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Handling Overheating in a Wireless-Communication Device

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Abstract:

This publication describes systems and techniques directed to handling overheating in a wireless-communication device. A wireless-communication device, *e.g.*, user equipment (UE), includes an overheating manager application. Under certain circumstances in a dual connectivity environment, where the UE is connected to a master node (MN) providing access to master cell group (MCG) and also connected to a secondary node (SN) providing access to a secondary cell group (SCG), a processor of the UE executing the overheating manager application directs the UE to perform operations to mitigate overheating local to the UE. Such operations may include the UE detecting the overheating condition and transmitting a degraded SN signal-quality measurement report for an SN carrier frequency, resulting in the UE being released from a state of dual connectivity. Such operations may also include the UE detecting the overheating condition and transmitting a degraded SN signal-quality measurement report for a portion of an SN carrier frequency, resulting in the UE being released from a state of dual connectivity using the portion of the SN carrier frequency.

Keywords:

dual connectivity, 5G NR, 3GPP LTE, overheating, radio resource control (RRC), master node, secondary cell group (SCG), secondary node, 4G LTE, 6G, power consumption

Background:

A wireless-communication device, *e.g.*, user equipment (UE), may be engaged in dual-connectivity communication with multiple base stations. For example, the UE may wirelessly communicate through a wireless connection to a master node (MN) providing access to a first wireless network of a first type, such as base station providing access to a 3rd Generation Partnership Project Long-Term Evolution (3GPP LTE), wireless network. Simultaneously, the UE may wirelessly communicate through another wireless connection to a secondary node (SN) providing access to a second wireless network of a second type, such as another base station providing access to a Fifth Generation New Radio (5G NR) wireless network. Due to a variety of factors that drive power consumption of the UE, such as an amount of data transmitted by the UE or a frequency spectrum used by the UE for transmitting the data, wireless communications by the UE may cause an overheating condition that is local to the UE.

Wireless communication protocols today (*e.g.*, 3GPP LTE protocols, 5G NR protocols, and so forth) do not offer provisions for the UE to identify such an overheating condition and resolve the problem.

Description:

This publication describes systems and techniques directed to handling overheating in a wireless-communication device. A wireless-communication device, *e.g.*, user equipment (UE), includes an overheating manager application. Under certain circumstances in a state of dual connectivity (DC), where the UE is connected to a master node (MN) providing access to master cell group (MCG) and also connected to a secondary node (SN) providing access to a secondary cell group (SCG), a processor of the UE executing the overheating manager application directs the UE to perform operations to mitigate overheating local to the UE.

Four example techniques that are applicable to the UE wirelessly communicating in the DC state with the MN and the SN are described. A first example technique includes the UE detecting the overheating condition, stopping wireless communications with the SN, and transmitting an SCG failure message to the MN. A second example technique includes the UE detecting the overheating condition, stopping wireless communications with the SN, and transmitting an MCG failure message to the MN that initiates an RRC reestablishment procedure between the UE and the MN. A third example technique includes the UE detecting the overheating condition and transmitting a degraded SN signal-quality measurement report, resulting in the UE being released from a state of dual connectivity. A fourth example technique includes the UE detecting the overheating condition and transmitting a degraded SN signal-quality measurement report for a portion of an SN carrier frequency, resulting in the UE being released from a state of dual connectivity using the portion of the SN carrier frequency.

Fig. 1, below, illustrate details of an example environment in which the UE wirelessly communicates in the state of dual connectivity and overheats.

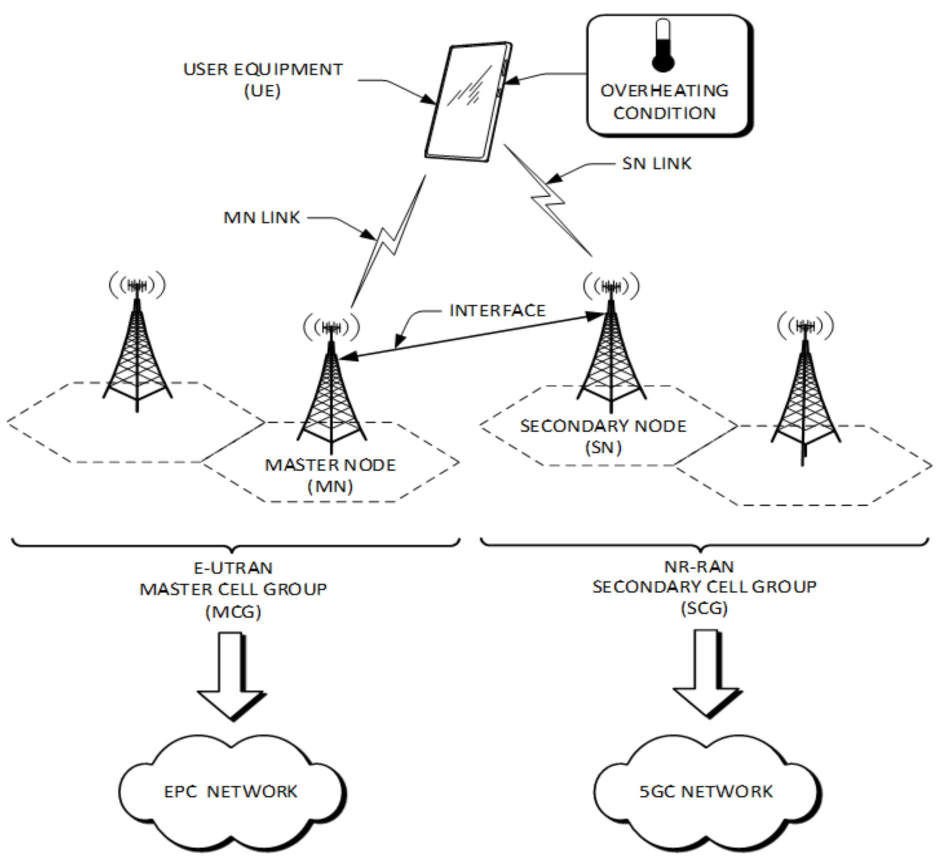

Fig. 1

In FIG. 1, the UE wirelessly connects to a master node (MN) of a master cell group (MCG) supporting an Evolved Universal Terrestrial Radio Access Network (E-UTRAN) for 3GPP LTE wireless communications. The MCG includes one or more nodes, or base stations, that connect to a core network (as illustrated, that is an Evolved Packet Core (EPC) core network). An MN wireless link (MN LINK) wirelessly connects the UE to the MN of the MCG, allowing uplink transmissions from the UE to the MN and downlink transmissions from the MN to the UE. Also as illustrated in FIG. 1, the UE wirelessly connects to a secondary node (SN) of a secondary cell group (SCG) supporting a New Radio Access Network (NR RAN) for 5G NR wireless communications. The SCG includes one or more nodes, or base stations, that connect to another core network (as illustrated, the other core network is a Fifth Generation Core (5GC) network). An SN wireless link (SN LINK) wirelessly connects the UE to the SN of the SCG, allowing uplink transmissions from the UE to the SN and downlink transmissions from the SN to the UE. In general, the MN LINK and the SN LINK correspond to resources of air interfaces (*e.g.*, resource blocks and resource elements spanning frequency and time domains) that may be allocated the MN and the SN.

