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(54) **JAMMING MITIGATION IN CBRS NETWORK**

(71) Applicant: **CHARTER COMMUNICATIONS OPERATING, LLC**, St. Louis, MO (US)

(72) Inventors: **Volkan Sevindik**, Parker, CO (US); **Haider Syed**, Parker, CO (US)

(73) Assignee: **CHARTER COMMUNICATIONS OPERATING, LLC**, St. Louis, MO (US)

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(51) **Int. Cl.**

H04W 4/00	(2018.01)
H04K 3/00	(2006.01)
H04W 8/02	(2009.01)
H04W 36/08	(2009.01)
H04W 76/18	(2018.01)
H04W 84/12	(2009.01)

(52) **U.S. Cl.**

CPC ***H04K 3/224*** (2013.01); ***H04W 8/02*** (2013.01); ***H04W 36/08*** (2013.01); ***H04W 76/18*** (2018.02); *H04W 84/12* (2013.01)

(58) **Field of Classification Search**

CPC H04K 3/224; H04W 8/02; H04W 36/08; H04W 36/24; H04W 76/18; H04W 84/12

USPC 370/331; 455/312

See application file for complete search history.

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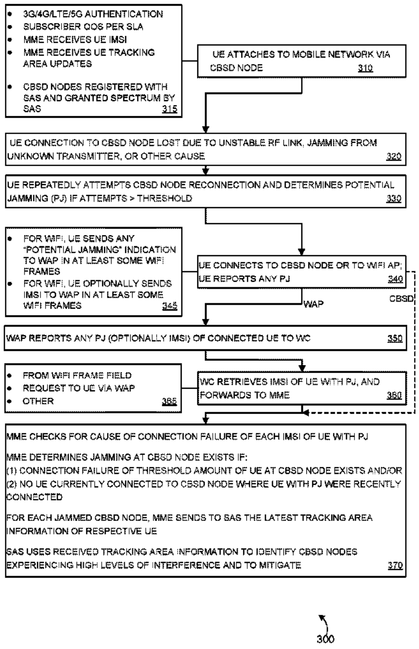
Primary Examiner — Marcos Batista

(74) *Attorney, Agent, or Firm* — Patent Beach PC

(57) **ABSTRACT**

Various embodiments comprise systems, methods, architectures, mechanisms and apparatus for managing service provider network nodes in a converged network by inserting mobile network UE information into WiFi network communications such that a WiFi control entity may, in response to determining that the UE-inserted information is indicative of a jamming condition at a Citizens Broadband Radio Service Devices (CBSDs) providing mobile network services to the UE, communicate the identification of such UE to various provider equipment such that CBSDs experiencing jamming signals may be identified and mitigation steps taken.

24 Claims, 3 Drawing Sheets


• 3G/4G/LTE/5G AUTHENTICATION
• SUBSCRIBER QOS PER SLA
• MME RECEIVES UE IMSI
• MME RECEIVES UE TRACKING AREA UPDATES
• CBSD NODES REGISTERED WITH SAS AND GRANTED SPECTRUM BY SAS 315
UE ATTACHES TO MOBILE NETWORK VIA CBSD NODE 310
UE CONNECTION TO CBSD NODE LOST DUE TO UNSTABLE RF LINK, JAMMING FROM UNKNOWN TRANSMITTER, OR OTHER CAUSE 320
UE REPEATEDLY ATTEMPTS CBSD NODE RECONNECTION AND DETERMINES POTENTIAL JAMMING (PJ) IF ATTEMPTS > THRESHOLD 330
• FOR WIFI, UE SENDS ANY "POTENTIAL JAMMING" INDICATION TO WAP IN AT LEAST SOME WIFI FRAMES
• FOR WIFI, UE OPTIONALLY SENDS IMSI TO WAP IN AT LEAST SOME WIFI FRAMES 345
UE CONNECTS TO CBSD NODE OR TO WIFI AP; UE REPORTS ANY PJ 340
WAP
CBSD
WAP REPORTS ANY PJ (OPTIONALLY IMSI) OF CONNECTED UE TO WC 350
• FROM WIFI FRAME FIELD
• REQUEST TO UE VIA WAP
• OTHER 365
WC RETRIEVES IMSI OF UE WITH PJ, AND FORWARDS TO MME 360
MME CHECKS FOR CAUSE OF CONNECTION FAILURE OF EACH IMSI OF UE WITH PJ
MME DETERMINES JAMMING AT CBSD NODE EXISTS IF:
(1) CONNECTION FAILURE OF THRESHOLD AMOUNT OF UE AT CBSD NODE EXISTS AND/OR
(2) NO UE CURRENTLY CONNECTED TO CBSD NODE WHERE UE WITH PJ WERE RECENTLY CONNECTED
FOR EACH JAMMED CBSD NODE, MME SENDS TO SAS THE LATEST TRACKING AREA INFORMATION OF RESPECTIVE UE
SAS USES RECEIVED TRACKING AREA INFORMATION TO IDENTIFY CBSD NODES EXPERIENCING HIGH LEVELS OF INTERFERENCE AND TO MITIGATE 370
300

