group in order to phase-align the duplicate bursts within each accumulation group. For example, signal power estimation circuit **402** may calculate a base

duplicate burst from each accumulation group and calculate a phase shift to apply to each of the remaining duplicate bursts of each accumulation group in order to phase align all of the duplicate bursts within each accumulation group, such as e.g. by selecting the initial duplicate burst (i.e. occurring earliest in time) of each accumulation group as the base duplicate burst (although base duplicate bursts other than the initial duplicate burst may alternatively be selected within each accumulation group). In the case of two total accumulation groups as introduced above (the first accumulation group composed of  $x(b, n)$  for  $b = 0, 1, \dots, \frac{M}{2} - 1$  and the second accumulation group composed of  $x(b, n)$  for  $b = \frac{M}{2}, \dots, M - 1$ ), signal power estimation circuit **402** may calculate a phase shift  $\hat{\theta}$  to apply each of the remaining duplicate bursts as follows

$$\hat{\theta}_{0,b} = \text{angle} \left( \sum_{n=0}^{N_{iq}-1} x(0, n) \cdot x^*(b, n) \right), \quad b = 0, 1, \dots, \frac{M}{2} - 1 \quad (2)$$

$$\hat{\theta}_{\frac{M}{2},b} = \text{angle} \left( \sum_{n=0}^{N_{iq}-1} x\left(\frac{M}{2}, n\right) \cdot x^*(b, n) \right), \quad b = \frac{M}{2}, \frac{M}{2} + 1, \dots, M - 1 \quad (3)$$

where  $\hat{\theta}_{0,b}$  and  $\hat{\theta}_{\frac{M}{2},b}$  give the phase shift to align the  $b$ -th duplicate burst with the initial duplicate burst of the first and second accumulation groups, respectively,  $\text{angle}(\cdot)$  gives the angle of a complex sample, and  $x^*(b, n)$  gives the complex conjugate of  $x(b, n)$ .

**[35]** Signal power estimation circuit **402** may then apply the respective phase shifts  $\hat{\theta}_{0,b}$  and  $\hat{\theta}_{\frac{M}{2},b}$  to the corresponding duplicate bursts of each accumulation group as

$$x'(b, n) = \begin{cases} x(b, n)e^{j\hat{\theta}_{0,b}}, & b = 0, 1, \dots, \frac{M}{2} - 1 \\ x(b, n)e^{j\hat{\theta}_{\frac{M}{2},b}}, & b = \frac{M}{2}, \frac{M}{2} + 1, \dots, M - 1 \end{cases} \quad (4)$$

[36] Signal power estimation circuit **402** may thus generate  $x'(b, n)$  where the duplicate bursts of the assigned accumulation groups of  $x'(b, n)$  are each phase aligned with the base duplicate burst (e.g. the initial duplicate bursts of each accumulation group). Signal power estimation circuit **402** may then perform IQ accumulation in **508** to accumulate the received samples of the duplicate bursts to obtain an accumulated burst for each accumulation group. Signal power estimation circuit **402** may thus calculate accumulated burst  $x_1(n)$  for the first accumulation group and accumulated burst  $x_2(n)$  for the second accumulation group as

$$\begin{aligned} x_1(n) &= \frac{2}{M} \sum_{b=0}^{\frac{M}{2}-1} x'(b, n), \quad n = 0, 1, \dots, N_{iq} - 1 \\ &= \frac{2}{M} \sum_{b=0}^{\frac{M}{2}-1} [hs(n)e^{j(j\pi \Delta f T_s + \theta_0)} + w(b, n)] \\ &= \frac{2}{M} \cdot \left( hs(n)e^{j(j\pi \Delta f T_s + \theta_0)} + \sum_{b=0}^{\frac{M}{2}-1} [w(b, n)] \right) \end{aligned} \quad (5)$$

$$\begin{aligned} x_2(n) &= \frac{2}{M} \sum_{b=\frac{M}{2}}^{M-1} x'(b, n), \quad n = 0, 1, \dots, N_{iq} - 1 \\ &= \frac{2}{M} \sum_{b=\frac{M}{2}}^{M-1} \left[ hs(n)e^{j(j\pi \Delta f T_s + \theta_{\frac{M}{2}})} + w(b, n) \right] \\ &= \frac{2}{M} \cdot \left( hs(n)e^{j(j\pi \Delta f T_s + \theta_{\frac{M}{2}})} + \sum_{b=\frac{M}{2}}^{M-1} [w(b, n)] \right) \end{aligned} \quad (6)$$

where  $\theta_0$  and  $\frac{\theta_M}{2}$  give the phase of the respective base duplicate bursts of the first and second accumulation groups.

[37] Signal power estimation circuit **402** may thus accumulate the received IQ samples of  $x(b, n)$  of the duplicate bursts of each accumulation group (after phase-alignment with a base duplicate burst of each accumulation group) to obtain accumulated bursts  $x_1(n)$  and  $x_2(n)$ . Such IQ accumulation may thus counter the affects of the white noise  $w(b, n)$  present in  $x(b, n)$ , thus emphasizing the contributions of the transmitted burst data and allowing for more robust signal level estimation.

[38] Signal power estimation circuit **402** may then calculate the downlink signal power from accumulated bursts  $x_1(n)$  and  $x_2(n)$  in **510** by relying on the underlying correlation stemming from the identical burst samples  $s(n)$  contained in  $x_1(n)$  and  $x_2(n)$ . Specifically, signal power estimation circuit **402** may calculate the downlink signal power by calculating the zero-lag cross-correlation between  $x_1(n)$  and  $x_2(n)$  as

$$P_s = \left| \frac{1}{N_{iq}} \sum_{n=0}^{N_{iq}-1} x_1(n) x_2^*(n) \right| \quad (7)$$

$$= \left| |h|^2 e^{j\left(\theta_0 - \frac{\theta_M}{2}\right)} + W \right|$$

where  $W$  is composed of the cross-correlation between white noise  $w(b, n)$  and  $x(b, n)$  and the cross-correlation between the white noise  $w(b, n)$  included in each of  $x_1(n)$  and  $x_2(n)$ .

[39] Assuming a probabilistically low similarity between white noise and the duplicate bursts,  $W$  may be assumed to be relatively negligible, thus allowing signal power estimation circuit **402** to obtain a reliable value for downlink signal power  $P_s$ . While straightforward IQ accumulation of the duplicate bursts may additionally accumulate noise samples, reliance on

the correlation between duplicate bursts may isolate the burst samples from the noise and accordingly provide more accurate downlink signal power estimates.

[40] As shown in FIG. 3, signal power estimation circuit 402 may provide  $P_s$  to SNR estimation circuit 406, which may also receive total power  $P_{total}$  from total power estimation circuit 404. Total power estimation circuit 404 may calculate the total signal power  $P_{total}$  in 512 as

$$P_{total} = \frac{1}{2N_{iq}} \sum_{n=0}^{N_{iq}-1} x_1(n)x_1^*(n) + \frac{1}{2N_{iq}} \sum_{n=0}^{N_{iq}-1} x_2(n)x_2^*(n) \quad (8)$$

[41] SNR estimation circuit 406 may then receive  $P_{total}$  and  $P_s$  and calculate the estimated SNR in 514. SNR estimation circuit 406 may calculate the noise power  $P_w$  as

$$P_w = P_{total} - P_s \quad (9)$$

and subsequently estimate the SNR in 514 as

$$S\hat{N}R = 10 \log_{10} \left( \frac{P_s}{P_w} \right) \quad (10)$$

[42] As shown in FIG. 4, SNR estimation circuit 406 may then provide controller 308 with the estimated SNR. Controller 308 may then determine the corresponding CC reporting value based on the SNR, where controller 308 may determine a high CC value for low SNR values (triggering a high repetition count to address poor radio conditions) and may determine a low CC value for high SNR values (triggering a low repetition count in view of strong radio conditions). Controller 308 may then generate a CC report according to the EC-GSM

communication protocols and transmit the CC report via uplink/downlink processing circuit **310**, RF transceiver **304**, and antenna system **302**. Controller **308** may generate a CC report that simply includes the CC value or may generate a CC report that additionally or alternatively includes the estimated SNR.

[43] Accordingly, signal power estimation circuit **402** may calculate downlink signal power  $P_s$  as the correlation between the accumulated bursts from each accumulation group, thus allowing mobile terminal **300** to separate the duplicate burst data from the surrounding noise and thus maintain high accuracy in both the obtained SNR values and generated CC reports.

[44] As previously indicated, in a second aspect of this disclosure mobile terminal **300** may additionally or alternatively obtain accurate downlink signal measurements by evaluating dummy bursts received during FCCH detection. Mobile terminal **300** may accordingly be able to implement one or both of downlink signal measurements based on dummy bursts and duplicate bursts, such as e.g. by applying dummy burst-based downlink signal measurement to provide an initial CC report (such as following initial attach to a GSM beacon carrier) and subsequently apply duplicate burst-based downlink signal measurement to provide CC reports once a blind repetition scheme is active.

[45] In a GSM context, a base station may broadcast a beacon carrier including the Broadcast Control Channel (BCCH) of the base station, which may carry important system information including cell identity, configuration, and scheduling in addition to other control information. Each base station may transmit the BCCH on the beacon carrier as a repeating pattern according to a 51-frame multiframe structure which allocates certain BCCH data to specific timeslots in each of the 51 frames of the multiframe.

[46] As GSM base stations are not assumed to be temporally aligned, a mobile terminal may not have prior knowledge of the current position within the 51-frame structure of the beacon carrier during initial attach to a base station. Furthermore, during initial attach a

mobile terminal may also need to correct for carrier frequency offsets (mismatches between local and counterpart RF oscillators) before beginning to receive traffic and control data on the beacon carrier.

[47] GSM protocols thus designate an FCCH-based multiframe boundary detection scheme, in which a mobile terminal may detect FCCH bursts allocated in a predefined pattern on the BCCH in order to identify both frame and multiframe boundaries as well as correct for frequency offsets. Accordingly, the 51-frame multiframe BCCH structure may contain 5 FCCH bursts, which a mobile terminal may detect and, via comparing the relative positions of the detected FCCH bursts, identify the multiframe boundaries and thus obtain timing synchronization with the beacon carrier. Depending on radio conditions, such FCCH-based multiframe boundary detection may take several multiframes, during which time a mobile terminal may receive each FCCH burst and subsequently identify the multiframe boundary.