While in the state of dual connectivity, the UE may not be able to effectively dissipate power. In such an instance, an overheating condition local to the UE may manifest. Furthermore, the MN and the SN may communicate with one another through an interface between the MN and the SN that is an Xn interface.

Although FIG. 1 describes dual connectivity using specific types of nodes (*e.g.*, base stations) associated with specific types of radio access networks (*e.g.*, E-UTRAN and NR RAN), the following techniques associated with the example environment are non-limiting and can apply to combinations of other types of nodes (*e.g.*, access points) associated with other radio access networks. For example, a node may correspond to a router or a "hotspot" provided by another UE. Examples of other radio access networks include, for example, radio access networks associated with a wireless local access network (WLAN) and a global system for mobile communications (GSM) network.

FIG. 2, below, illustrates example details of systems supporting techniques described in this publication.

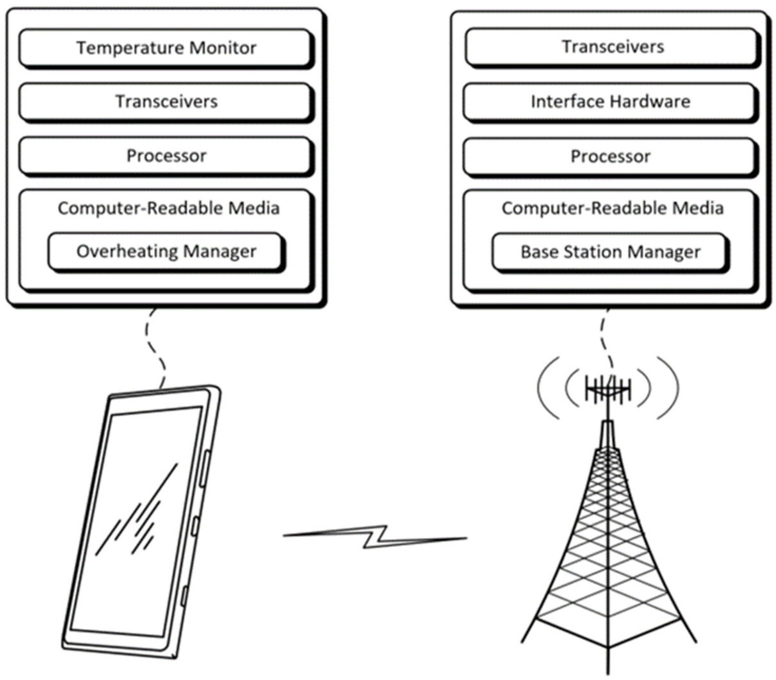

Fig. 2

FIG. 2 illustrates a UE that is a smartphone. However, other UEs (*e.g.*, a tablet, a laptop computer, a wearable device, or the like) can also support techniques to handle overheating. The UE includes a temperature monitor (*e.g.*, temperature detection circuitry) and transceivers (*e.g.*, a 3GPP LTE transceiver and a 5G NR transceiver for transmitting data to, and receiving data from, the MN and the SN of FIG. 1). The UE also includes a processor and a computer-readable medium (CRM) storing executable instructions of an overheating manager application. The overheating manager application, when executed by the processor of the UE, causes the UE to perform operations described within this document.

FIG. 2 also illustrates a base station. The base station may be the MN and/or the SN of FIG. 1. The base station includes transceiver(s) (*e.g.*, a combination of one or more 3GPP LTE transceivers and/or 5G NR transceivers) to wirelessly communicate with the UE. The base station includes interface hardware for communicating with another base station. The base station also includes a processor and a computer-readable medium (CRM) storing executable instructions of a base station manager application. The base station manager application, when executed by the processor of the base station, causes the base station to perform operations described within this document.

FIG. 3 illustrates a first example technique associated with handling overheating in the UE. As part of handling the overheating in the UE, the first example technique incorporates an SCG failure information message to mitigate a detected overheating condition.

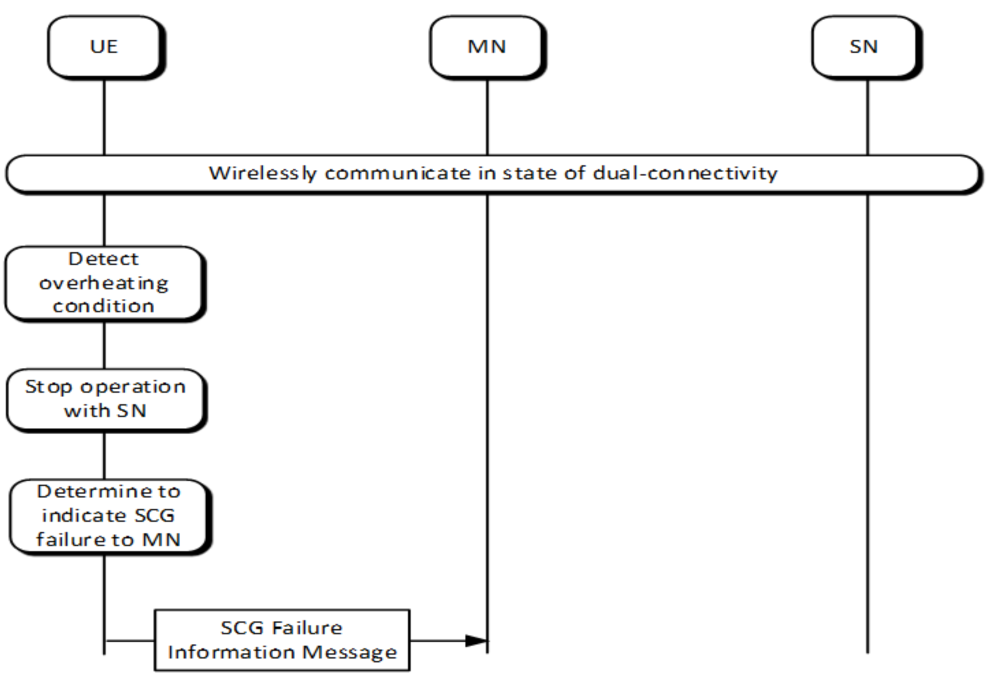

Fig. 3

As illustrated in FIG. 3, the UE is wirelessly communicating in a state of dual connectivity with the MN of an MCG and the SN of an SCG. The UE, the MN, and SN may be those as represented in FIGs. 1 and 2.