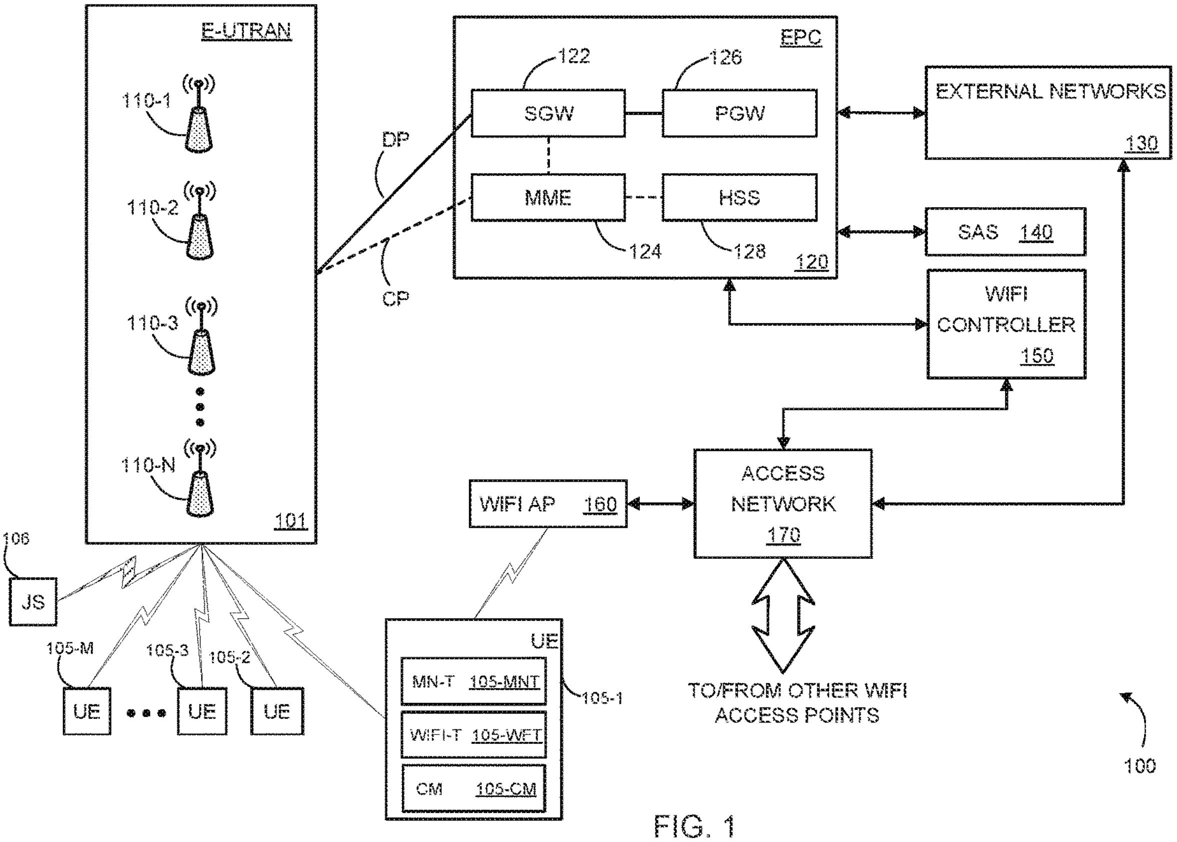
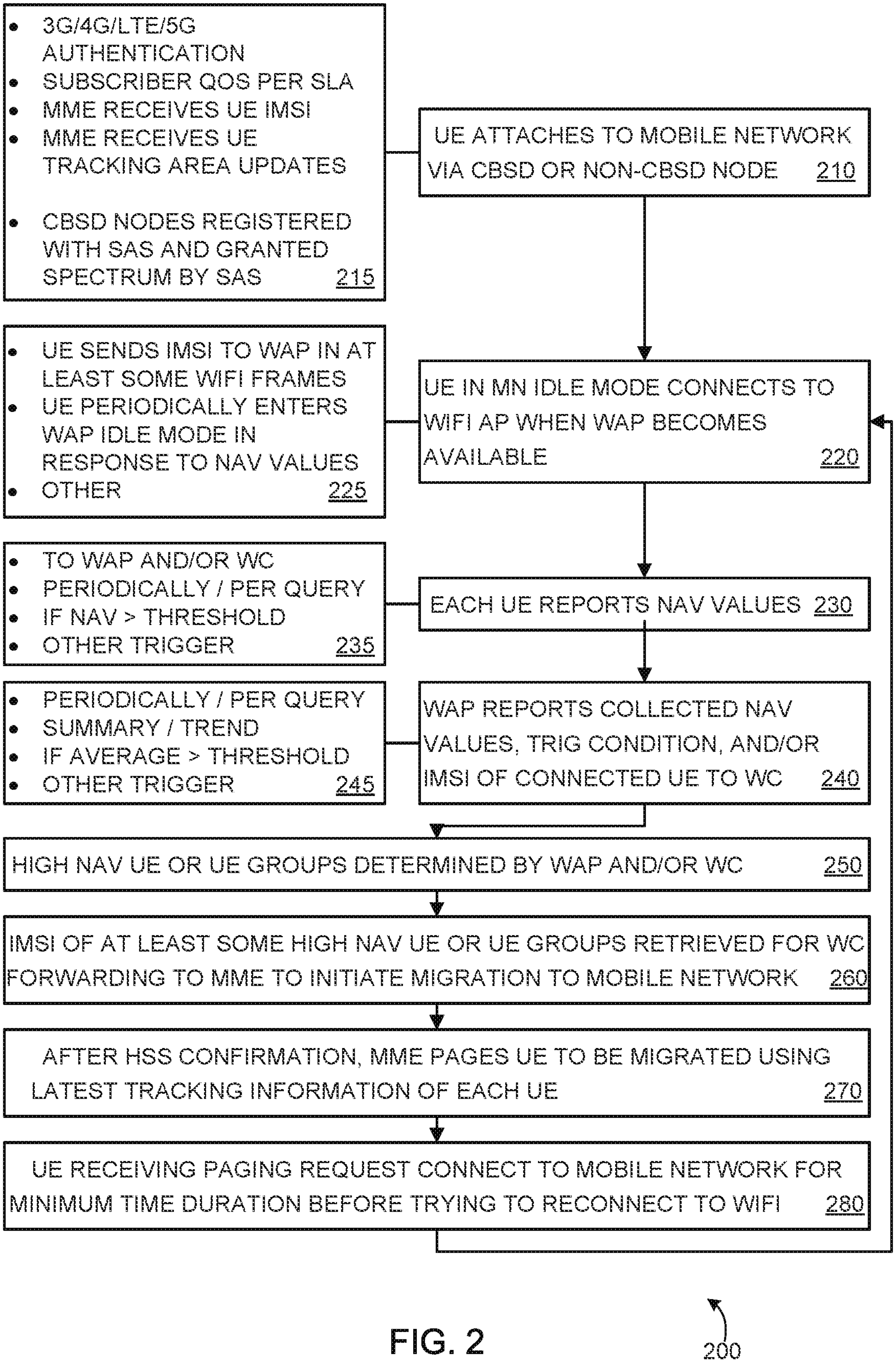

E-UTRAN
110-1
110-2
110-3
110-N
101
DP
CP
EPC
122
SGW
126
PGW
MME
HSS
124
128
120
EXTERNAL NETWORKS
130
SAS 140
WIFI CONTROLLER 150
ACCESS NETWORK 170
WIFI AP 160
TO/FROM OTHER WIFI ACCESS POINTS
106
JS
105-M
UE
105-3
UE
105-2
UE
UE
MN-T 105-MNT
WIFI-T 105-WFT
CM 105-CM
105-1
100