[48] In a conventional measurement approach, a mobile terminal may also employ the received FCCH bursts to estimate downlink signal levels for CC reporting. However, a mobile terminal may not be able to effectively isolate the FCCH bursts from the surrounding noise due to the presence of an unknown frequency offset, which may limit the effectiveness of noise filtering. For example, the initial frequency offsets may be up to 20 ppm, e.g. a [-18, +18] kHz range in the 900 MHz band, which may thus only allow a mobile terminal to apply an 18 kHz low-pass filter in order to avoid inadvertently filtering the desired portion of the received downlink signal (which may have been shifted up to 18 kHz in either direction by the associated frequency offset). Accordingly, a mobile terminal may not be able to apply a narrow enough low-pass filter to effectively remove noise effects. Furthermore, as there may be only 5 FCCH bursts per multiframe, a mobile terminal may have a relatively limited sample size to employ in IQ accumulation.

[49] As opposed to sole reliance on FCCH bursts, mobile terminal 300 may instead rely on both dummy bursts and FCCH bursts for signal level measurement. In addition to the

aforementioned control information, base stations may additionally allocate numerous timeslots of the beacon carrier for traffic channel bursts, which may each contain traffic data intended for certain mobile terminals. In the event of low network load, a base station may not have any traffic data to transmit, and accordingly may transmit a “dummy burst” in the unused timeslots. In certain low load conditions, a single 51-frame multiframe may contain more than 120 dummy bursts, where each dummy burst may contain fixed “mixed bit” sequence. As will be detailed, mobile terminal **300** may exploit the ample presence of such dummy bursts in order to improve signal level measurement.

**[50]** FIG. 6 shows an alternative configuration of mobile terminal **300**, which may include antenna system **302**, RF transceiver **304**, and baseband system **306** including uplink/downlink processing circuit **310** and controller **308** as detailed above. As shown in FIG. 6, uplink/downlink processing circuit **310** may include FCCH/dummy SNR estimation circuit **314**, which as shown in FIG. 7 may include FCCH detection circuit **702**, FCCH SNR estimation circuit **704**, FCCH SNR averaging circuit **706**, SNR combination circuit **708**, dummy detection circuit **710**, false dummy removal circuit **712**, dummy SNR estimation circuit **714**, and dummy SNR averaging circuit **716**. SNR combination circuit **708** may combine an FCCH burst SNR estimate calculated by FCCH detection circuit **702**, FCCH SNR estimation circuit **704**, and FCCH SNR averaging circuit **706** with a dummy burst SNR estimate calculated by dummy detection circuit **710**, false dummy removal circuit **712**, dummy SNR estimation circuit **714**, and dummy SNR averaging circuit **716**. SNR combination circuit **708** may then provide the combined SNR value to controller **308**, which may select a CC reporting value according to the combined SNR value and generate a CC report for transmission via uplink/downlink processing circuit **310**, RF transceiver **304**, and antenna system **302**.

**[51]** In order to utilize the dummy bursts for SNR estimation, FCCH/dummy SNR estimation circuit **314** may need to detect each dummy burst within the received beacon

carrier and subsequently an obtain SNR estimate with the detected dummy bursts. However, reliable dummy burst detection may be complicated by the aforementioned unknown initial frequency offset, as uncorrected initial frequency offsets may render traditional cross-correlation calculations unsuitable for detection purposes. Consequently, FCCH/dummy SNR estimation circuit **314** may address these issues by utilizing a lagged differential correlation in order to effectively detect dummy bursts in the face of any existing frequency offsets. Additionally, FCCH/dummy SNR estimation circuit **314** may utilize FCCH detection results to identify the position of FCCH bursts within the beacon carrier, which FCCH/dummy SNR estimation circuit **314** may then utilize to identify the possible positions of dummy bursts within the 51-frame multiframe. The FCCH/dummy SNR estimation circuit **314** may thus be able to accurately identify dummy bursts within the beacon carrier and subsequently apply the identified dummy bursts in SNR estimation.

**[52]** Similar to as detailed above regarding duplicate burst SNR estimation circuit **312**, FCCH/dummy SNR estimation circuit **314** may receive baseband IQ samples previously received and processed by antenna system **302**, RF transceiver **304/RX**, and any required preprocessing circuitry of uplink/downlink processing circuit **310**. The received signal  $x(n)$  may be expressed as

$$x(n) = \sum_{l=0}^L h(l)s(n-l)e^{-j2\pi(n-l)T_s\Delta f + \theta} + w(n), \quad n = 0, 1, \dots, N-1 \quad (11)$$

where  $h(k), k = 0, 1, \dots, L-1$  is the multipath fading profile with  $L$  taps,  $s(n), n = 0, 1, \dots, N-1$  is the GMSK-modulated IQ samples of the dummy burst,  $T_s$  is the symbol duration ( $\frac{48}{13e6} \approx 3.69 \mu s$ ),  $\Delta f$  is the frequency offset,  $\theta$  is the phase offset, and  $w(n)$  gives the  $n$ -th noise sample.

**[53]** As previously indicated, traditional cross-correlation-based detection may not be sufficient to detect the dummy bursts due to the uncorrected frequency offset. As can be seen in Equation (11), the presence of the frequency offset term  $\Delta f$  in the complex exponential term may result in a phase offset that varies according to the sample index  $n$ . Accordingly, the varying phase offsets in each sample of  $x(n)$  may prevent the FCCH/dummy burst SNR detection circuit **314** from applying a straightforward cross-correlation between  $x(n)$  and the fixed sequence  $s(n)$  to detect  $s(n)$ .

**[54]** In order to address this deficiency, dummy detection circuit **710** may employ a differential correlation operation in order to effectively detect dummy bursts. Dummy detection circuit **710** may obtain a differential product dummy burst  $d(n)$  as

$$d(n) = s^*(n) \cdot s(n - M), \quad n = 0, 1, \dots, N - 1 \quad (12)$$

where  $M$  is an arbitrary lag value, thus producing differential product dummy burst  $d(n)$  as the element-wise product of the complex conjugate of dummy  $s(n)$  and lagged dummy burst  $s(n - M)$ . As the dummy burst data is predefined, the calculation of  $d(n)$  may be performed offline and subsequently preprogrammed into dummy detection circuit **710**.

**[55]** Upon receiving  $x(n)$  from RF transceiver **304/RX**, dummy detection circuit **710** may calculate the differential correlation  $c(n)$  between  $x(n)$  and  $s(n)$  as

$$\begin{aligned} c(n) &= \frac{1}{N} \sum_{k=0}^{N-1} [x(n+k) \cdot x^*(n+k-M)] \cdot d(k) \\ &= \frac{1}{N} \sum_{k=0}^{N-1} \left[ \sum_{l=0}^L \|h(l)\|^2 \cdot d^*(n+k-l) e^{-j2\pi M T_s \Delta f} + \tilde{w}(n) \right] \cdot d(k) \\ &= \frac{1}{N} \sum_{k=0}^{N-1} \sum_{l=0}^L \|h(l)\|^2 \cdot d^*(n+k-l) \cdot d(k) e^{-j2\pi M T_s \Delta f} + \tilde{w}(n) \end{aligned} \quad (13)$$

**[56]** When  $n = 0$ , i.e. no timing difference, differential correlation  $c(n)$  yields

$$\begin{aligned} c(0) &= \frac{1}{N} \sum_{k=0}^{N-1} \|h(0)\|^2 \cdot \|d(k)\|^2 e^{-2\pi M T_s \Delta f} + \tilde{w}(0) \\ &= \|h(0)\|^2 \cdot A^2 e^{-2\pi M T_s \Delta f} + \tilde{w}(0) \end{aligned} \quad (14)$$

where  $A = \|d(n)\|$  for all  $n$  values and  $\tilde{w}(n)$  is reduced with increasing of correlation length  $N$ .

**[57]** As can be seen in Equation (13), differential correlation  $c(n)$  may contain frequency offset  $\Delta f$  as a complex exponential term that is constant across all samples of  $c(n)$ . Dummy detection circuit **710** may thus evaluate  $c(n)$  for local peaks, which may accordingly indicate the presence of dummy sequence  $s(n)$  at a given local peak sample index  $n$ . Accordingly, dummy detection circuit **710** may detect dummy bursts within  $x(n)$  by calculating  $c(n)$  for  $n = 0, 1, \dots, N - 1$  and comparing each  $c(n)$  to a detection threshold and identifying dummy burst positions as the sample indices  $n$  that produce a  $c(n)$  that satisfies the detection threshold, where the detection threshold may be preconfigured according to a desired detection sensitivity. Dummy detection circuit **710** may additionally detect local peaks in the even that multiple differential correlation samples  $c(n)$  that occur in close proximity satisfy the detection threshold. Dummy detection circuit **710** may thus produce a set of dummy burst positions that each indicate the detected location of a dummy burst within  $x(n)$  and subsequently provide the detected dummy burst positions to false dummy removal circuit **712**.

**[58]** FCCH detection circuit **702** may perform FCCH detection in order to detect FCCH bursts within  $x(n)$ . As previously indicated, mobile terminal **300** may not have prior knowledge of the 51-frame multiframe timing position, and accordingly may need to perform a sliding cross-correlation on  $x(n)$  to detect the FCCH bursts using predefined information

for the FCCH bursts. As shown in FIG. 7, FCCH detection circuit **702** may provide dummy detection circuit **710** with preliminary results for the detected FCCH positions (i.e. prior to obtaining the final 51-frame multiframe boundary), which dummy detection circuit **710** may apply to refine the detected dummy burst positions supplied to false dummy removal circuit **710**.