As part of the first example technique, the UE (*e.g.*, the temperature monitor of FIG. 2) detects an overheating condition that is local to the UE. For instance, detecting the overheating condition may include the temperature monitor of the UE detecting a temperature that is equal to or larger than a predetermined value. Upon detecting the overheating condition, the UE stops operation with the SN. In this first example technique, stopping operation with the SN may include the UE stopping uplink transmissions to the SN, stopping receiving downlink transmissions from the SN, or combinations thereof. This may include the UE disabling a transceiver, or portions of a transceiver (*e.g.*, a transmitter, a receiver), that it uses to wirelessly communicate with the SN.

The UE then indicates a secondary cell group (SCG) failure to the MN by transmitting one or more SCG failure information messages (*e.g.*, a SCGFailureInformation message) to the MN. In some instances, the one or more SCG failure information messages can include a failure type (*e.g.*, t310-Expiry, randomAccessProblem, rlc-MaxNumRetx, synchReconfigFailure-SCG, scd-reconfigFailure, srb-IntegrityFailure, overheating). In response, the MN transmits to the UE a message (*e.g.*, a radio resource control (RRC) release message) that releases the UE from the state of dual connectivity.

Additional operations may be included as part of the first example technique. For example, after the UE has stopped operations with the SN (*e.g.*, exited the state of dual connectivity), the UE may measure a carrier frequency that is associated with the SN and transmit to the MN a degraded SN signal-quality measurement report. In an instance when the temperature condition exists, such a signal-quality measurement report may include an artificially poor SN signal-quality measurement spoofed by the UE to indicate a poor signal quality and prevent the MN from transmitting a message that configures the UE to recover from the SCG failure (*e.g.*, configure the UE to recover the stopped operation with the SN or another SN of the SCG). In an instance when the overheating condition no longer exists, another signal-quality measurement report may include a "true" SN signal-quality measurement that causes. The "true" signal-quality measurement may cause MN to transmit to the UE another message (a radio resource control (RRC) reconfiguration message) that configures the UE to recover from the SCG failure (and resume the stopped operation with the SN or another SN of the SCG).

FIG. 4 illustrates a second example technique to handle overheating in a UE. As part of handling the overheating in the UE, the second example technique incorporates an SCG failure information message to mitigate a detected overheating condition.

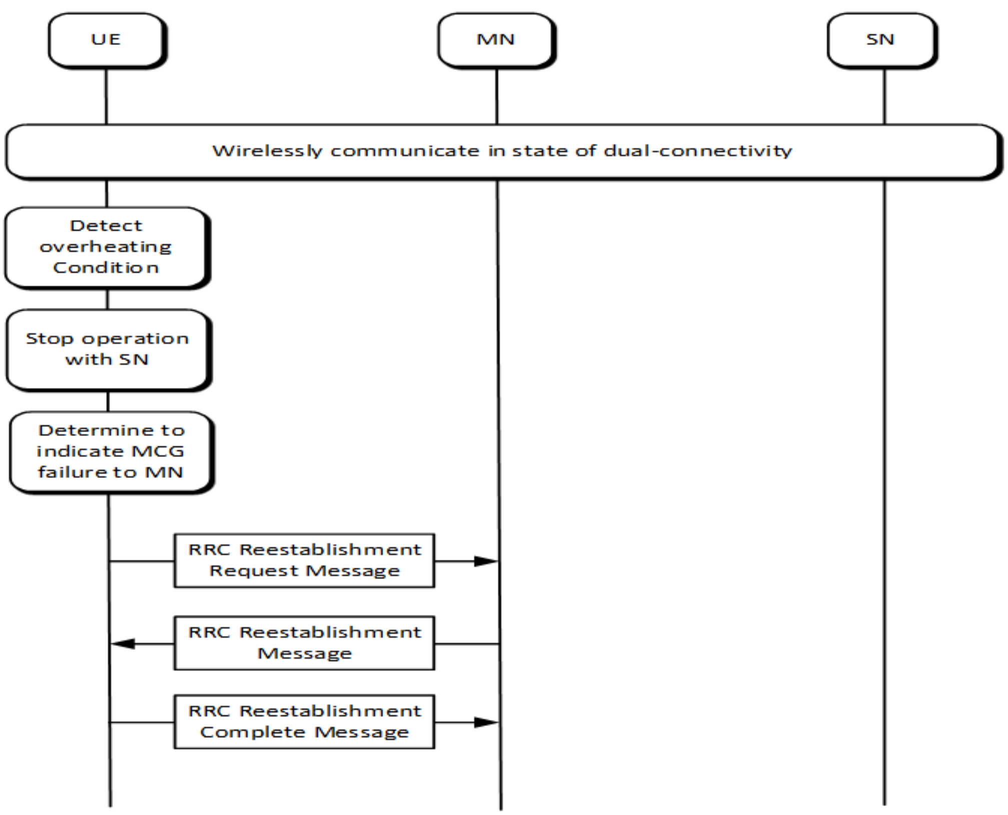

Fig. 4

As illustrated in FIG. 4, the UE is in a state of dual connectivity with the MN of an MCG and the SN of an SCG. The UE may be in the state of dual connectivity that corresponds to the example environment of FIG. 1.