FIG. 1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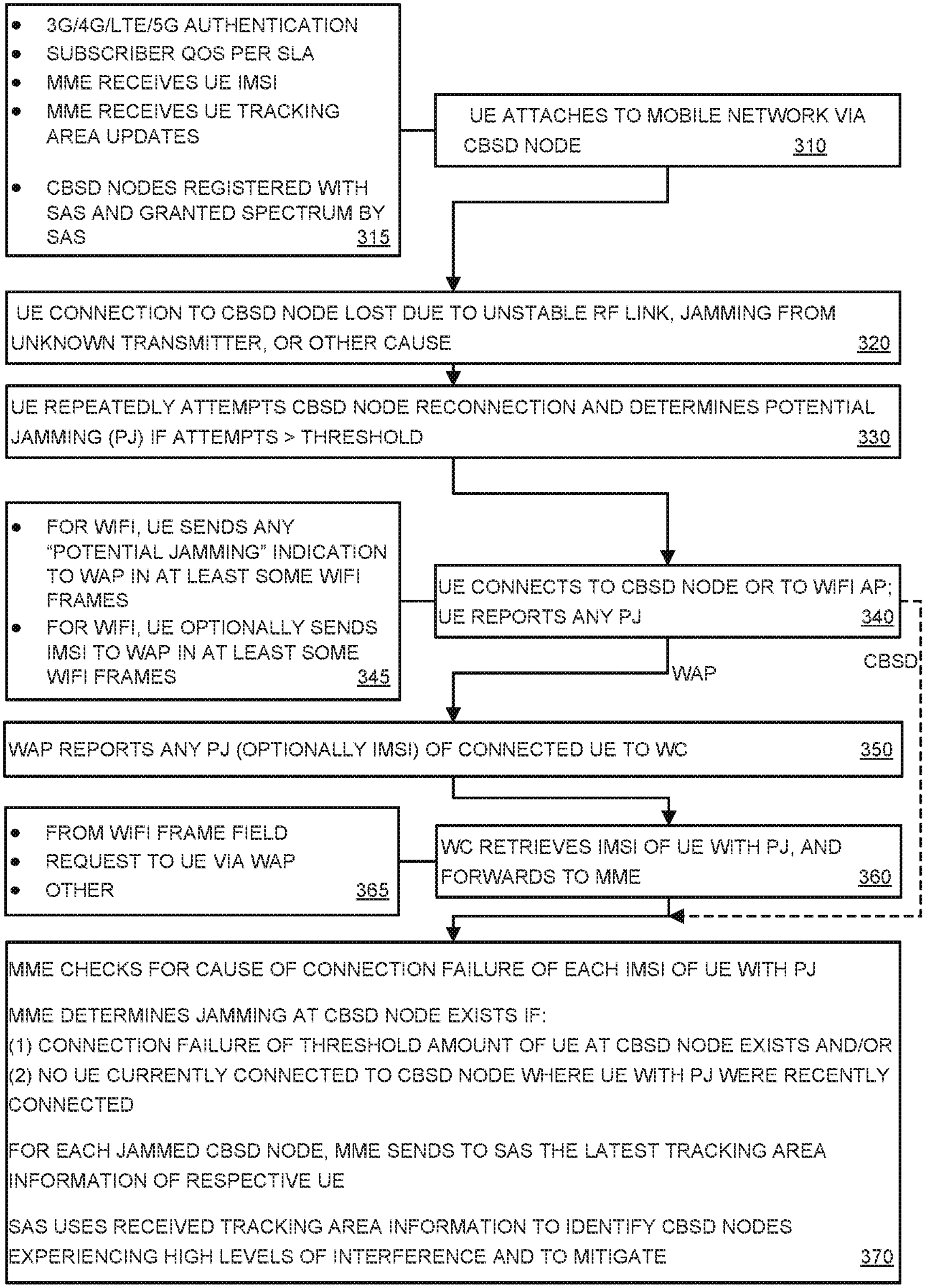
• MME RECEIVES UE TRACKING AREA UPDATES
• CBSD NODES REGISTERED WITH SAS AND GRANTED SPECTRUM BY SAS 215
UE ATTACHES TO MOBILE NETWORK VIA CBSD OR NON-CBSD NODE 210
• UE SENDS IMSI TO WAP IN AT LEAST SOME WIFI FRAMES
• UE PERIODICALLY ENTERS WAP IDLE MODE IN RESPONSE TO NAV VALUES
• OTHER 225
UE IN MN IDLE MODE CONNECTS TO WIFI AP WHEN WAP BECOMES AVAILABLE 220
• TO WAP AND/OR WC
• PERIODICALLY / PER QUERY
• IF NAV > THRESHOLD
• OTHER TRIGGER 235
EACH UE REPORTS NAV VALUES 230
• PERIODICALLY / PER QUERY
• SUMMARY / TREND
• IF AVERAGE > THRESHOLD
• OTHER TRIGGER 245
WAP REPORTS COLLECTED NAV VALUES, TRIG CONDITION, AND/OR IMSI OF CONNECTED UE TO WC 240
HIGH NAV UE OR UE GROUPS DETERMINED BY WAP AND/OR WC 250
IMSI OF AT LEAST SOME HIGH NAV UE OR UE GROUPS RETRIEVED FOR WC FORWARDING TO MME TO INITIATE MIGRATION TO MOBILE NETWORK 260
AFTER HSS CONFIRMATION, MME PAGES UE TO BE MIGRATED USING LATEST TRACKING INFORMATION OF EACH UE 270
UE RECEIVING PAGING REQUEST CONNECT TO MOBILE NETWORK FOR MINIMUM TIME DURATION BEFORE TRYING TO RECONNECT TO WIFI 280
200

FIG. 2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300

FIG. 3

JAMMING MITIGATION IN CBRS NETWORK

FIELD OF THE DISCLOSURE

The present disclosure generally relates to wireless communications systems and related networks, and more particularly to mechanisms supporting the reduction of interference of jamming within the citizens broadband radio service (CBRS) band by unregistered Citizens Broadband Radio Service Devices (CBSDs).

BACKGROUND

This section is intended to introduce the reader to various aspects of art, which may be related to various aspects of the present invention that are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present invention. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

Operators of mobile systems, such as Universal Mobile Telecommunications Systems (UMTSs), Long Term Evolution (LTE), and 5th Generation New Radio (5G-NR) described and being developed by the Third Generation Partnership Project (3GPP), are increasingly relying on wireless macrocell radio access networks (RANs) such as traditional cellular base stations, eNodeBs and the like, along with wireless small cell or microcell RANs in order to deploy, for example, indoor voice and data services to enterprises and other customers. For both macrocell RANs and small/micro cell RANs, increasing demands for wireless throughput make access to additional wireless spectrum desirable.

An example of additional spectrum which is becoming available is that of the citizens broadband radio service (CBRS), a 150 MZ band between 3.55 GHz and 3.70 GHz. Access is currently granted to Citizens Broadband Radio Service Devices (CBSDs) operating according to a Generic Authorized Access (GAA) from 3.55 GHz to 3.65 GHz, with full access to 3.70 GHz expected in the future.

Unfortunately, since any device having a 3.5 GHz transceiver can transmit in the CBRS spectrum, such transmissions may jam or interfere with base stations operating in this band, either intentionally or unintentionally. When a Citizens Broadband Radio Service Device (CBSDs) registered with the Spectrum Access System (SAS) creates more than an acceptable amount of interference to other CBSDs in a CBRS network, the SAS may configure the operation of the offending CBSD to control such interference. However, if a device not registered with the SAS jams or interferes with 3.5 GHz band operations, the SAS has no way of knowing this device or controlling this device. Further, there is also no way of knowing this device at all if there are no complaints about the device.

SUMMARY

Various deficiencies in the prior art are addressed by systems, apparatus, and methods for managing service provider network nodes in a converged network by inserting mobile network user equipment (UE) information into WiFi network communications such that a WiFi control entity may, in response to determining that the UE-inserted information is indicative of a jamming condition at a Citizens Broadband Radio Service Devices (CBSDs) providing mobile network services to the UE, communicate the identification of such UE to various provider equipment such that CBSDs experiencing jamming signals may be identified and mitigation steps taken.