[59] While the overall process of FCCH-based multiframe boundary detection may take several multiframe to obtain reliable multiframe boundary results, FCCH detection circuit **702** may detect multiple FCCH bursts during each multiframe prior to the final determination of the multiframe boundary. FCCH detection circuit **702** may then provide dummy detection circuit **710** with the detected FCCH burst positions, which dummy detection circuit **710** may utilize in order to refine the detected dummy burst positions based on the relative position between the detected FCCH burst positions and the detected dummy burst positions (i.e. the sample indices containing local peaks that satisfy the dummy detection threshold). As each burst of the beacon carrier is slot-aligned in time, each real dummy burst must fall at an integer multiple of the GSM burst period from an FCCH burst. Accordingly, dummy detection circuit **710** may compare each of the detected dummy burst positions to the detected FCCH burst positions provided by FCCH detection circuit **702** to identify any of the detected dummy burst positions that do not fall at an integer multiple of the GSM burst period (156.25 symbols) from the reported FCCH burst positions, i.e. may identify any false dummy burst positions. Dummy detection circuit **710** may subsequently discard any detected dummy burst positions that do not obey slot-alignment with the detected FCCH burst positions and only select detected dummy burst positions that are slot-aligned to provide to false dummy removal circuit **712**.

[60] FCCH detection circuit **702** may complete multiframe boundary detection and provide the detected FCCH burst positions to FCCH SNR estimation circuit **704**, which may subsequently perform SNR estimation on  $x(n)$  with the detected FCCH burst positions.

Although not explicitly shown in FIG. 7, FCCH detection circuit **702** may additionally report the multiframe boundary to controller **308**, which may employ the multiframe boundary as synchronization information for further communication with the base station.

[61] FCCH detection circuit **702** may additionally provide the multiframe boundary to false dummy removal circuit **712**, which as previously detailed may receive the refined dummy burst positions from dummy detection circuit **710**. False dummy removal circuit **712** may then perform another round of dummy burst removal based on the multiframe boundary provided by FCCH detection circuit **702**. In addition to the aforementioned slot-alignment constraint, the dummy bursts on the beacon carrier must additionally obey certain scheduling pattern constraints imposed by the 51-frame multiframe structure. Accordingly, dummy bursts may only be able to occupy specific timeslots within the 51-frame multiframe (which may be predefined according to the scheduling configuration), and accordingly false dummy removal circuit **712** may identify and remove any further false dummy burst positions from the refined dummy burst positions provided by dummy detection circuit **710**. False dummy removal circuit **712** may thus identify the final dummy burst positions and provide the final dummy burst positions to dummy SNR estimation circuit **714**.

[62] FCCH SNR estimation circuit **704** and dummy SNR estimation circuit **714** may subsequently perform SNR estimation on  $x(n)$  using the FCCH and dummy burst positions respectively provided by FCCH detection circuit **702** and false dummy removal circuit **712**, for which any number of established SNR estimation techniques may be employed and may include IQ accumulation, signal and noise power estimation, and subsequent SNR calculation. In particular for the case of dummy SNR estimation circuit **714**, dummy SNR estimation circuit **714** may employ an SNR estimation process as detailed above for duplicate burst SNR estimation circuit **312** with dummy bursts utilized as an analog to duplicate bursts as detailed above. Dummy SNR estimation circuit **714** may thus include a signal power estimation circuit, total power estimation circuit, and SNR estimation circuit configured to perform SNR

estimation based on dummy bursts analogous to signal power estimation circuit **402**, total power estimation circuit **404**, and SNR estimation circuit **406** in the case of duplicate bursts.

[63] FCCH SNR estimation circuit **704** and dummy SNR estimation circuit **714** may provide the resulting SNR estimates to FCCH SNR averaging circuit **706** and dummy SNR averaging circuit **716**, respectively, which may average the received SNR estimates in order to refine the SNR estimates to FCCH SNR averaging circuit **706** and dummy SNR averaging circuit **716** may then provide the resulting averaged SNR estimates to SNR combination circuit **708**, which may perform a weighted combination of the averaged FCCH burst SNR estimate and the averaged dummy burst SNR estimate to obtain a combined SNR estimate. For example, SNR combination circuit **708** may combine the averaged FCCH and averaged dummy SNR estimations based on the number of detected dummy bursts and the number of the detected FCCH bursts, such as by calculating the combined SNR as

$$SNR_C = \frac{K \cdot N_{dummy} \cdot SNR_{dummy} + N_{fch} \cdot SNR_{fch}}{K \cdot N_{dummy} + N_{fch}} \quad (15)$$

where  $N_{dummy}$  is the number of detected dummy bursts,  $SNR_{dummy}$  is the averaged dummy burst SNR,  $N_{fch}$  is the number of detected FCCH bursts,  $SNR_{fch}$  is the averaged FCCH burst SNR, and  $K$  is a correction factor (e.g. a real number between 0 and 1).

[64] SNR combination circuit **708** may thus calculate the combined SNR estimation and provide the combined SNR estimate to controller **308**, which may determine a CC reporting value according to the combined SNR estimate and subsequently generate a CC report according to the determined CC reporting value. Controller **308** may then transmit the CC report to the base station via uplink/downlink processing circuit **310**, RF transceiver **304**, and antenna system **302**, thus prompting the base station to adopt a repetition count for the various logical channels of mobile terminal **300** according to the CC reporting value.

[65] Accordingly, through use of the differential correlation calculation by dummy detection circuit **710** according to Equation (13), FCCH/dummy SNR estimation circuit **314** may be able to accurately detect dummy burst positions (in spite of high frequency offsets by reliance of the differential product dummy burst  $d(n)$ ) and subsequently estimate SNR values based on the detected dummy bursts for combination with FCCH-based SNR estimates. As there may exist 120 or more dummy bursts in a given 51-frame multiframe, FCCH/dummy SNR estimation circuit **314** may be able to obtain highly reliable dummy burst SNR estimates, which when combined with the existing FCCH-based SNR estimates may yield robust SNR estimates that are well-suited for CC reporting.

[66] Furthermore, as mobile terminal **300** may already need to employ sliding detection on the beacon carrier to detect FCCH bursts, the FCCH/dummy burst SNR estimation procedure may not require extra use of RF transceiver **304** (as RF transceiver **304** will need to be active to constantly receive and provide beacon carrier samples for sliding detection).

[67] Accordingly, mobile terminal **300** may be able to employ one or both (by including both duplicate burst SNR estimation **312** and FCCH/dummy SNR estimation circuit **314** in baseband modem **306**) of duplicate burst SNR and FCCH/dummy burst SNR estimation in order to obtain SNR estimates. While an EC-GSM context with blind repetition and CC reporting has been referenced above, the downlink signal level and SNR estimation procedures detailed herein are not limited to such. Accordingly, the application of the signal level estimation techniques included herein in any context are within the scope of this disclosure.

[68] FIG. 8 shows method **800** of performing radio measurements. As shown in FIG. 8, method **800** may include processing beacon carrier data to establish synchronization with a beacon carrier based on one or more synchronization bursts included in the beacon carrier data (**810**), identifying one or more dummy bursts included the beacon carrier data (**820**), and determining a downlink signal level measurement using the one or more dummy bursts (**830**).

[69] FIG. 9 shows method **900** of performing radio measurements. As shown in FIG. 9, method **900** may include performing a synchronization burst detection operation on beacon carrier data (**910**), identifying one or more dummy bursts in the beacon carrier data during the frequency synchronization burst detection operation (**920**), and determining a downlink signal level measurement with the one or more dummy bursts (**930**).

[70] FIG. 10 shows method **1000** of performing radio measurements. As shown in FIG. 10, method **1000** may include receiving a plurality of duplicate data bursts (**1010**), accumulating a first subset of the plurality of duplicate data bursts and a second subset of the plurality of duplicate data burst to obtain a first accumulated data burst and a second accumulated data burst (**1020**), determining a signal level measurement as a correlation between the first accumulated data burst and the second accumulated data burst (**1030**).

[71] In one or more further exemplary aspects of the disclosure, one or more of the features described above in reference to FIGS. 1-7 may be further incorporated into method **800**, **900**, and/or **1000**. In particular, method **800**, **900**, and/or **1000** may be configured to perform further and/or alternate processes as detailed regarding mobile terminal **300**.

[72] The terms “user equipment”, “UE”, “mobile terminal”, “user terminal”, etc., may apply to any wireless communication device, including cellular phones, tablets, laptops, personal computers, wearables, multimedia playback devices, consumer/home/office/commercial appliances, vehicles, etc., and any number of additional electronic devices capable of wireless communications.

[73] While the above descriptions and connected figures may depict electronic device components as separate elements, skilled persons will appreciate the various possibilities to combine or integrate discrete elements into a single element. Such may include combining two or more circuits for form a single circuit, mounting two or more circuits onto a common chip or chassis to form an integrated element, executing discrete software components on a common processor core, etc. Conversely, skilled persons will recognize the possibility to

separate a single element into two or more discrete elements, such as splitting a single circuit into two or more separate circuits, separating a chip or chassis into discrete elements originally provided thereon, separating a software component into two or more sections and executing each on a separate processor core, etc.

[74] It is appreciated that implementations of methods detailed herein are demonstrative in nature, and are thus understood as capable of being implemented in a corresponding device. Likewise, it is appreciated that implementations of devices detailed herein are understood as capable of being implemented as a corresponding method. It is thus understood that a device corresponding to a method detailed herein may include a one or more components configured to perform each aspect of the related method.

[75] The following examples pertain to further aspects of this disclosure:

[76] Example 1 is a method of performing radio measurements, the method including processing beacon carrier data to establish synchronization with a beacon carrier based on one or more synchronization bursts included in the beacon carrier data, identifying one or more dummy bursts included the beacon carrier data, and determining a downlink signal level measurement using the one or more dummy bursts.

[77] In Example 2, the subject matter of Example 1 can optionally include wherein processing the beacon carrier data to establish synchronization with the beacon carrier based on the one or more synchronization bursts included the beacon carrier data includes detecting the one or more synchronization bursts included in the beacon carrier data to establish timing synchronization with the beacon carrier.

[78] In Example 3, the subject matter of Example 2 can optionally include wherein the one or more dummy bursts are multiplexed into the beacon carrier data with the one or more synchronization bursts.

[79] In Example 4, the subject matter of Example 2 or 3 can optionally include wherein detecting the one or more synchronization bursts included within the beacon carrier data to

establish timing synchronization with the beacon carrier includes identifying a multiframe boundary of the beacon carrier based on a relative time positioning of each of the one or more synchronization bursts in the beacon carrier data.