As part of the second example technique, the UE (*e.g.*, the temperature monitor of FIG. 2) detects an overheating condition that is local to the UE. Upon detecting the overheating condition, the UE stops operation with the SN. In this second example technique, stopping operation with the SN includes the UE stopping uplink transmissions to the SN and stopping receiving downlink transmissions from the SN. Stopping operation with the SN, as part of the second example technique, may also include the UE disabling a transceiver it uses to wirelessly communicate with the SN.

The UE indicates a master cell group (MCG) failure to the MN. Indicating the MCG failure includes initiating an RRC reestablishment procedure by transmitting an RRC reestablishment request message (*e.g.*, an RRCConnectionReestablishmentRequest) to the MN. The RRC request message can include a failure type (*e.g.*, reconfigurationFailure, otherFailure, overheating). In response, and as part of the RRC reestablishment procedure, the MN transmits an RRC reestablishment message (*e.g.*, an RRCConnectionReestablishment) to the UE. The UE then responds and transmits, to the MN, an RRC reestablishment complete (*e.g.*, an RRCConnectionRestablishmentComplete) message.

Additional operations may be included as part of the second example technique. For example, and after the UE received the RRC reestablishment request message, the UE may receive an RRC reconfiguration message from the MN, start communicating data over a data radio bearer (DRB) with the MN, and then transmit an RRC reconfiguration complete message to the MN.

FIGs. 5-7 illustrate variations of a third example technique associated with handling overheating in the UE. As part of handling the overheating in the UE, the third example technique incorporates a degraded signal-quality measurement report to mitigate a detected overheating condition.

As illustrated in FIG. 5, below, a first variation of the third example technique, the UE is in a state of dual connectivity with the MN of an MCG and the SN of an SCG. The state of dual connectivity includes the UE wirelessly communicating with the MN using a first carrier frequency and wirelessly communicating with the SN using a second carrier frequency.

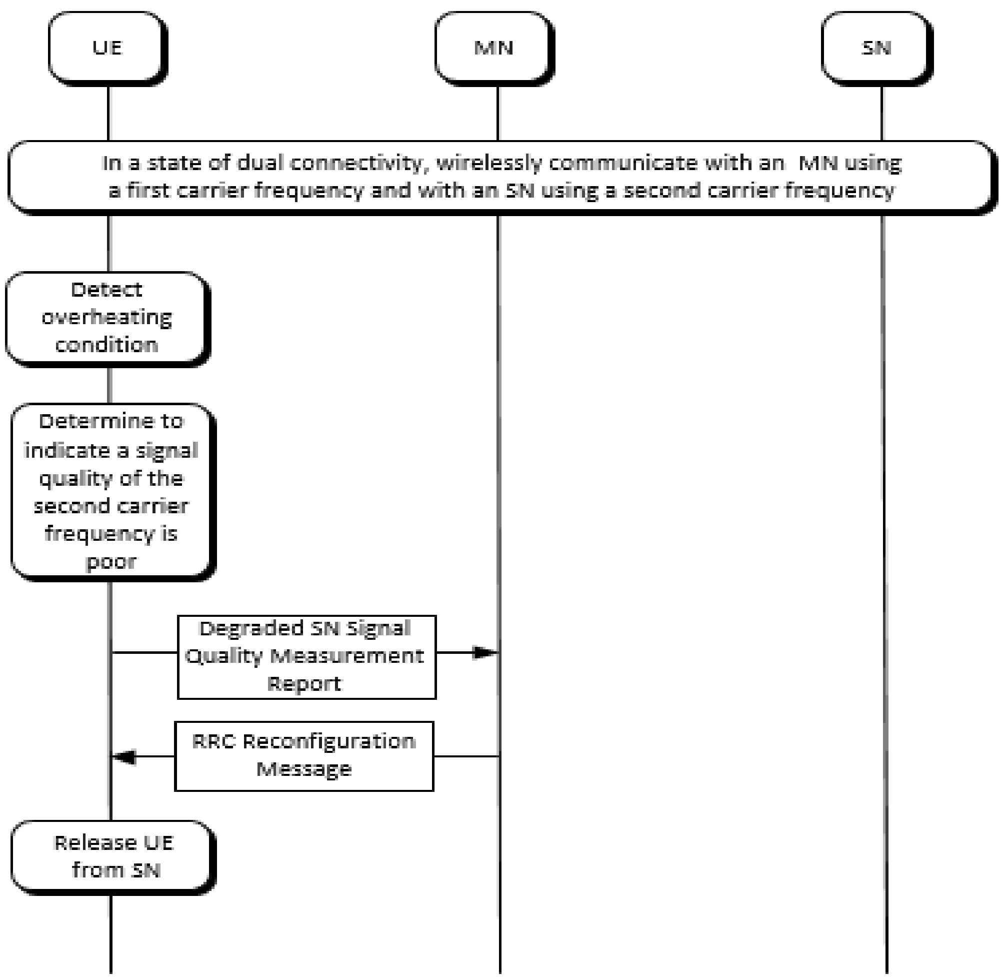

Fig. 5

In the first variation of the third example technique, the UE initiates the release of the UE from the SN by sending a degraded SN signal-quality measurement report to the MN. The UE detects an overheating condition that is local to the UE, and even though a signal quality associated with the second carrier frequency may be "good," the UE determines to indicate to the MN that the signal quality of the second carrier frequency is "poor." The UE transmits, to the MN, a degraded SN signal-quality measurement report that includes an artificially poor SN signal-quality measurement that is spoofed by the UE (*e.g.*, spoofing may be performed by the processor executing instructions of the overheating manager application of FIG. 2). As an example, the degraded SN signal-quality measurement report may include a channel quality indicator (CQI) having an invalid value (*e.g.*, a value of zero) and be transmitted by the UE using a physical uplink control channel (PUCCH). As another example, the degraded SN signal-quality measurement report may include at least one of at least one reference signal received power (RSRP) value, at least one reference signal received quality (RSRQ) value and at least one signal to noise and interference ratio (SINR) value.

In response to receiving the degraded SN signal-quality measurement report, the MN transmits an RRC reconfiguration message to the UE, wherein the RRC reconfiguration message configures the UE for release from the SN. In response to receiving the RRC reconfiguration message, the UE releases from the SN and stops wireless communications with the SN to mitigate the detected overheating condition.

As illustrated in FIG. 6 below, a second variation of the third example technique, the MN initiates the release of the UE from the SN. The state of dual connectivity includes the UE wirelessly communicating with the MN using a first carrier frequency and wirelessly communicating with the SN using a second carrier frequency.