According to one embodiment, a method for use at a mobility management entity (MME) configured to manage user equipment (UE) connectivity to service provider nodes in a mobile network comprises receiving, from a WiFi controller configured to manage a plurality of service provider wireless access points (WAPs) providing network services to UE connected thereto, a message identifying UE associated with a Citizens Broadband Radio Service Device (CBSD) potential jamming condition; and transmitting, toward at least a portion of the identified UE associated with the CBSD potential jamming condition, paging messages configured to cause receiving UE to connect to a respective proximate service provider node of the mobile network.

Additional objects, advantages, and novel features of the invention will be set forth in part in the description which follows, and will become apparent to those skilled in the art upon examination of the following or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present invention and, together with a general description of the invention given above, and the detailed description of the embodiments given below, serve to explain the principles of the present invention.

FIG. **1** depicts a block diagram of a network services architecture suitable for use in various embodiments; and

FIG. **2** depicts a flow diagram of a communications management method according to an embodiment; and

FIG. **3** depicts a flow diagram of a jamming detection and management method according to an embodiment.

It should be understood that the appended drawings are not necessarily to scale, presenting a somewhat simplified representation of various features illustrative of the basic principles of the invention. The specific design features of the sequence of operations as disclosed herein, including, for example, specific dimensions, orientations, locations, and shapes of various illustrated components, will be determined in part by the particular intended application and use environment. Certain features of the illustrated embodiments have been enlarged or distorted relative to others to facilitate visualization and clear understanding. In particular, thin features may be thickened, for example, for clarity or illustration.

DETAILED DESCRIPTION

The following description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Additionally, the term, “or,” as used herein, refers to a non-exclusive or, unless otherwise indicated (e.g., “or else” or “or in the alternative”). Also, the various embodiments described herein are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

The numerous innovative teachings of the present application will be described with particular reference to the presently preferred exemplary embodiments. However, it should be understood that this class of embodiments provides only a few examples of the many advantageous uses of the innovative teachings herein. In general, statements made in the specification of the present application do not necessarily limit any of the various claimed inventions. Moreover, some statements may apply to some inventive features but not to others. Those skilled in the art and informed by the teachings herein will realize that the invention is also applicable to various other technical areas or embodiments.

When known/managed Citizens Broadband Radio Service Devices (CBSDs), or CBSDs such as IoT hubs or gateways, create more than acceptable interference, the Spectrum Access System (SAS) may adapt CBSD operation to control interference to other CBSDs in the CBRS network. However, if a device jams 3.5 GHz, the SAS has no way of knowing this device since this device is not registered with SAS, and there is also no way of knowing this device if there are no complaints about the device.

Various embodiments find particular utility within the context of converged networks configured to enable user equipment (UE) to access subscriber services via any of a plurality of available wireless networks as long as the QoS requirements are satisfied, such as a Wi-Fi network, 4G/LTE/5G network, unlicensed spectral regions and/or more than one network simultaneously. Unlicensed spectrum may comprise, illustratively, the Citizens Broadband Radio Service (CBRS) band at ~3.5 GHz which is utilized by Citizens Broadband Radio Service Devices (CBSDs) registered with a Spectrum Access System (SAS) capable of adapting CBSD operation in accordance with government requirements, network congestions, network interference and the like.

Various embodiments provide systems, methods, and apparatus by UE operational information is leveraged among management entities of multiple subscriber service delivering networks to identity the presence and location of potential jammers in the 3.5 GHz band.

For example, one embodiment contemplates UEs determining that dropped connections to CBSD nodes (e.g., 4G/LTE base stations, eNodeBs and the like) may be jammer related and communicating this determination to provider equipment (PE) management entities upon reconnecting to the CBSD node or connecting to a WiFi access point. The PE management entities may comprise, illustratively, a WiFi controller managing WiFi access points that receives jammer related determinations from UE via the access network servicing the WiFi access points, and various evolved packet core (EPC) entities managing CBSD nodes including the CBSD node associated with the potential jamming. In this manner, the PE management entities may take appropriate mitigating actions. Thus, information pertaining to UE authenticated to receive subscriber network services from both a 4G/LTE network and a WiFi network may be leveraged to identify areas of potential jamming of unlicensed 3.5 GHz signal.

FIG. **1** depicts a block diagram of a network services architecture suitable for use in various embodiments. Specifically, FIG. **1** depicts a converged network services architecture in which user equipment (UE) utilizing network services (e.g., voice, streaming media, data upload/download etc.) may access any available/compatible network as long as the quality of service (QoS) requirements of the relevant network services are satisfied, such as a WiFi network (e.g., 802.11xx networks) or mobile network (e.g., 3G, 4G/LTE, 5G).

Specifically, user equipment (UE) **105-1** through **105**-M (collectively UE **105**) are depicted as being configured for wirelessly communicating with one or more mobile network nodes **100-1** through **110**-N (collectively nodes **110**), the nodes **110** forming a E-UTRAN (e.g., LTE access network) **101** which is connected to an evolved packet core (EPC) **120** so as to provide thereby network services, such as from/to external networks **130**. The UE **105** is also depicted as depicted as being configured for wirelessly communicating with a WiFi Access Point (WAP or AP) **160** which is connected to a WiFi Controller **150** via, illustratively, an access network **170** such as provided by a telecommunications, cable television, and/or other network services provider.

The WAP **160** may comprise an access point such as an 802.11xx wireless access point at a home, business or other location configured to communicate with UE **105** and with an access network **170**. In various embodiments, a network services provider utilizes numerous such access points distributed over a “coverage footprint” to provide network services to mobile devices such as the UE **105** discussed herein.

The nodes **110** may comprise macrocells, small cells, microcells and the like such as eNodeBs, cellular network base stations, 4G/5G repeaters, and similar types of provider equipment. The nodes **110** may include nodes that use licensed 3G/4G/LTE/5G spectrum, unlicensed spectrum such as citizens broadband radio service (CBRS) spectrum, or a combination of licensed and unlicensed spectrum. In the case of nodes **110** having Citizens Broadband Radio Service Device (CBSD) capability, allocations of CBRS spectrum are provided via a Spectrum Access System (SAS) **140**.

The UE **105** may comprise any type of wireless device configured for use in accordance with the various embodiments, such as user terminals (e.g., mobile phones, laptops, tablets and the like), fixed wireless access devices (e.g., set top boxes, digital video recorders, stationary computing devices and the like), Internet of Things (IoT) devices (e.g., sensors, monitoring devices, alarm system devices and the like), and/or other wireless devices. The UE **105** may include UE that use licensed 3G/4G/LTE/5G spectrum, unlicensed spectrum such as CBRS spectrum, or a combination of licensed and unlicensed spectrum. In the case of nodes **110** having CBSD capability, allocations of CBRS spectrum are provided vi **140**. The various embodiments contemplate the UE are configured to communicate via at least one mobile network (MN) radio access technology (RAT) such as 3G, 4G/LTE, and 5G, and at least one WiFi access point technology such as 802.11xx (e.g., 802.11b, 802.11a, 802.11g, 802.11n, 802.11ac, 802.11ax and so on).