**[80]** In Example 5, the subject matter of any one of Examples 1 to 4 can optionally include wherein identifying the one or more dummy bursts included the beacon carrier data includes calculating a differential correlation between a predefined reference dummy burst sequence and the beacon carrier data, and identifying the one or dummy bursts based on one or more peaks in the differential correlation.

**[81]** In Example 6, the subject matter of any one of Examples 1 to 5 can optionally include wherein determining the signal level measurement using the one or more dummy bursts includes estimating a first signal-to-noise ratio (SNR) from the one or more dummy bursts.

**[82]** In Example 7, the subject matter of Example 6 can optionally include wherein determining the signal level measurement using the one or more dummy bursts further includes estimating a second SNR from the one or more synchronization bursts, and combining first SNR and the second SNR to obtain the signal level measurement.

**[83]** In Example 8, the subject matter of Example 6 can optionally include wherein the first SNR is the signal level measurement.

**[84]** In Example 9, the subject matter of any one of Examples 1 to 8 can optionally include wherein the signal level measurement is a signal-to-noise ratio (SNR).

**[85]** In Example 10, the subject matter of any one of Examples 1 to 9 can optionally include wherein the beacon carrier is a Broadcast Control Channel (BCCH) carrier of a Global System for Mobile Communications (GSM) cell and the one or more synchronization burst include one or more Frequency Correction Channel (FCCH) bursts.

**[86]** In Example 11, the subject matter of any one of Examples 1 to 10 can optionally further include receiving the beacon carrier data prior to establishing synchronization with the beacon carrier.

**[87]** In Example 12, the subject matter of any one of Examples 1 to 11 can optionally include wherein identifying the one or more dummy bursts included in the beacon carrier data includes identifying the one or more dummy bursts included in the beacon carrier data during processing of the beacon carrier data to establish synchronization with the beacon carrier.

**[88]** In Example 13, the subject matter of any one of Examples 1 to 12 can optionally include wherein identifying the one or more dummy bursts included in the beacon carrier data includes identifying the one or more dummy bursts included in the beacon carrier data prior to establishing synchronization with the beacon carrier.

**[89]** In Example 14, the subject matter of any one of Examples 1 to 13 can optionally include wherein identifying the one or more dummy bursts included in the beacon carrier data includes identifying one or more potential dummy bursts the beacon carrier data, detecting a first synchronization burst of the one or more synchronization bursts, and selecting the one or more dummy bursts from the one or more potential dummy bursts based on a timing position of the first synchronization burst within the beacon carrier data.

**[90]** In Example 15, the subject matter of Example 14 can optionally include wherein selecting the one or more dummy bursts from the one or more potential dummy bursts based on the timing position of the first synchronization burst within the beacon carrier data includes identifying one or more of the one or more potential dummy bursts that approximately occur an integer multiple of a predefined time period from the timing position of the synchronization burst as the one or more dummy bursts.

**[91]** In Example 16, the subject matter of Example 15 can optionally include wherein selecting the one or more dummy bursts from the one or more potential dummy bursts based on the timing position of the first synchronization burst within the beacon carrier data

includes separating the one or more potential dummy bursts into one or more first dummy bursts that approximately occur an integer multiple of a predefined time period from the timing position of the synchronization burst and one or more second dummy bursts that do not approximately occur an integer multiple of a predefined time period from the timing position of the synchronization burst, and selecting the one or more first dummy bursts as the one or more dummy bursts.

**[92]** In Example 17, the subject matter of any one of Examples 1 to 16 can optionally further include receiving the beacon carrier data from a base station as part of an initial attach procedure with the base station.

**[93]** In Example 18, the subject matter of any one of Examples 1 to 17 can optionally further include generating a measurement report that indicates the signal level measurement, and transmitting the measurement report to a radio access network node.

**[94]** In Example 19, the subject matter of Example 18 can optionally include wherein the measurement report is a Coverage Class (CC) report.

**[95]** In Example 20, the subject matter of Example 19 can optionally further include receiving a plurality of duplicate data bursts, wherein the number of duplicate data bursts of the plurality of duplicate data bursts is dependent on the signal level measurement indicated in the measurement report.

**[96]** In Example 21, the subject matter of Example 20 can optionally include wherein receiving the plurality of duplicate data bursts includes receiving the plurality of duplicate data bursts as part of a blind repetition scheme.

**[97]** In Example 22, the subject matter of Example 21 can optionally include wherein the blind repetition scheme is an Extended Coverage Global System for Mobile Communications (EC-GSM) blind repetition scheme.

**[98]** Example 23 is a mobile terminal device configured to perform the method of any one of Examples 1 to 22.

**[99]** Example 24 is a baseband modem configured to perform the method of any one of Examples 1 to 22.

**[100]** Example 25 is a non-transitory computer readable medium storing instructions that when executed by a processor direct the processor to perform the method of any one of Examples 1 to 23.

**[101]** Example 26 is a communication circuit arrangement including a synchronization burst detection circuit configured to process beacon carrier data to establish synchronization with a beacon carrier based on one or more synchronization bursts included in the beacon carrier data, a dummy burst detection circuit configured to identify one or more dummy bursts included in the beacon carrier data, and a signal measurement circuit configured to determine a signal level measurement using the one or more dummy bursts.

**[102]** In Example 27, the subject matter of Example 26 can optionally include wherein the synchronization burst detection circuit is configured to process the beacon carrier data to establish synchronization with the beacon carrier based on the one or more synchronization bursts included in the beacon carrier data by detecting the one or more synchronization bursts included in the beacon carrier data to establish timing synchronization with the beacon carrier.

**[103]** In Example 28, the subject matter of Example 26 or 27 can optionally include wherein the one or more dummy bursts are multiplexed into the beacon carrier data with the one or more synchronization bursts.

**[104]** In Example 29, the subject matter of any one of Examples 26 to 28 can optionally include wherein the synchronization burst detection circuit is configured to detect the one or more synchronization bursts included in the beacon carrier data to establish timing synchronization with the beacon carrier by identifying a multiframe boundary of the beacon carrier based on a relative time positioning of each of the one or more synchronization bursts in the beacon carrier data.

**[105]** In Example 30, the subject matter of any one of Examples 26 to 29 can optionally include wherein identifying the one or more dummy bursts included in the beacon carrier data includes calculating a differential correlation between a predefined reference dummy bursts sequence and the beacon carrier data, and identifying the one or more dummy bursts based on one or more peaks in the differential correlation.

**[106]** In Example 31, the subject matter of any one of Examples 26 to 30 can optionally include wherein the signal measurement circuit is configured to determine the signal level measurement using the one or more dummy bursts by estimating a first signal-to-noise ratio (SNR) from the one or more dummy bursts.

**[107]** In Example 32, the subject matter of Example 31 can optionally include wherein the signal measurement circuit is further configured to determine the signal level measurement using the one or more dummy bursts by estimating a second SNR from the one or more synchronization bursts, and combining first SNR and the second SNR to obtain the signal level measurement.

**[108]** In Example 33, the subject matter of Example 31 can optionally include wherein the first SNR is the signal level measurement.

**[109]** In Example 34, the subject matter of any one of Examples 26 to 33 can optionally include wherein the signal level measurement is a signal-to-noise ratio (SNR).

**[110]** In Example 35, the subject matter of any one of Examples 26 to 34 can optionally include wherein the beacon carrier is a Broadcast Control Channel (BCCH) carrier of a Global System for Mobile Communications (GSM) cell and the one or more synchronization burst include one or more Frequency Correction Channel (FCCH) bursts.

**[111]** In Example 36, the subject matter of any one of Examples 26 to 35 can optionally further include a receiver circuit configured to receive the beacon carrier data prior to establishing synchronization with the beacon carrier.

**[112]** In Example 37, the subject matter of any one of Examples 26 to 36 can optionally include wherein the dummy burst detection circuit is configured to identify the one or more dummy bursts included in the beacon carrier data while the synchronization burst detection circuit processes the beacon carrier data to establish synchronization with the beacon carrier.

**[113]** In Example 38, the subject matter of any one of Examples 26 to 37 can optionally include wherein the dummy burst detection circuit is configured to identify the one or more dummy bursts included in the beacon carrier data by identifying the one or more dummy bursts included in the beacon carrier data before the synchronization burst detection circuit establishes synchronization with the beacon carrier.

**[114]** In Example 39, the subject matter of any one of Examples 26 to 38 can optionally include wherein the dummy burst detection circuit is configured to identify the one or more dummy bursts included in the beacon carrier data by identifying one or more potential dummy bursts the beacon carrier data, detecting a first synchronization burst of the one or more synchronization bursts, and selecting the one or more dummy bursts from the one or more potential dummy bursts based on a timing position of the first synchronization burst within the beacon carrier data.

**[115]** In Example 40, the subject matter of Example 39 can optionally include wherein the dummy burst detection circuit is configured to select the one or more dummy bursts from the one or more potential dummy bursts based on the timing position of the first synchronization burst within the beacon carrier data by identifying one or more of the one or more potential dummy bursts that approximately occur an integer multiple of a predefined time period from the timing position of the synchronization burst as the one or more dummy bursts.

**[116]** In Example 41, the subject matter of Example 40 can optionally include wherein the dummy burst detection circuit is configured to select the one or more dummy bursts from the one or more potential dummy bursts based on the timing position of the first synchronization burst within the beacon carrier data by separating the one or more potential dummy bursts into

one or more first dummy bursts that approximately occur at an integer multiple of a predefined time period from the timing position of the synchronization burst and one or more second dummy bursts that do not approximately occur an integer multiple of a predefined time period from the timing position of the synchronization burst, and selecting the one or more first dummy bursts as the one or more dummy bursts.

**[117]** In Example 42, the subject matter of any one of Examples 26 to 35 can optionally further include a receiver circuit configured to receive the beacon carrier data from a radio access node as part of an initial attach procedure with the radio access node.

**[118]** In Example 43, the subject matter of any one of Examples 26 to 41 can optionally further include a control circuit configured to generate a measurement report that indicates the signal level measurement, and a transmitter circuit configured to transmit the measurement report to a radio access node.