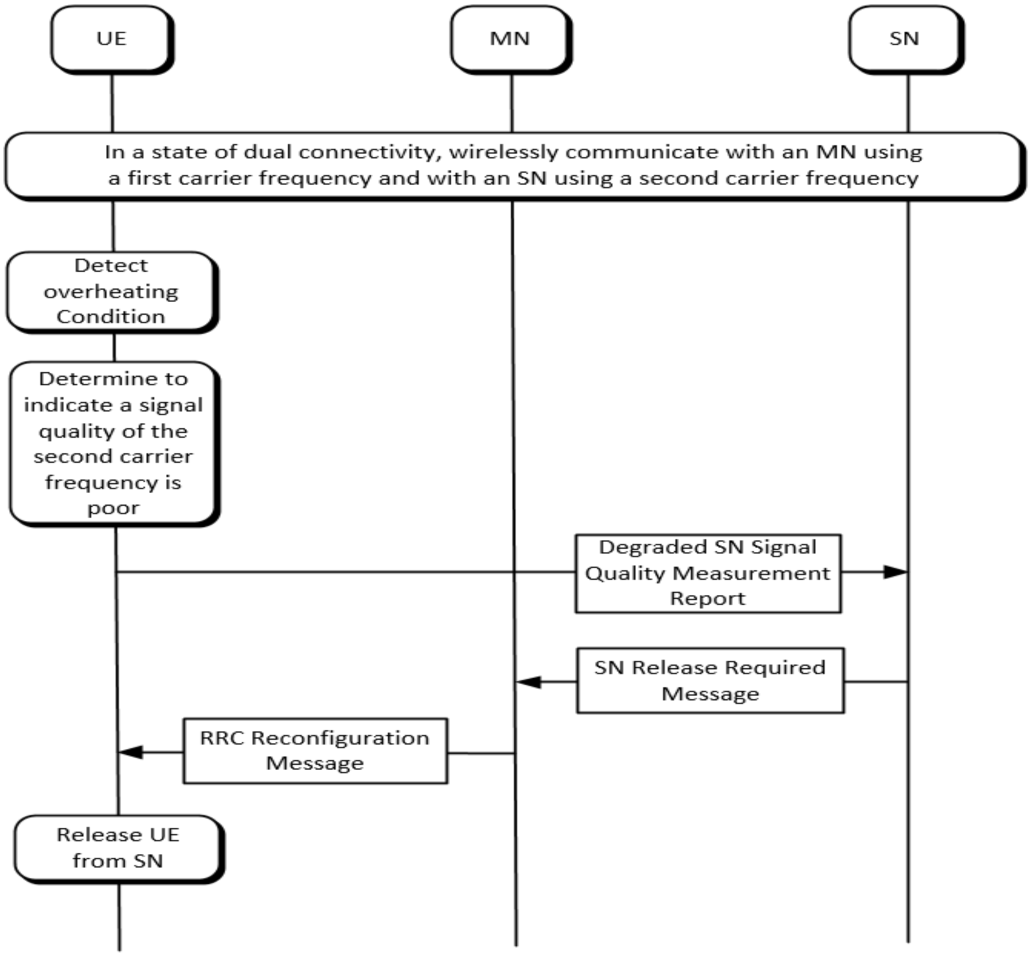

Fig. 6

As part of the second variation of the third example technique, the UE detects an overheating condition that is local to the UE. Upon detecting the overheating condition, and even though the signal quality associated with the second carrier frequency is "good," the UE determines to indicate to the SN that the signal quality of the second carrier frequency is "poor." The UE transmits, to the SN, a degraded SN signal-quality measurement report that includes an artificially poor SN signal-quality measurement spoofed by the UE. In response, the SN transmits an SN release required message to the MN, which in turn transmits an RRC reconfiguration message to the UE. The RRC reconfiguration message configures the UE for release from the SN.

In response to receiving the RRC reconfiguration message, the UE releases from the SN and stops wireless communications with the SN to mitigate the detected overheating condition.

In some instances, if the UE no longer detects the overheating condition, the UE may transmit to the MN another signal-quality measurement report. The other signal-quality measurement report may cause the MN to transmit an RRC reconfiguration message that configures the UE to reconnect to the SN (or another base station/SN of the SCG).

FIG. 7, below, illustrates a third variation of the third example technique. In this third variation of the third example technique, the SN initiates the release of the UE from the SN.