As depicted in FIG. **1**, a jamming source (JS) **106** is generating radio frequency (RF) signal in a spectral region proximate that used by UE **105** to communicate with a CBSD node **110**, illustratively a spectral region proximate the 3.5 GHz spectral region or band managed by the SAS **140**. In the case of JS **106** transmitting

The UE **105** comprises a mobile network transceiver **105**-MNT configured for communications with any of nodes **110**, a WiFi transceiver **105**-WFT configured for communication with WAP **160**, and a connection manager **105**-CM configured to manage communications with the nodes **110** and APs **160**, and to facilitate handoffs and UE migration between different nodes **110**, between different APs **160**, and between a node **110** and a WAP **160** as described herein. The UE **105** also comprises various other components, modules, antennas, and the like (not shown).

The connection manager **105**-CM may be configured to cause the UE to give priority to WiFi connections when the UE becomes IDLE in 4G network, as discussed below with respect to FIG. **2**. Further, the connection manager **105**-CM may be configured to insert a UE identifier such as a international mobile subscriber identifier (IMSI) of the UE into a "Connection Information" field included within some or all of the WiFi frames transmitted to the WAP **160** so that the WAP **160** knows the IMSI of connected UE, thereby facilitating rapid migration of such UE from the WiFi network of a WAP **160** to the mobile network of a MN node **110**. Other UE identifiers may also be used depending on the type of UE, provider equipment, network protocols, regulatory requirements and the like, such as a International Mobile Equipment Identity (IMEI), a mobile equipment identifier (MEID), an Electronic serial numbers (ESNs) and so on. The connection manager **105**-CM may be configured to sense the type of connection or radio access network (RAN) currently used by the UE, and to store authentication, location information, subscriber identification and the like associated with the currently used RAN and any previously used RAN.

The nodes **110** are configured to communicate with user equipment (UE) **105** as discussed herein. While the nodes **110** and UE **105** may operate in accordance with various radio access technologies (RATs), the embodiments will be discussed within the context of those nodes **110** and UE **105** configured to communicate with each other as Citizens Broadband Radio Service Devices (CBSDs) configured for operation within the Citizens Broadband Radio Service (CBRS), such as the 100 MHz band from 3.55 GHz to 3.65 GHz, the 150 MZ band between 3.55 GHz and 3.70 GHz, or some other spectral range as defined by the relevant authorities.

As depicted in FIG. **1**, the EPC **120** comprises four network elements; namely, a Serving Gateway (SGW) **122**, a Mobility Management Entity (MME) **124**, a Packet Data Network (PDN) Gateway (PGW) **126**, and a Home Subscriber Server (HSS) **128**. Other network and management elements are typically included within or used to manage an evolved packet core and related communications therewith as will be known to those skilled in the art.

The SGW **122** and PGW **126** handle user data or data plane (DP) functions; they transport the internet protocol (IP) data traffic (i.e., incoming and outgoing packets) between the User Equipment (UE) **105** and the external networks **130**. The external networks **130** may comprise any external network, such as an IP Multimedia Core Network Subsystem (IMS).

The SGW **122** is a point of interconnect between the radio-side (e.g., via a backhaul connection to the E-UTRAN **101** as depicted or some other wireless network) and the EPC **120**. As its name indicates, this gateway serves the UE by routing the incoming and outgoing IP packets. The SGW **122** is the anchor point for intra-LTE mobility (i.e. in case of handover between eNodeBs **110**) and between LTE and other 3GPP accesses. The SGW **122** is logically connected to the PGW **126**.

The PGW **126** is the point of interconnect for routing packets between the EPC **120** and external packet data networks (e.g., Internet Protocol (IP) networks) **330**. The PGW also performs various functions such as IP address/IP prefix allocation, policy control and charging, and other functions.

The MME **124** and HSS **128** handle user signaling or control plane (CP) functions; they process signaling related to mobility and security for E-UTRAN **101** access. The MME **124** is responsible for the tracking and the paging of UE in idle-mode. It is the termination point of the Non-Access Stratum (NAS). The HSS **128** comprises a database that contains user-related and subscriber-related information, and provides support functions in mobility management, call and session setup, user authentication, access authorization, and other functions. It is noted that the SGW **122** may also be used to handle some control plane signaling in various configurations.

An EPC control plane signaling path CP may be used to provide information such as UE messages or signaling may be provided to the MME **124** or SGW **122**. The MME **124** may also interact with various other EPC nodes such as the HSS **128** and SGW **122** to determine information helpful in generating reports and/or providing other information for managing the various networks in implementing the embodiments described herein.

As depicted in FIG. **1**, a Spectrum Access System (SAS) **140** communicates with the EPC **120** and is configured to control access to the CBRS frequency band for RANs and other CBSD devices such as nodes **110** and UEs **105**. Generally speaking, the SAS **140** is configured to ensure that the CBRS frequency band is allocated in accordance with the regulations promulgated by the relevant authorities. The SAS **140** may also communicate with the network manager **150** to perform various tasks in accordance with the embodiments.

As depicted in FIG. **1**, a WiFi controller (WC) **150** communicates with a WiFi Access Point (WAP or AP) **160** via an access network **170**. For simplification of the discussion, only one WAP **160** is shown in FIG. **1** as communicating with WiFi controller **150**, and only one UE **105** (i.e., **105-1**) is shown in FIG. **1** as communicating with that WAP **160**. The WiFi controller **150**, which may be implemented via a general purpose computer server, network operations center (NOC) equipment, or other provider equipment, is configured to perform various WiFi control functions associated with a large number of APs **160**, as well as an even larger number of UEs **105** configured to communicate with the various APs **160**.

The WC **150** may include a WiFi resource management mechanism which manages the coverage, the capacity, and/or other characteristics of individual WAPs **160** in order to optimize the quality of the services delivered to UE **105** via the WAPs **160**. The population of WAPs to be managed may run into the tens or hundreds of thousands, including WAPs that support both private and public WiFi access. Each WAP is associated with a maximum number of WiFi users (UE) that may be connected at any given time. Each connected user must be managed by the WAP. Further, since each WAP may provide one or more carrier signals having formed thereon respective communications channels (illustratively, eleven in basic 802.11 schemes), each WAP must also manage its various channels including inter-channel interference and the like (e.g., by selecting the channels experiencing the least amount of interference).

Generally speaking, the WiFi controller (WC) **150** manages various operational aspects of the WAPs **160** and UE **105** connected thereto in accordance with WAP policies, subscriber/user profiles (e.g., such as defined in service level agreements) and the like. For example, each UE may be associated with a corresponding subscriber/user profile having defined therein guaranteed minimum levels of service, such as a minimum WAP download (DL) throughput, minimum upload (UL) throughput, and/or other minimum QoS levels.

The system **100** of FIG. **1** contemplates UE **105** associated with a network services provider capable of providing network services via either of a mobile network (e.g., 3G/4G/LTE/5G network) or a WiFi network (e.g., 802.11xx network). The WC **150** is configured to enable UE **105** to receive the appropriate QoS when connected to a WAP **160** (e.g., per subscriber policy), and that the WAP **160** is configured to provide the appropriate QoS to the UE **105**.