**[119]** In Example 44, the subject matter of Example 43 can optionally include wherein the measurement report is a Coverage Class (CC) report.

**[120]** In Example 45, the subject matter of Example 44 can optionally further include a receiver circuit configured to receive a plurality of duplicate data bursts, wherein the number of duplicate data bursts of the plurality of duplicate data bursts is dependent on the signal level measurement indicated in the measurement report.

**[121]** In Example 46, the subject matter of Example 45 can optionally include wherein the receiver circuit is configured to receive the plurality of duplicate data bursts as part of a blind repetition scheme.

**[122]** In Example 47, the subject matter of Example 46 can optionally include wherein the blind repetition scheme is an Extended Coverage Global System for Mobile Communications (EC-GSM) blind repetition scheme.

**[123]** Example 48 is a mobile terminal device including the communication circuit arrangement of any one of Examples 26 to 47.

**[124]** Example 49 is a baseband modem including the communication circuit arrangement of any one of Examples 26 to 47.

**[125]** Example 50 is a method of performing radio measurements, the method including performing a synchronization burst detection operation on beacon carrier data, identifying one or more dummy bursts in the beacon carrier data during the frequency synchronization burst detection operation, and determining a downlink signal level measurement with the one or more dummy bursts.

**[126]** Example 51 is a mobile terminal device configured to perform the method of Example 50.

**[127]** Example 52 is a baseband modem configured to perform the method of Example 50.

**[128]** Example 53 is a non-transitory computer readable medium storing instructions that when executed by a processor direct the processor to perform the method of Example 50.

**[129]** Example 54 is a method of performing radio measurements, the method including receiving a plurality of duplicate data bursts, accumulating a first subset of the plurality of duplicate data bursts and a second subset of the plurality of duplicate data burst to obtain a first accumulated data burst and a second accumulated data burst, determining a signal level measurement as a correlation between the first accumulated data burst and the second accumulated data burst.

**[130]** In Example 55, the subject matter of Example 54 can optionally include wherein accumulating the first subset of the plurality of duplicate data bursts and the second subset of the plurality of duplicate data burst to obtain the first accumulated data burst and the second accumulated data burst includes accumulating samples of each duplicate data burst of the first subset of the plurality of duplicate data bursts to obtain the first accumulated data burst, and accumulating samples of each duplicate data burst of the second subset of the plurality of duplicate data bursts to obtain the second accumulated data burst.

**[131]** In Example 56, the subject matter of Example 54 or 55 can optionally further include processing the first subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the first subset of the plurality of duplicate bursts respective to each other, and processing the second subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the second subset of the plurality of duplicate data bursts respective to each other.

**[132]** In Example 57, the subject matter of Example 56 can optionally include wherein processing the first subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the first subset of the plurality of duplicate bursts respective to each other includes estimating a phase of a first duplicate data burst of the first subset of the plurality of duplicate data bursts, phase aligning each duplicate data burst of the first subset of the plurality of duplicate data bursts according to the phase.

**[133]** In Example 58, the subject matter of Example 56 can optionally include wherein processing the first subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the first subset of the plurality of duplicate bursts respective to each other includes selecting a target duplicate data burst from the first subset of the plurality of duplicate data bursts, and phase-aligning each duplicate data burst of the first subset of the plurality of duplicate data bursts with the target duplicate data burst.

**[134]** In Example 59, the subject matter of Example 56 can optionally include wherein accumulating the first subset of the plurality of duplicate data bursts and the second subset of the plurality of duplicate data burst to obtain the first accumulated data burst and the second accumulated data burst includes accumulating the phase-aligned first subset of the plurality of duplicate data bursts and the phase-aligned second subset of the plurality of duplicate data bursts to obtain the first accumulated data burst and the second accumulated data burst.

**[135]** In Example 60, the subject matter of any one of Examples 54 to 59 can optionally include wherein determining the signal level measurement as the correlation between the first

accumulated data burst and the second accumulated data burst includes calculating the signal level measurement as a zero-lag cross-correlation between the first accumulated data burst and the second accumulated data burst.

**[136]** In Example 61, the subject matter of Example 60 can optionally include wherein the signal level measurement is a downlink signal power measurement, the method further including generating a noise power measurement, and estimating a Signal-to-Noise ratio (SNR) from the downlink signal power measurement and the noise power measurement.

**[137]** In Example 62, the subject matter of Example 61 can optionally further include generating a measurement report indicating the SNR, and transmitting the SNR to a network access node.

**[138]** In Example 63, the subject matter of any one of Examples 54 to 62 can optionally include wherein receiving the plurality of duplicate data bursts includes receiving the first subset of the plurality of duplicate data bursts prior to receiving the second subset of the plurality of duplicate data bursts.

**[139]** In Example 64, the subject matter of Example 54 can optionally include wherein receiving the plurality of duplicate data bursts includes receiving the plurality of duplicate data bursts according to a first repetition count of a transmission repetition scheme, the method further including reporting the signal level measurement as a transmission repetition report for the transmission repetition scheme, and receiving a second plurality of duplicate data bursts according to a second repetition count depending on the signal level measurement reported in the transmission repetition report.

**[140]** In Example 65, the subject matter of Example 64 can optionally include wherein the transmission repetition report is a Coverage Class (CC) report for an Extended Coverage Global System for Mobile Communications (EC-GSM) radio access technology.

**[141]** Example 66 is a mobile terminal device configured to perform the method of any one of Examples 54 to 64.

**[142]** Example 67 is a baseband modem configured to perform the method of any one of Examples 54 to 64.

**[143]** Example 68 is a non-transitory computer readable medium storing instructions that when executed by a processor direct the processor to perform the method of any one of Examples 54 to 64.

**[144]** Example 69 is a communication circuit arrangement including a signal level estimation circuit configured to accumulate a first subset of a plurality of duplicate data bursts and a second subset of the plurality of duplicate data bursts to obtain a first accumulated data burst and a second accumulated data burst, and determine a signal level measurement as a correlation between the first accumulated data burst and the second accumulated data burst.

**[145]** In Example 70, the subject matter of Example 69 can optionally further include a radio receiver circuit configured to receive the plurality of duplicate data bursts.

**[146]** In Example 71, the subject matter of Example 69 or 70 can optionally include wherein the signal level estimation circuit is configured to accumulate the first subset of the plurality of duplicate data bursts and the second subset of the plurality of duplicate data burst to obtain the first accumulated data burst and the second accumulated data burst by accumulating samples of each duplicate data burst of the first subset of the plurality of duplicate data bursts to obtain the first accumulated data burst, and accumulating samples of each duplicate data burst of the second subset of the plurality of duplicate data bursts to obtain the second accumulated data burst.

**[147]** In Example 72, the subject matter of any one of Examples 69 to 71 can optionally further include a preprocessing circuit configured to provide the samples of each of the plurality of duplicate data bursts to the signal level estimation circuit.

**[148]** In Example 73, the subject matter of any one of Examples 69 to 72 can optionally include wherein the signal level estimation circuit is further configured to process the first subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the

first subset of the plurality of duplicate bursts respective to each other, and process the second subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the second subset of the plurality of duplicate data bursts respective to each other.

**[149]** In Example 74, the subject matter of Example 73 can optionally include wherein the signal level estimation circuit is configured to process the first subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the first subset of the plurality of duplicate bursts respective to each other by estimating a phase of a first duplicate data burst of the first subset of the plurality of duplicate data bursts, phase aligning each duplicate data burst of the first subset of the plurality of duplicate data bursts according to the phase.

**[150]** In Example 75, the subject matter of Example 73 can optionally include wherein the signal level estimation circuit is configured to process the first subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the first subset of the plurality of duplicate bursts respective to each other by selecting a target duplicate data burst from the first subset of the plurality of duplicate data bursts, and phase-aligning each duplicate data burst of the first subset of the plurality of duplicate data bursts with the target duplicate data burst.

**[151]** In Example 76, the subject matter of Example 73 can optionally include wherein the communication circuit arrangement is configured to accumulate the first subset of the plurality of duplicate data bursts and the second subset of the plurality of duplicate data burst to obtain the first accumulated data burst and the second accumulated data burst by accumulating the phase-aligned first subset of the plurality of duplicate data bursts and the phase-aligned second subset of the plurality of duplicate data bursts to obtain the first accumulated data burst and the second accumulated data burst.

**[152]** In Example 77, the subject matter of any one of Examples 69 to 76 can optionally include wherein the signal level estimation circuit is configured to determine the signal level measurement as the correlation between the first accumulated data burst and the second

accumulated data burst by calculating the signal level measurement as a zero-lag cross-correlation between the first accumulated data burst and the second accumulated data burst.

**[153]** In Example 78, the subject matter of Example 77 can optionally include wherein the signal level measurement is a downlink signal power measurement, communication circuit arrangement further including a signal-to-noise ratio (SNR) estimation circuit configured to generate a noise power measurement, and estimate an SNR with the downlink signal power measurement and the noise power measurement.

**[154]** In Example 79, the subject matter of Example 78 can optionally further include a control circuit configured to generate a measurement report indicating the SNR, and a transmitter circuit configured to transmit the SNR to a network access node.

**[155]** In Example 80, the subject matter of any one of Examples 69 to 79 can optionally further include a receiver circuit configured to receive the first subset of the plurality of duplicate data bursts prior to receiving the second subset of the plurality of duplicate data bursts.

**[156]** In Example 81, the subject matter of any one of Examples 69 to 79 can optionally further include a receiver circuit configured to receive the plurality of duplicate data bursts according a first repetition count of a transmission repetition scheme, a control circuit configured to report the signal level measurement as a transmission repetition report for the transmission repetition scheme, and a receiver circuit configured to receive a second plurality of duplicate data bursts according to a second repetition count depending on the signal level measurement reported in the transmission repetition report.

**[157]** In Example 82, the subject matter of Example 81 can optionally include wherein the transmission repetition report is a Coverage Class (CC) report for an Extended Coverage Global System for Mobile Communications (EC-GSM) radio access technology.