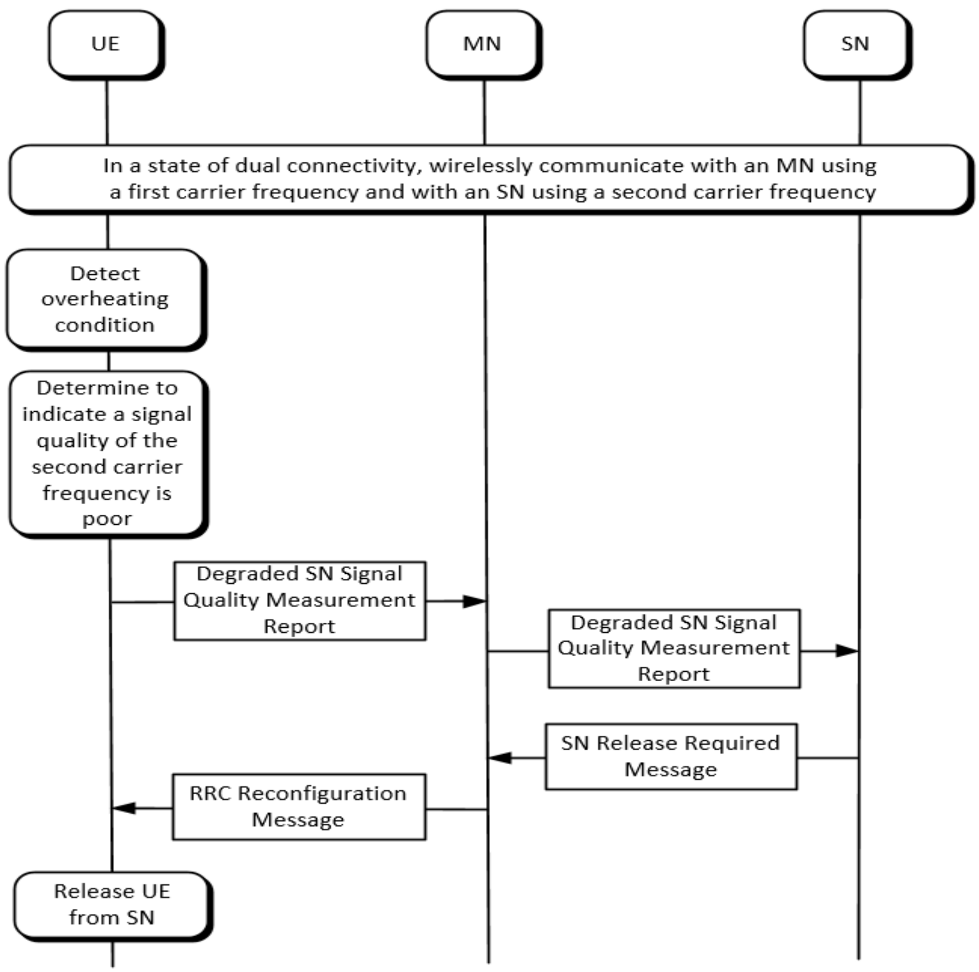

Fig. 7

The state of dual connectivity includes the UE wirelessly communicating with the MN using a first carrier frequency and wirelessly communicating with SN using a second carrier frequency. The state of dual connectivity includes a downlink (signal radio bearer (SRB)) for the UE to receive data from the SN, but not an uplink (another signal radio bearer (SRB)) for the UE to transmit a signaling or control transaction message to the SN.

As illustrated in FIG. 7, the UE detects an overheating condition that is local to the UE. Upon detecting the overheating condition, and even though a signal quality associated with the second carrier frequency is “good,” the UE determines to indicate to the MN that the signal quality of the second carrier frequency is “poor.” The UE transmits, to the MN, a degraded SN signal-quality measurement report that includes an artificially poor SN signal-quality measurement spoofed by the UE. In response, the MN transmits to the SN (through an interface between the MN and the SN) the degraded SN signal-quality measurement report. The SN, responds and transmits, to the MN, an SN release required message. The MN, in turn, transmits an RRC reconfiguration message to the UE. The RRC reconfiguration message configures the UE for release from the SN. In response to receiving the RRC reconfiguration message, the UE releases from, and stops wireless communications with the SN (*e.g.*, stops receiving data from the SN) and mitigates the detected overheating condition.

FIGs. 8-10 illustrate variations of a fourth example technique associated with handling overheating in the UE. As part of handling the overheating in the UE, the fourth example technique incorporates a degraded signal-quality measurement report for a portion of an SN carrier frequency and effectuates the UE reducing carrier aggregation with the SN. The portion of the SN carrier frequency, in general, corresponds to a reduced number of air interface resources allocated by the SN.

As illustrated in FIG. 8, below, a first variation of the fourth example technique, the UE is in a state of dual connectivity with the MN of an MCG and the SN of an SCG. The state of dual connectivity includes the UE wirelessly communicating with the MN using a first carrier frequency and wirelessly communicating with the SN using a second carrier frequency. The state of dual connectivity includes a downlink (signal radio bearer (SRB)) for the UE to receive data from the SN, but not an uplink (another signal radio bearer (SRB)) for the UE to transmit a signaling or control transaction message to the SN. The UE, performing carrier aggregation operations with the SN, is able to control frequencies (*e.g.*, carriers, subcarriers) to drop from the carrier aggregation operations to mitigate a detected overheating condition.