As discussed below with respect to FIG. **2**, UE **105** authenticated to the mobile network (e.g., E-UTRAN network **101**) may be opportunistically migrated to the WiFi network (e.g., connected to a WAP **160**), and may provide mobile network information (e.g., IMSI and location data) via the WiFi network to the WC **150** to enable, illustratively, rapid and seamless migration of the UE **105** back to the mobile network. That is, since the WC **150** also communicates with the EPC **120** (e.g., with MME **124**), the WC **150** is able to provide information to the MME **124** (e.g., UE IMSI, WAP **160** location and the like) suitable for use in rapidly migrating UE from coordinate the delivery of network services to subscriber/user UE **105**.

Various elements or portions thereof depicted in FIG. **1** and having functions described herein are implemented at least in part as computing devices having communications capabilities, including for example the UE **105**, nodes **110**, SAS **140**, WC **150**, WAP **160** and various portions of the EPC **120**. These elements or portions thereof have computing devices of various types, though generally a processor element (e.g., a central processing unit (CPU) or other suitable processor(s)), a memory (e.g., random access memory (RAM), read only memory (ROM), and the like), various communications interfaces (e.g., more interfaces enabling communications via different networks/RATs), input/output interfaces (e.g., GUI delivery mechanism, user input reception mechanism, web portal interacting with remote workstations and so on) and the like.

As such, the various functions depicted and described herein may be implemented at the elements or portions thereof as hardware or a combination of software and hardware, such as by using a general purpose computer, one or more application specific integrated circuits (ASIC), or any other hardware equivalents or combinations thereof. In various embodiments, computer instructions associated with a function of an element or portion thereof are loaded into a respective memory and executed by a respective processor to implement the respective functions as discussed herein. Thus various functions, elements and/or modules described herein, or portions thereof, may be implemented as a computer program product wherein computer instructions, when processed by a computing device, adapt the operation of the computing device such that the methods or techniques described herein are invoked or otherwise provided. Instructions for invoking the inventive methods may be stored in tangible and non-transitory computer readable medium such as fixed or removable media or memory, or stored within a memory within a computing device operating according to the instructions.

CBSD Registration & Deregistration

Generally speaking, before a new CBSD (e.g., a node **110** being added to the network **101**) can transmit in the CBRS frequency band, it needs to register with the SAS **140**. The CBSD sends a registration request to the SAS **140** containing information about its installation parameters, such at the owner, location, and transmit characteristics of a node **110**. The SAS **140** responds to the CBSD with a registration response. If the SAS **140** approves the registration request, then the SAS **140** will respond with a CBSD ID, and the CBSD is registered. If the SAS **140** rejects the registration request, then the SAS **140** will respond with an error message. The CBSD needs to correct the error and send another registration request.

Normally the CBSD requires CPI validation. In a single-step registration process, the CPI provides the installation parameters of the CBSD (signed with its own CPI certificate) to the CBSD. Then, the CBSD sends a registration request to the SAS including the signed installation parameters in a "cpiSignatureData" field. In a multi-step registration process, the CPI uses the SAS Portal (or another user interface that's integrated with the SAS Portal) to send the installation parameters to the SAS. Then, the CBSD sends a registration request to the SAS without installation parameters. The SAS combines the information from the SAS Portal and the CBSD to process the registration request.

If a CBSD needs to be decommissioned or simply moved, it will first send a deregistration request to the SAS. Thereby indicating that the CBSD no longer wishes to be listed in the SAS with the parameters that it sent in its registration request.

If a CBSD subsequently needs to transmit again, then the CBSD may send a registration request with updated parameters later.

Therefore, in operation a CBSD such as a node **110** registers with the SAS **140** (directly or via PE such as a network manager) by providing the SAS **140** with location and capability information as discussed above.

A UE wireless device such as a user terminal, fixed wireless access device, IoT device or other UE waits for authorization from its corresponding CBSD (e.g., corresponding node **110**) before transmitting in the CBRS frequency band. Each CBSD such as a node **110** operating within the CBRS frequency band will transmit and receive wireless data within one or more respective coverage areas as discussed above, wherein some of the coverage areas may be overlapping.

Connection Manager and Connection Information

Various embodiments contemplate systems, methods, mechanisms and the like to reduce idle moments in UE converged network communications by dynamically migrating users between WiFi networks (e.g., 802.11xx) and mobile networks (e.g., 3G, 4G/LTE, 5G) by updating and maintaining UE information for each network (e.g., identification/attachment information), using congestion-indicative information to opportunistically identify UE handoff/migration opportunities, and rapidly executing handoff/migration of one or more UE using the updated/maintained UE information.

An indicator of WiFi network utilization level is a network allocation vector (NAV), which is used by UE such as mobile phones to signal to other UE an amount of time for the other UE to wait before accessing the same WiFi network channel; essentially a virtual count-down from some number that, when reaching zero, triggers access to the network. Thus, the NAV may be used as a virtual carrier sensing mechanism for UE accessing transmission channels in a WiFi network.

The connected UE indicates a NAV is set by a UE connected to a WiFi channel according to (1) the expected UE data transmission time, and (2) the expected NACK/ACK time for the data transmitted. That is, the NAV set by the connected UE is generally equal to the expected time for data transmission/reception and related acknowledgment of the UE currently transmitting/receiving data. To avoid collisions and conserve battery power, other UE will wait in an idle state for at least the duration of the NAV countdown before trying to access to the network. These idle times/moments become problematic with increasing number of WiFi-enabled UE and interference in WiFi bands.

In various embodiments, the structure of the WiFi frame use by UE to communicate with the WAP is modified to include a "Connection Information" field implemented as part of a data or payload portion of a frame, part of header portion of a frame, part of a reserved frame type or subtype, or via some other modification to the WiFi frame or packet structure. By communicating the IMSI of the UE with each WiFi frame such as via the Connection Information field, the WAP **160** and WC **150** know exactly which UEs are connected to the WAP **160**. In this manner, a decision to migrate one or more UE from a WAP **160** to a MN node **110** may be quickly executed by forwarding the known IMSI of the UE to the MME to initiate thereby the MN attachment procedure. This decision may be made by the WC **150** or some other management entity.

TABLE 1

Simplified 802.11 Frame Format

FC	D/I	Add1	Add2	Add3	Sequence control	Add4	Frame body	Frame check seq

An 802.11 frame format such as may be used in the various embodiments generally comprises a plurality of fields concatenated as follows (including optional fields and frame-type specific fields), as follows:

Frame Control (FC, 2 octets): Indicates the type of frame (control, management, or data) and provides control information. Control information includes whether the frame is to or from a DS, fragmentation information, and privacy information.

Duration/Connection ID (D/I, 2 octets): If used as a duration field, indicates the time (in microseconds) the channel will be allocated for successful transmission of a MAC frame. In some control frames, this field contains an association, or connection, identifier.

Address 1 (6 octets): Receiver Address for all frame types.

Address 2 (6 octets): Transmitter Address for all frame types.

Address 3 (6 octets): BSSID for management frames, BSSID or source address (SA) or destination address (DA) for data frames.

Sequence Control (6 octets): Contains a 4-bit fragment number subfield, used for fragmentation and reassembly, and a 12-bit sequence number used to number frames sent between a given transmitter and receiver.