**[158]** Example 83 is a mobile terminal device including the communication circuit arrangement of any one of Examples 69 to 82.

**[159]** Example 84 is a baseband modem including the communication circuit arrangement of any one of Examples 69 to 82.

**[160]** All acronyms defined in the above description additionally hold in all claims included herein.

**[161]** While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

### Claims

What is claimed is:

1. A communication circuit arrangement comprising:
  - a synchronization burst detection circuit configured to process beacon carrier data to establish synchronization with a beacon carrier based on one or more synchronization bursts included in the beacon carrier data;
  - a dummy burst detection circuit configured to identify one or more dummy bursts included in the beacon carrier data; and
  - a signal measurement circuit configured to determine a signal level measurement using the one or more dummy bursts.
2. The communication circuit arrangement of claim 1, wherein the synchronization burst detection circuit is configured to process the beacon carrier data to establish synchronization with the beacon carrier based on the one or more synchronization bursts included in the beacon carrier data by:
  - detecting the one or more synchronization bursts included in the beacon carrier data to establish timing synchronization with the beacon carrier.
3. The communication circuit arrangement of claim 1, wherein the signal measurement circuit is configured to determine the signal level measurement using the one or more dummy bursts by:
  - estimating a first signal-to-noise ratio (SNR) from the one or more dummy bursts.

4. The communication circuit arrangement of claim 3, wherein the signal measurement circuit is further configured to determine the signal level measurement using the one or more dummy bursts by:

estimating a second SNR from the one or more synchronization bursts; and  
combining first SNR and the second SNR to obtain the signal level measurement.

5. The communication circuit arrangement of any one of claims 1 to 4, wherein the beacon carrier is a Broadcast Control Channel (BCCH) carrier of a Global System for Mobile Communications (GSM) cell and the one or more synchronization burst comprise one or more Frequency Correction Channel (FCCH) bursts.

6. The communication circuit arrangement of any one of claims 1 to 4, further comprising a receiver circuit configured to:

receive the beacon carrier data prior to establishing synchronization with the beacon carrier.

7. The communication circuit arrangement of any one of claims 1 to 4, wherein the dummy burst detection circuit is configured to identify the one or more dummy bursts included in the beacon carrier data by:

identifying one or more potential dummy bursts the beacon carrier data;  
detecting a first synchronization burst of the one or more synchronization bursts; and  
selecting the one or more dummy bursts from the one or more potential dummy bursts based on a timing position of the first synchronization burst within the beacon carrier data.

8. The communication circuit arrangement of claim 7, wherein the dummy burst detection circuit is configured to select the one or more dummy bursts from the one or more

potential dummy bursts based on the timing position of the first synchronization burst within the beacon carrier data by:

identifying one or more of the one or more potential dummy bursts that approximately occur an integer multiple of a predefined time period from the timing position of the synchronization burst as the one or more dummy bursts.

9. The communication circuit arrangement of claim 1, further comprising a receiver circuit configured to receive a plurality of duplicate data bursts, wherein the number of duplicate data bursts of the plurality of duplicate data bursts is dependent on the signal level measurement indicated in the measurement report.

10. The communication circuit arrangement of claim 9, wherein the receiver circuit is configured to receive the plurality of duplicate data bursts as part of a blind repetition scheme.

11. The communication circuit arrangement of claim 10, wherein the blind repetition scheme is an Extended Coverage Global System for Mobile Communications (EC-GSM) blind repetition scheme.

12. A mobile terminal device comprising the communication circuit arrangement of any one of claims 1 to 4.

13. A communication circuit arrangement comprising:

a signal level estimation circuit configured to:

accumulate a first subset of a plurality of duplicate data bursts and a second subset of the plurality of duplicate data bursts to obtain a first accumulated data burst and a second accumulated data burst; and

determine a signal level measurement as a correlation between the first accumulated data burst and the second accumulated data burst.

14. The communication circuit arrangement of claim 13, wherein the signal level estimation circuit is configured to accumulate the first subset of the plurality of duplicate data bursts and the second subset of the plurality of duplicate data burst to obtain the first accumulated data burst and the second accumulated data burst by:

accumulating samples of each duplicate data burst of the first subset of the plurality of duplicate data bursts to obtain the first accumulated data burst; and

accumulating samples of each duplicate data burst of the second subset of the plurality of duplicate data bursts to obtain the second accumulated data burst.

15. The communication circuit arrangement of claim 13, wherein the signal level estimation circuit is further configured to:

process the first subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the first subset of the plurality of duplicate bursts respective to each other; and

process the second subset of the plurality of duplicate data bursts to phase-align the duplicate data bursts of the second subset of the plurality of duplicate data bursts respective to each other.

16. The communication circuit arrangement of claim 15, wherein the communication circuit arrangement is configured to accumulate the first subset of the plurality of duplicate data bursts and the second subset of the plurality of duplicate data burst to obtain the first accumulated data burst and the second accumulated data burst by:

accumulating the phase-aligned first subset of the plurality of duplicate data bursts and the phase-aligned second subset of the plurality of duplicate data bursts to obtain the first accumulated data burst and the second accumulated data burst.

17. The communication circuit arrangement of any one of claims 13 to 16, wherein the signal level estimation circuit is configured to determine the signal level measurement as the correlation between the first accumulated data burst and the second accumulated data burst by:

calculating the signal level measurement as a zero-lag cross-correlation between the first accumulated data burst and the second accumulated data burst.

18. The communication circuit arrangement of claim 17, wherein the signal level measurement is a downlink signal power measurement, communication circuit arrangement further comprising a signal-to-noise ratio (SNR) estimation circuit configured to:

generate a noise power measurement; and

estimate an SNR with the downlink signal power measurement and the noise power measurement.

19. The communication circuit arrangement of any one of claims 13 to 16, further comprising a receiver circuit configured to receive the first subset of the plurality of duplicate data bursts prior to receiving the second subset of the plurality of duplicate data bursts.

20. The communication circuit arrangement of any one of claims 13 to 16, further comprising:

a receiver circuit configured to receive the plurality of duplicate data bursts according a first repetition count of a transmission repetition scheme;

a control circuit configured to report the signal level measurement as a transmission repetition report for the transmission repetition scheme; and

a receiver circuit configured to receive a second plurality of duplicate data bursts according to a second repetition count depending on the signal level measurement reported in the transmission repetition report.

21. The communication circuit arrangement of claim 20, wherein the transmission repetition report is a Coverage Class (CC) report for an Extended Coverage Global System for Mobile Communications (EC-GSM) radio access technology.

22. A method of performing radio measurements, the method comprising:

processing beacon carrier data to establish synchronization with a beacon carrier based on one or more synchronization bursts included in the beacon carrier data;

identifying one or more dummy bursts included the beacon carrier data; and

determining a downlink signal level measurement using the one or more dummy bursts.

23. A non-transitory computer readable medium storing instructions that when executed by a processor direct the processor to perform the method of claim 22.

24. A method of performing radio measurements, the method comprising:

receiving a plurality of duplicate data bursts;

accumulating a first subset of the plurality of duplicate data bursts and a second subset of the plurality of duplicate data burst to obtain a first accumulated data burst and a second accumulated data burst;

determining a signal level measurement as a correlation between the first accumulated data burst and the second accumulated data burst.

25. A non-transitory computer readable medium storing instructions that when executed by a processor direct the processor to perform the method of claim 24.