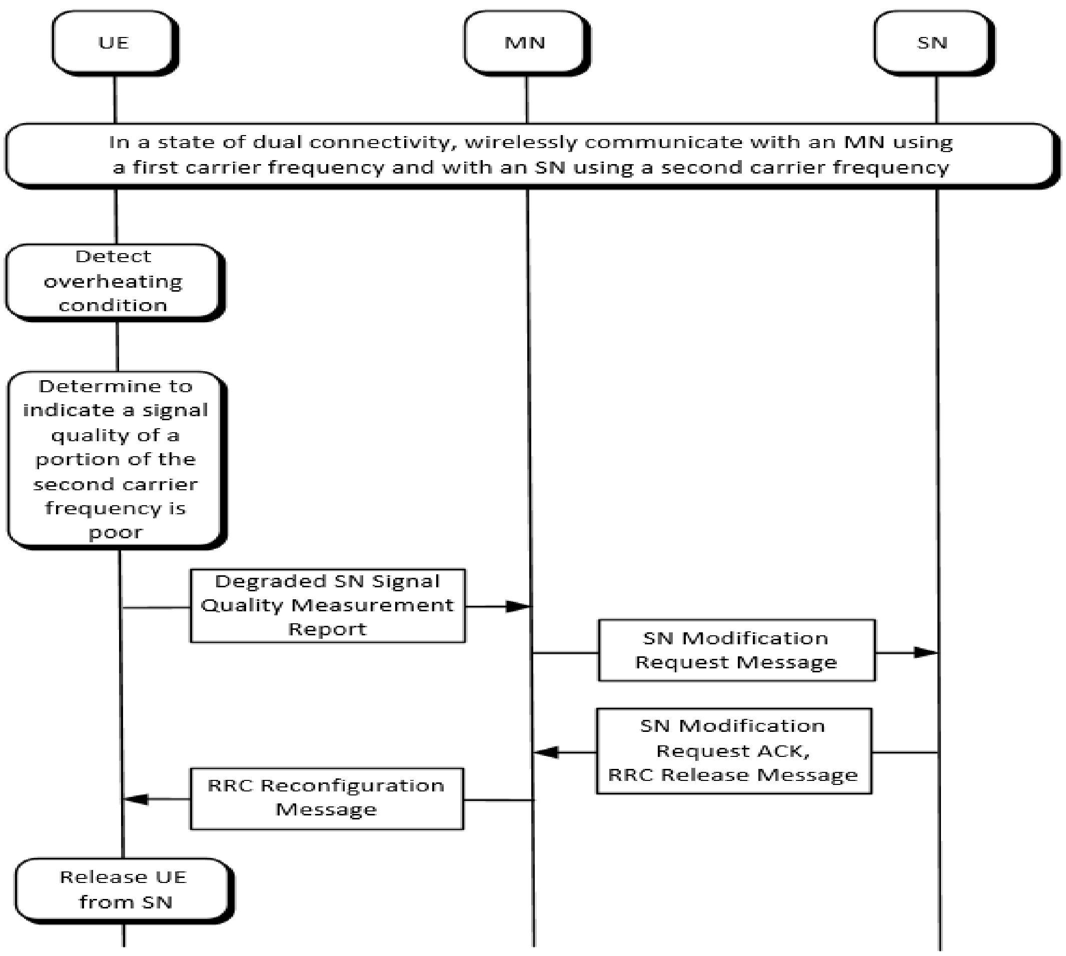

Fig. 8

As illustrated in FIG. 8, the UE detects an overheating condition that is local to the UE. Upon detecting the overheating condition, and even though a signal quality associated with a portion of the second carrier frequency (*e.g.*, a subcarrier within the second carrier frequency) is "good," the UE determines to indicate to the MN that the signal quality of the portion of second carrier frequency is "poor." The UE transmits, to the MN, a degraded SN signal-quality measurement report that includes an artificially poor SN signal-quality measurement spoofed by the UE. In response, the MN transmits to the SN (through an interface between the MN and the SN) an SN modification request which identifies the portion of the second carrier frequency to the SN.

The SN responds and transmits, to the MN, an SN modification request acknowledgment (ACK) that includes an RRC reconfiguration message. The MN, in turn, transmits the RRC reconfiguration message to the UE. The RRC reconfiguration message configures the UE for release from the SN. In response to receiving the RRC reconfiguration message, the UE releases from receiving the portion of the second carrier frequency (*e.g.*, receiving data using the portion of the second carrier frequency) and mitigates the detected overheating condition.

FIG. 9, below, illustrates a second variation of the fourth example technique. The UE is in a state of dual connectivity with the MN of an MCG and the SN of an SCG. The state of dual connectivity includes the UE wirelessly communicating with the MN using a first carrier frequency and wirelessly communicating with the SN using a second carrier frequency. In this example instance, the SN may initiate the release of the UE from wirelessly communicating with the SN using a portion of the second carrier frequency (*e.g.*, transmitting or receiving data using the portion of the second carrier frequency).

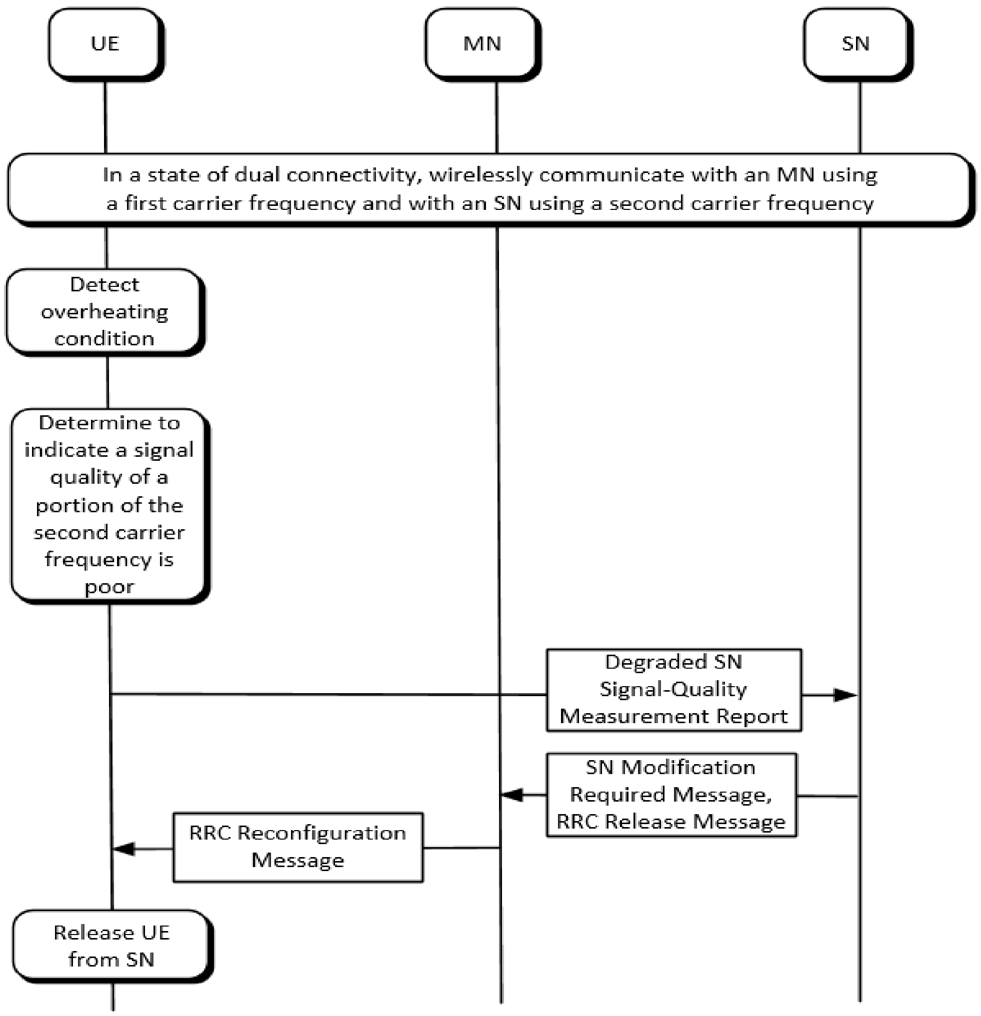

Fig. 9

As illustrated in FIG. 9, the UE detects an overheating condition that is local to the UE. Upon detecting the overheating condition, and even though a signal quality associated with a portion of the second carrier frequency (*e.g.*, a subcarrier within the second carrier frequency) is "good," the UE determines to indicate to the SN that the signal quality of the portion of second carrier frequency is "poor." The UE transmits, to the SN, a degraded SN signal-quality measurement report that includes an "artificially poor" SN signal-quality measurement spoofed by the UE. In response, the SN transmits to the MN (through an interface between the MN and the

SN) an SN modification required message that includes an RRC release message. The MN then transmits, to the UE, the RRC release message. In response to receiving the RRC release message, the UE releases from wirelessly communicating with the SN using the portion of the second carrier frequency (*e.g.*, transmitting or receiving data using the portion of the second carrier frequency) and mitigates the detected overheating condition.