Address 4 (6 octets) BSSID or SA for data frames.

Frame Body (0 to 2312 octets): Contains a medium access control (MAC) service data unit (MSDU) or a fragment of an MSDU. The MSDU is a LLC protocol data unit or MAC control information.

Frame Check Sequence (4 octets): A 32-bit cyclic redundancy check.

The transmitter address and receiver address are the MAC addresses of stations joined to the WAP that are transmitting and receiving frames over the wireless LAN. The service set ID (SSID) identifies the wireless LAN over which a frame is transmitted. The source address and destination address are the MAC addresses of stations, wireless or otherwise, that are the ultimate source and destination of this frame.

Various embodiments contemplate a communication mechanism for NAV in which, for example, the MAC layer frame headers contain a duration field that specifies the transmission time required for the frame, during which time the medium will be busy. The stations listening on the wireless medium read the Duration field (D/I field in the picture) and set their NAV, which is an indicator for a station on how long it must defer from accessing the medium. In this manner, all UEs decode a header part of MAC frames that other UEs are sending over the air, and read duration fields of these MAC frames in order to set their own NAV values (i.e., to set a 'wait time' before accessing to medium).

Jamming Detection, Jamming Information, and Jamming Mitigation

Various embodiments contemplate systems, methods, mechanisms and the like to identify possible jamming of, or interference with, unlicensed spectrum such as CBRS spectrum used by CBSD nodes **110** communicating with UE **105** as previously discussed.

An indicator of CBRS spectrum jamming is a loss of connection between UE **105** and a CBSD node **110** where a plurality of reconnection attempts fail. The number of reconnection attempts indicative of failure may be selected as 5, 10 or some other predetermined number of attempts. The number of reconnection attempts indicative of failure may be selected or modified based upon criteria such as existing network congestion, historical loss of connection at that node **110** or by that UE **105**, and/or other criteria. For example, given a relatively congested network (e.g., utilization level above some threshold amount such as 90% or 95%), it may be the case that occasional connection losses occur and that several or more that a usual amount of attempts at reconnection is normal.

In various embodiments, the structure of the WiFi frame use by UE to communicate with the WAP is modified to include a "Jamming Information" field implemented as part of a data or payload portion of a frame, part of header portion of a frame, part of a reserved frame type or subtype, or via some other modification to the WiFi frame or packet structure. By communicating an indication of jamming (e.g., a number of reconnection attempts after a connection loss) or determination that jamming may have occurred such as via the Jamming Information filed, the WAP **160** and WC **150** know exactly which UEs may have been subjected to jamming and the respective UE information may be used to locate the source of such jamming.

It is noted that the information transmitted by the UE as described above with respect to the Connection Information field and Jamming Information field may be included within a single field (e.g., jamming related information may be included within the connection information filed along with IMSI, NAV and/or other UE information).

FIG. **2** depicts a flow diagram of a communications management method according to an embodiment. The method **200** of FIG. **2** contemplates various functions performed by UE **105**, nodes **110**, SAS **140**, WC **150**, WAP **160**, and other functional entities as described above with respect to FIG. **1**.

Generally speaking, the method **200** of FIG. **2** is directed to managing UE **105** associated with a network services provider capable of providing network services via either of a mobile network (e.g., 3G/4G/LTE/5G network) or a WiFi network (e.g., 802.11xx network). The method **200** contemplates that UE **105** authenticated to the mobile network and opportunistically migrated to the WiFi network while also providing mobile network information to the WC **150** to enable thereby a rapid and seamless migration of the UE back to the mobile network.

At step **210**, UE attached to the mobile network via a CBSD node **110** or a non-CBSD node **110** (e.g., UE **105** attaches to a node **110** of a 3G, 4G/LTE, or 5G mobile network). Referring to box **215**, the attachment comprises various known steps such as the UE being authenticated by the mobile network, and the UE being associated with a subscriber having a service level agreement (SLA) defining quality of service (QoS) and other metrics of network services to be provided to the subscriber. The international mobile subscriber identifier (IMSI) of the UE and other information is provided to the MME, along with the current tracking area of the UE, which is periodically updated as the UE location moves between different nodes **110** or sectors thereof. Other functions are also contemplated during this attachment as is known. It is noted that the a CBSD node **110** is mobile network node that has previously been registered with the SAS **140**, and which has been granted spectrum by the SAS **140** for use in communicating with UE **105** and for performing other functions as is known.

At step **220**, UE currently in a mobile network idle mode (still authenticated to the MN, but not currently receiving network services from the MN) searches for a WiFi Access Point (WAP or AP) such as WAP **160** and, if a WAP is available, connects to the WAP. At which time the UE begins obtaining networks services such as voice, streaming media, sensor upload/download and/or other network services via the WAP **160** rather than via a node **110**.

Referring to box **225**, the UE connects to and begins receiving network services from the WAP (e.g., from a specific one or more channels of the WAP). The UE includes its IMSI in some or all of the WiFi frames sent to the WAP within a “Connection Information” field implemented as part of a data or payload portion of a frame, part of header portion of a frame, part of a reserved frame type or subtype, or via some other modification to the WiFi frame or packet structure.

Further, all UE receiving network services from the WAP enter and exit a WAP idle mode associated with their respective one or more channels of the WAP they are using in response to respective one or more NAV values associated with UE currently using those one or more channels of the WAP.

At step **230**, each UE reports its NAV values. Referring to box **235**, the NAV values (e.g., individual, average and/or trend) of the UE may be reported to the WAP **160** or directly to the WC **150**, the NAV values of the UE may be reported periodically, in response to a query, if greater than a threshold level, and/or if some other triggering condition being met.

At step **240**, each WAP **160** reports the collected NAV values (e.g., actual, rolling average etc.) and/or trigger condition levels (e.g., individual or group average and/or trend), and (optionally) the stored IMSI of currently connected UE to the WC **150**. Referring to box **245**, the NAV values of each WAP **160** may be reported to the WC **150** either periodically, in response to a query, if greater than a threshold level, and/or in response to some other triggering condition being met. Optionally, the IMSI values extracted from WiFi frame received from the UE serviced by the WAP **160** may be reported to the WC **150** along with the NAV values.

At step **250**, UE or group(s) of UE (e.g., UE attached to a particular WAP, or UE from a particular customer/company) exhibiting nigh NAV values are determined by the WAP or WC. This determination may be made with respect to minimum desired NAV values for any UE, respective minimum desired NAV values for UE of differing classes (e.g., gold, silver, bronze subscription tiers), NAV values of UE associated with specific customers or users and so on. Generally speaking, the NAV values are used as a proxy for congestion or QoS, and UE are migrated to the MN to reduce such congestion and/or improve QoS for both migrated and non-migrated UE.

At step **260**, the IMSI or other identifier of the determined UE or group(s) of UE to be migrated are obtained from WAP(s) supporting the determined UE (or data already stored at the WP **150** for the WAP(s) **160**). As previously noted, each WAP **160** knows the IMSI of each UE **105** communicating with the WAP **160** due to the UE **105** inserting its IMSI into a Connection Information” field in each WiFi frame transmitted to the WAP. As such, there is no need to obtain the IMSI from the UE at this time, though a request message may optionally be transmitted to the UE to verify UE connection and/or IMSI.