FIG. 1

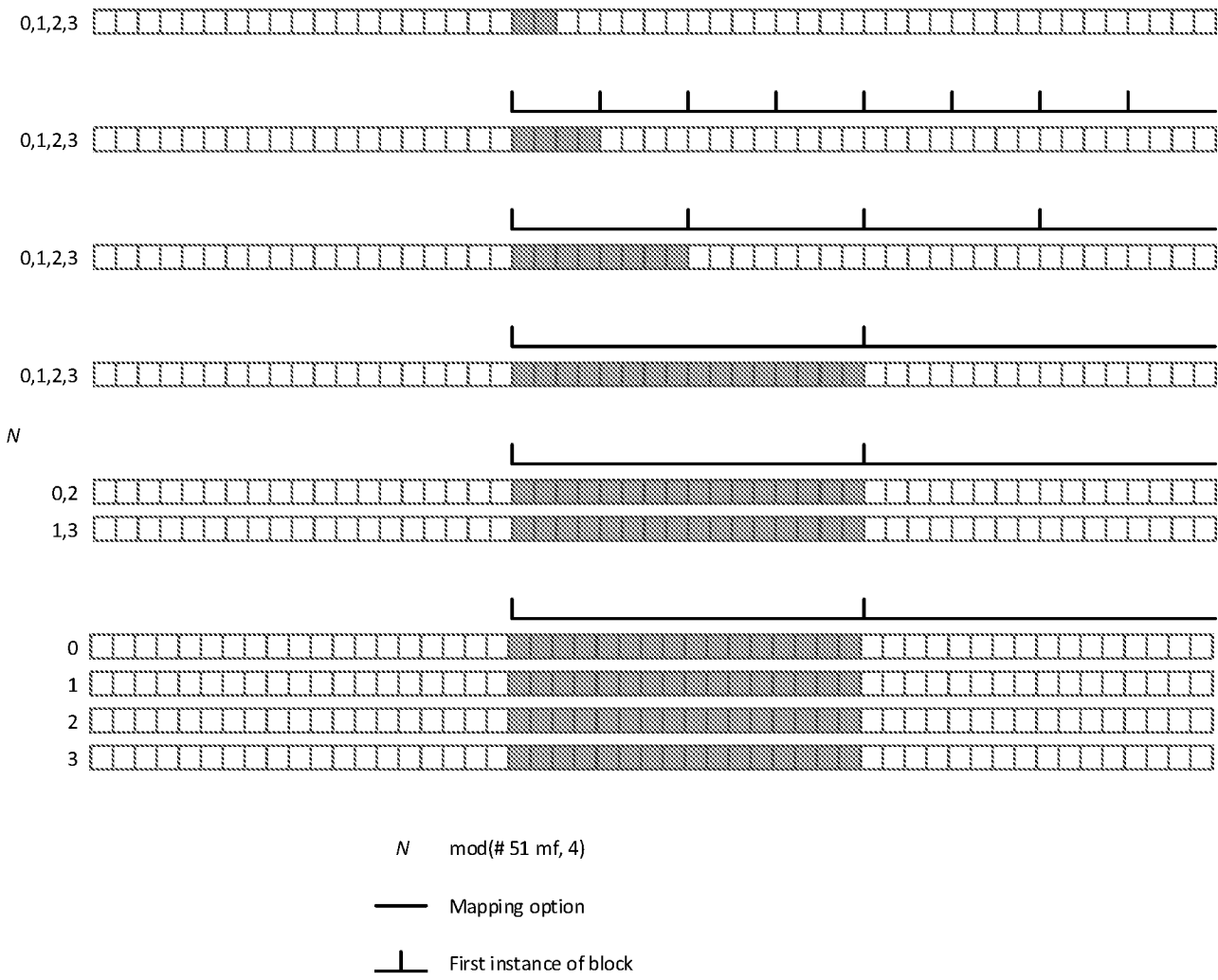


FIG. 2

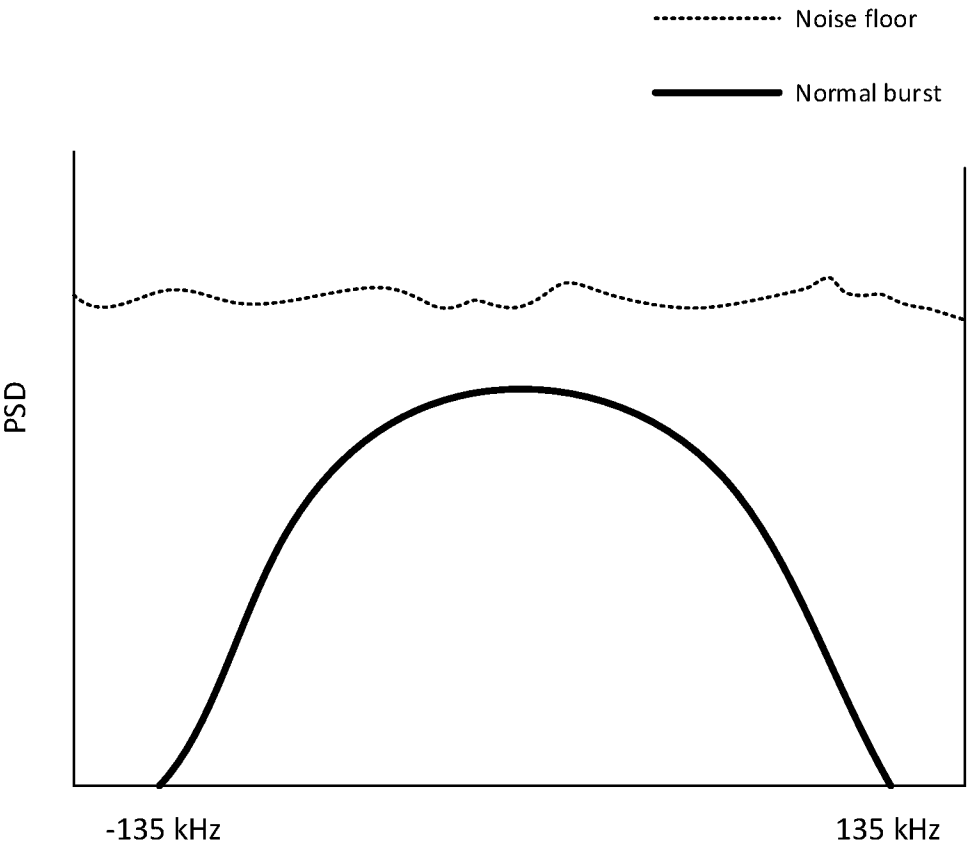


FIG. 3

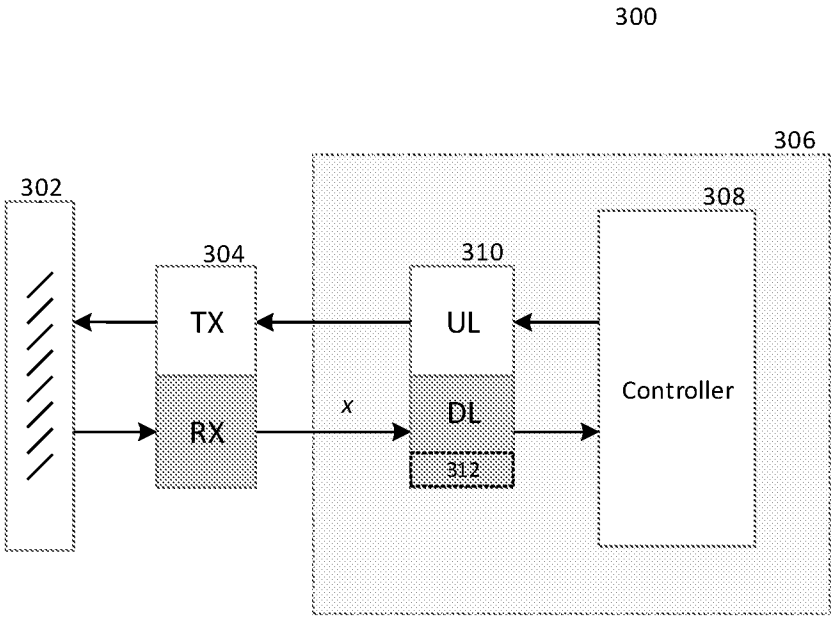
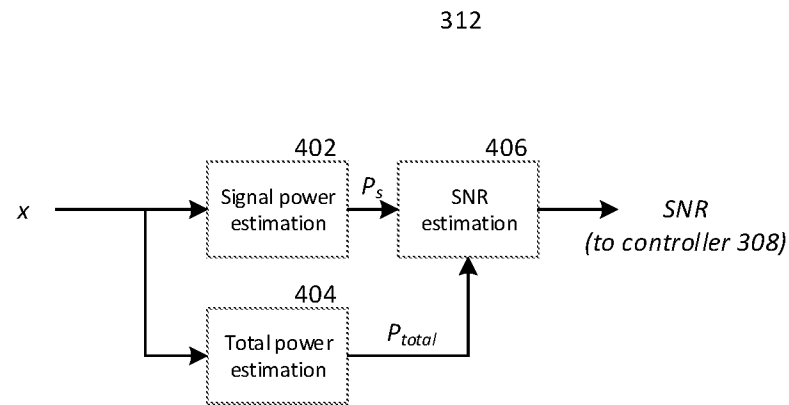


FIG. 4



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FIG. 5

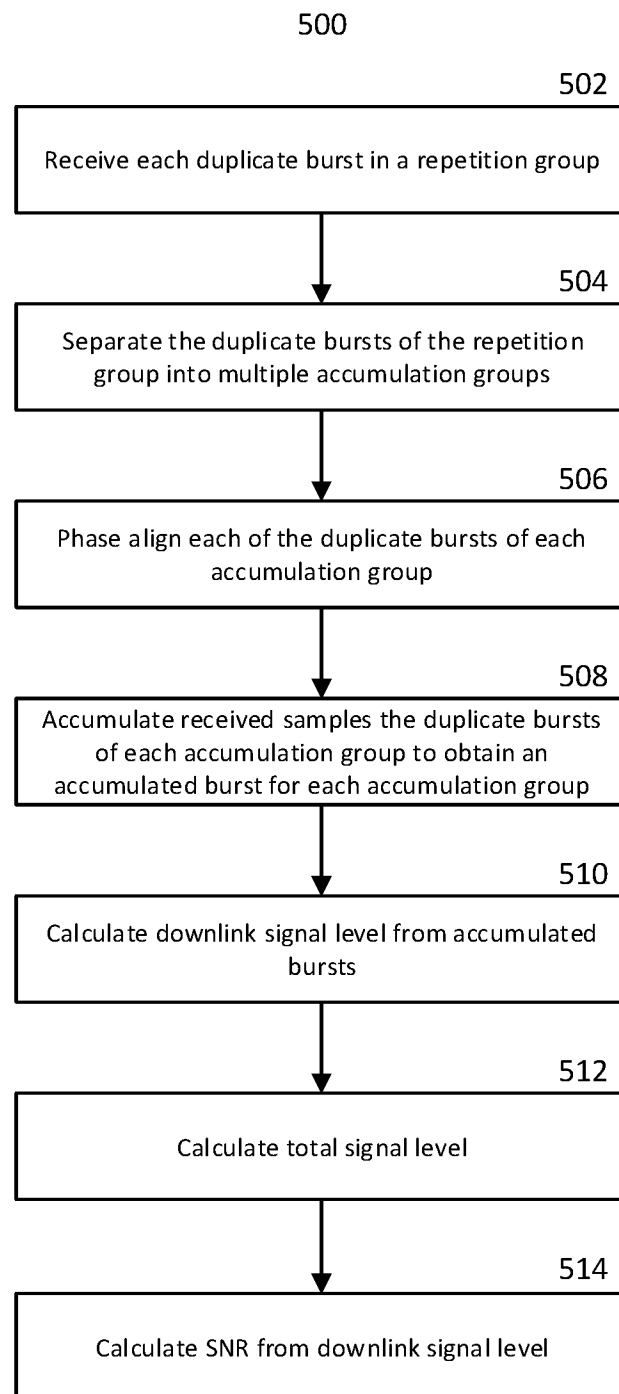
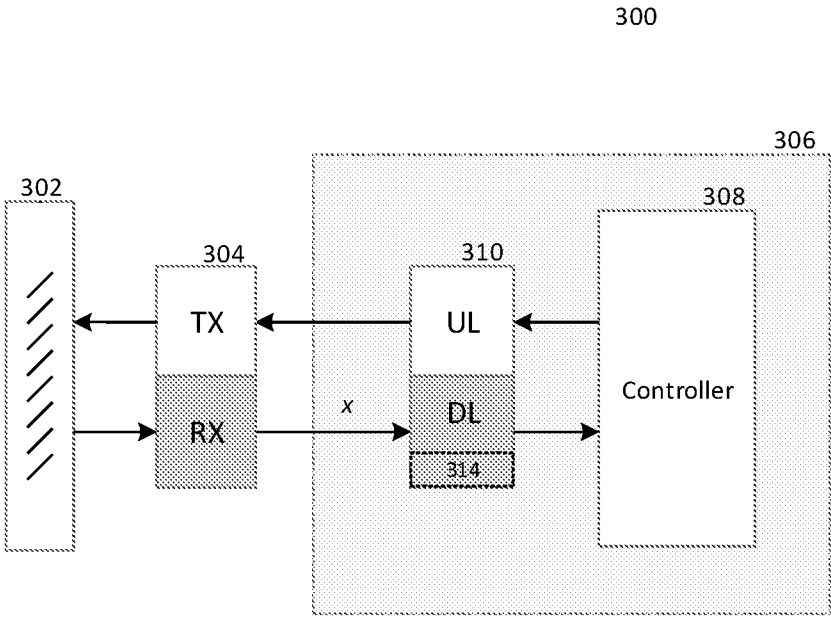
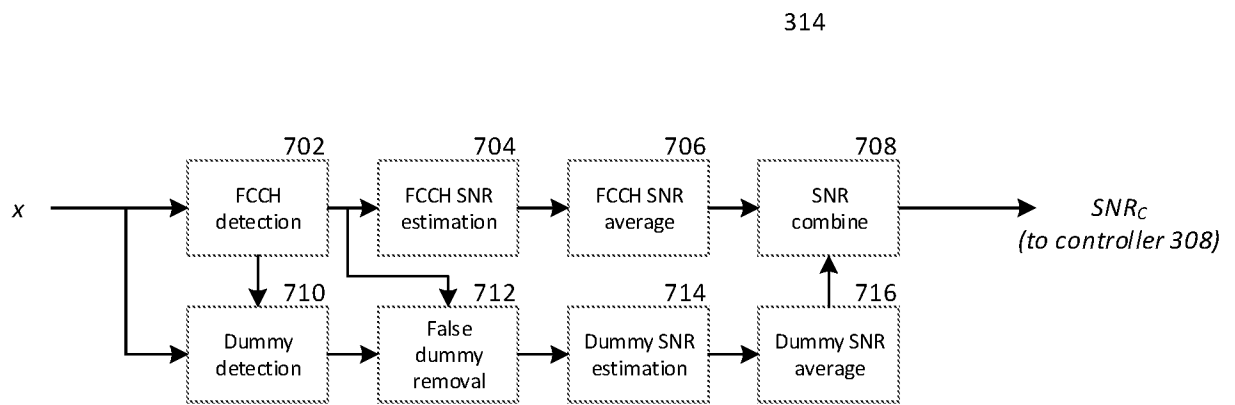