The SN responds and transmits, to the MN, an SN modification required message that includes an RRC release message. The MN, in turn, transmits the RRC reconfiguration message to the UE. The RRC reconfiguration message configures the UE for release from the SN. In response to receiving the RRC reconfiguration message, the UE releases from receiving the portion of the second carrier frequency (*e.g.*, receiving data using the portion of the second carrier frequency) to mitigate the detected overheating condition.

FIG. 10, below, illustrates a third variation of the fourth example technique. The UE is in a state of dual connectivity with the MN of an MCG and the SN of an SCG. The state of dual connectivity includes a downlink (signal radio bearer (SRB)) for the UE to receive data from the SN, but not an uplink (another signal radio bearer (SRB)) for the UE to transmit a signaling or control transaction message to the SN. In this example instance, the MN may initiate the release of the UE from wirelessly communicating with the SN using a portion of the second carrier frequency (*e.g.*, receiving data using the portion of the second carrier frequency).

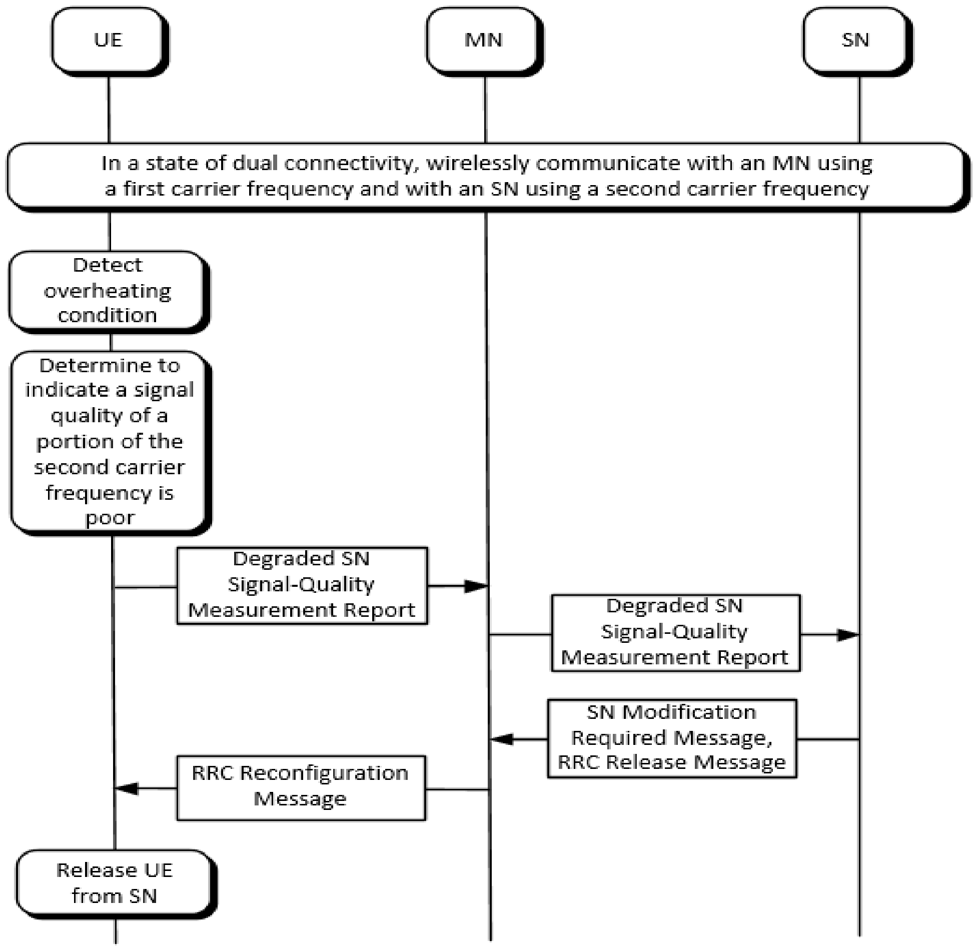

Fig. 10

As illustrated in FIG. 10, the UE detects an overheating condition that is local to the UE. Upon detecting the overheating condition, and even though a signal quality associated with a portion of the second carrier frequency (*e.g.*, a subcarrier within the second carrier frequency) is "good," the UE determines to indicate to the MN that the signal quality of the portion of second carrier frequency is "poor." The UE transmits, to the MN, a degraded SN signal-quality measurement report that includes an artificially poor SN signal-quality measurement spoofed by the UE. In response, the MN transmits to the SN (through an interface between the MN and the SN) the degraded SN signal-quality measurement report.

The SN responds and transmits, to the MN, an SN modification required message that includes an RRC reconfiguration message. The MN, in turn, transmits the RRC reconfiguration message to the UE. The RRC reconfiguration message configures the UE for release from the SN. In response to receiving the RRC reconfiguration message, the UE releases from receiving the portion of the second carrier frequency (*e.g.*, receiving data using the portion of the second carrier frequency) to mitigate the detected overheating condition.

In the description above, the RRC reconfiguration message can be an RRCConnectionReconfiguration message or an RRCReconfiguration message.

In summary, the aforementioned techniques offer provisions for the UE to identify overheating conditions that are local to the UE. The techniques comply with wireless communication protocols today (*e.g.*, 3GPP LTE wireless communication protocols, 5G NR wireless communication protocols). Furthermore, the aforementioned techniques are non-limiting and applicable to additional wireless communication protocols, such as Fourth Generation Long-Term Evolution (4G LTE) wireless communication protocols and Sixth Generation (6G) wireless communication protocols.

References:

[1] 3GPP R2-1802414, UE overheating for EN-DC, in 3GPP TSG-RAN WG2 Meeting #101, Apple Inc.

[2] Xu, Haibo, Jian Wang, Yongbo Zeng, Lipin Chen, and Hongyue. Method, Apparatus, and System for Adjusting Radio Resource Configuration. WO 2018130115A1, filed January 4, 2018, and published July 19, 2018.

[3] Raghavan, Vasanthan, Junyi Li, Assaf Touboul. Methods for Beam Switching in Millimeter Wave Systems to Manager Thermal Constraints, US Patent 10,218,422 B2, filed March 2, 2018, and issued on February 26, 2019.

[4] 3GPP TS 37.340 v15.4.0

[5] 3GPP TS 36.331 v15.4.0

[6] 3GPP TR 38.331 v16.0.0

[7] 3GPP TS 37.340 v15.5.0

[8] 3GPP TS 36.331 v15.5.0

[9] 3GPP TR 38.331 v15.5.0