FIG. 6



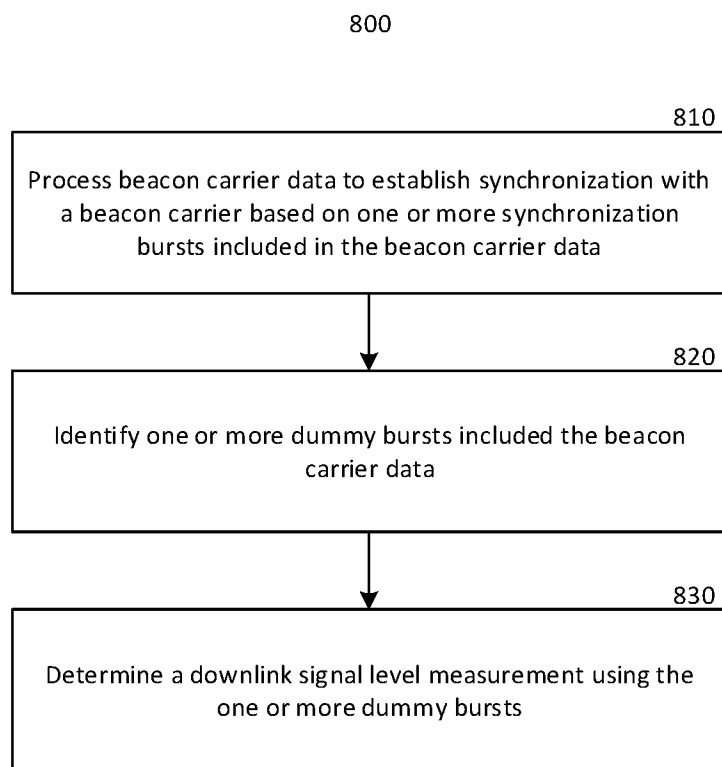
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FIG. 7



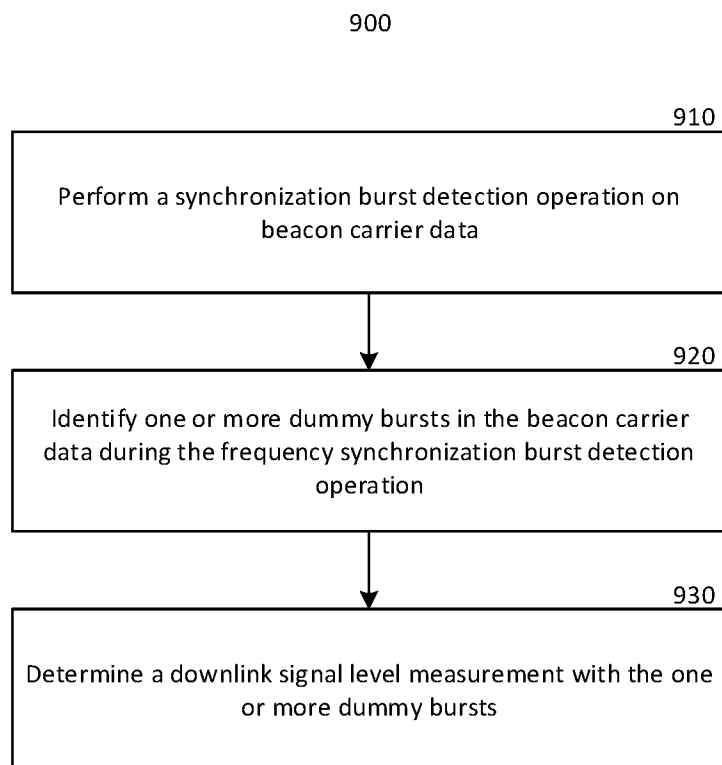
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FIG. 8



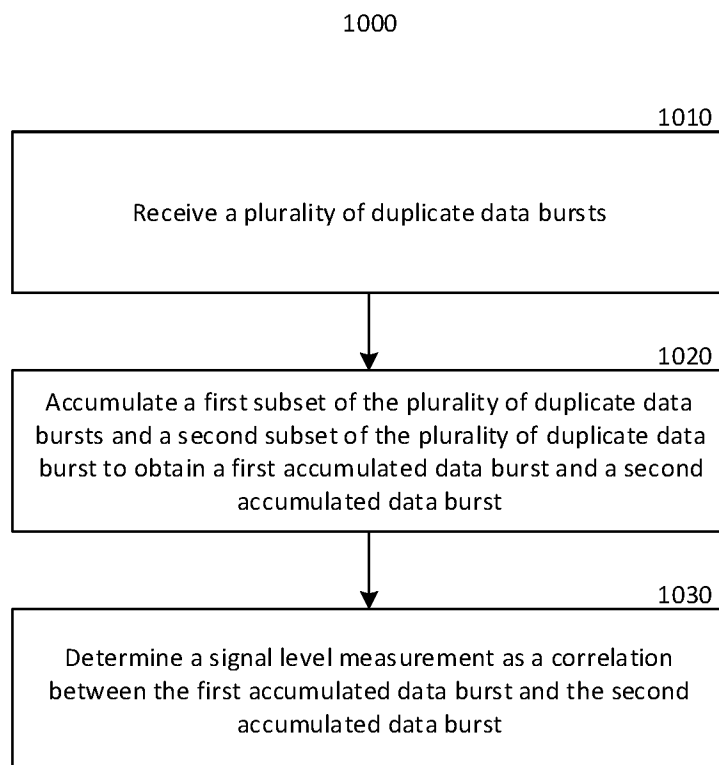
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FIG. 9



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FIG. 10



## INTERNATIONAL SEARCH REPORT

International application No.

**PCT/CN2016/077796****A. CLASSIFICATION OF SUBJECT MATTER**

H04L 25/06(2006.01)i

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)

H04L 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 practicable, search terms used)

WPI, EPODOC, CNPAT, CNKI: signal level, burst, beacon carrier, dummy, duplicate, SNR

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                 | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | US 8428186 B1 (EXALT COMMUNICATIONS INCORPORATED) 23 April 2013 (2013-04-23)<br>the whole document                                                                                                                                                                                 | 1-25                  |
| A         | CN 102681359 A (HEFEI ADVANTOOLS SEMICONDUCTOR CO., LTD.) 19 September 2012 (2012-09-19)<br>the whole document                                                                                                                                                                     | 1-25                  |
| A         | DZIERMA, Y. et al. "Huygens Probe descent dynamics inferred from Channel B signal level measurements"<br><i>Planetary and Space Science</i> , Vol. 55, No. 13, 30 November 2007 (2007-11-30),<br>ISSN: 0032-0633,<br>page 1887, 2.Channel B signal level measurements, figures 1-2 | 1-25                  |

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents:

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"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

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Date of the actual completion of the international search

**20 December 2016**

Date of mailing of the international search report

**04 January 2017**

Name and mailing address of the ISA/CN

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**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/CN2016/077796**

| Patent document<br>cited in search report |           |    | Publication date<br>(day/month/year) | Patent family member(s) |            |    | Publication date<br>(day/month/year) |
|-------------------------------------------|-----------|----|--------------------------------------|-------------------------|------------|----|--------------------------------------|
| US                                        | 8428186   | B1 | 23 April 2013                        | US                      | 8040870    | B1 | 18 October 2011                      |
|                                           |           |    |                                      | US                      | 8295304    | B1 | 23 October 2012                      |
|                                           |           |    |                                      | US                      | 2013044626 | A1 | 21 February 2013                     |
| CN                                        | 102681359 | A  | 19 September 2012                    | None                    |            |    |                                      |