At step **270**, after the MME receives subscription confirmation from the HSS, the MME begins pages the UE to be migrated using the latest tracking information of each UE (e.g., the tracking information provided to the MME during initial authentication or later).

At step **280**, each UE receiving a paging request connects to the mobile network for a minimum time duration before trying to opportunistically reconnect to a WAP.

The method **200** then proceeds to step **220**.

FIG. **3** depicts a flow diagram of a jamming detection and management method according to an embodiment. Specifically, the method **300** of FIG. **3** contemplates various functions performed by UE **105**, nodes **110**, WAP **160**, and other functional entities as described above with respect to FIG. **1**.

At step **310**, UE attached to the mobile network via a CBSD node or a non-CBSD node (e.g., UE **105** attaches to a node **110** of a 3G, 4G. LTE, or 5G mobile network). Referring to box **315**, the attachment comprises various known steps such as the UE being authenticated by the mobile network, and the UE being associated with a subscriber having a service level agreement (SLA) defining quality of service (QoS) and other metrics of network services to be provided to the subscriber. The international mobile subscriber identifier (IMSI) of the UE and other information is provided to the MME, along with the current tracking area of the UE, which is periodically updated as the UE moves between nodes **110** or sectors thereof. Other functions are also contemplated during this attachment as is known. It is noted that the a CBSD node is one that has previously been registered with the SAS and which has granted spectrum by the SAS for use in communicating with CBSD and performed other functions as is known.

At step **320**, the UE connection to the CBSD node is lost due to an unstable RF link, jamming from an unknown transmitter or some other cause.

At step **330**, the UE attempts to reconnect to the CBSD node for at least a predetermined number of attempts. If the number of attempts exceeds a threshold level, then a potential jamming condition exists. As previously noted, the number of attempts indicative of a potential jamming condition may comprise five, 10, 20 or some other number of attempts, and that the number of attempts indicative of a potential jamming condition may be adapted in response to network congestion and/or other factors.

At step **340**, the UE connects to a CBSD node **110** or to a WAP **160**. If a potential jamming condition exists, then the UE communicates this condition.

If the UE has reconnected to the CBSD node after more than a threshold number of attempts, then the potential jamming condition is communicated to the CBSD node which in turn transmits a message to the MME indicating the potential jamming condition. In this case, the method **300** may proceed to step **370**.

Referring to box **345**, if at step **340** the UE connects to a WAP **160**, then a potential jamming indication may be communicated to the WAP **160** and WC **150** within a Wi-Fi frame such as discussed above with respect to the connection information field and/or jamming information field. Optionally, the IMSI of the UE may also be included in the WiFi frame.

At step **350**, the WAP **160** reports any potential jamming indication (optionally along with UE IMSI) to the WC **150**, either via direct message or by forwarding the UE WiFi frames including relevant information fields.

At step **360**, the WC **150** retrieves the IMSI of any UE reporting a potential jamming condition and forwards the retrieved IMSI to the MME **124**. Referring to box **365**, the WC **150** may retrieve this information from UE WiFi frames including relevant information fields, by directly requesting the IMSI from the UE via the WAP, or by some other means (e.g., WAP storage of IMSI of connected UE).

At step **370**, the MME checks for the cause of connection failure of each IMSI of UE associated with a potential jamming condition.

In particular, the MME determines that jamming at a CBSD node **110** exists if (1) a threshold amount of connection failure is associated with the CBSD node **110** and/or (2) no UE **105** are currently connected to the CBSD node **110** where UE associated with a potential jamming condition were recently connected.

Further, for each CBSD node determined by the MME to be jammed, the MME transmits to the SAS **140** the latest tracking area information stored by the MME (or other provider equipment) of the UE associated with a potential jamming condition.

Further, the SAS **140** receives the UE tracking area information to identify one or more CBSD nodes proximate the tracking area which may be experiencing high levels of interference and to take mitigation steps. Such mitigation steps may include migrating UE from the identified CBSD nodes to other CBSD nodes, proximate WAPs and/or other wireless networks depending upon coverage areas, location of UE, subscriber agreements and the like.

Various modifications may be made to the systems, methods, apparatus, mechanisms, techniques and portions thereof described herein with respect to the various figures, such modifications being contemplated as being within the scope of the invention. For example, while a specific order of steps or arrangement of functional elements is presented in the various embodiments described herein, various other orders/arrangements of steps or functional elements may be utilized within the context of the various embodiments. Further, while modifications to embodiments may be discussed individually, various embodiments may use multiple modifications contemporaneously or in sequence, compound modifications and the like. It will be appreciated that the term "or" as used herein refers to a non-exclusive "or," unless otherwise indicated (e.g., use of "or else" or "or in the alternative").

Although various embodiments which incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings. Thus, while the foregoing is directed to various embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof.

What is claimed is:

1. At a mobility management entity (MME) configured to manage user equipment (UE) connectivity to service provider nodes in a mobile network, a method comprising:

receiving, from a Wi-Fi controller configured to manage a plurality of service provider wireless access points (WAPs) providing network services to UE connected thereto, a message identifying UE associated with a Citizens Broadband Radio Service Device (CBSD) potential jamming condition; and

transmitting, toward at least a portion of the identified UE associated with the CBSD potential jamming condition, paging messages configured to cause receiving UE to connect to a respective proximate service provider node of the mobile network.

2. The method of claim **1**, wherein MME transmitting of the paging messages toward the UE is responsive to receiving Home Subscriber Server (HSS) confirmation of mobile network subscription associated with the UE.

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

responsive to determining that a jamming condition at one or more CBSD nodes exists, transmitting toward a Spectrum Access System (SAS) tracking area information of identified UE associated with each of the one or more CBSD nodes.

4. The method of claim **3**, further comprising determining that a jamming condition exists at a CBSD node associated with a potential jamming condition if an amount of UE connection failure at the CBSD node exceeds a threshold amount, or if there are currently no UE connected to the CBSD node.

5. The method of claim **3**, wherein the transmitted SAS tracking area information is configured to enable SAS mitigation of proximate CBSD node jamming conditions.

6. The method of claim **1**, wherein the transmitted paging messages are configured to migrate identified UE associated with the CBSD potential jamming condition to a different service provider CBSD node.

7. The method of claim **1**, wherein the transmitted paging messages are configured to migrate other UE associated with the CBSD potential jamming condition to a different service provider CBSD node.

8. The method of claim **3**, wherein the respective proximate service provider node of the mobile network comprises a CBSD node identified by the SAS as having a location associated with the SAS tracking area information of the identified UE.

9. The method of claim **1**, wherein the UE associated with the CBSD potential jamming condition are identified via international mobile subscriber identifier (IMSI) values included within the message received from the Wi-Fi controller.

10. The method of claim **1**, wherein the CBSD potential jamming condition comprises an indication by a UE of a failure of the UE to connect to the CBSD node after a threshold number of attempts.

11. The method of claim **10**, further comprising storing the indication of the CBSD potential jamming condition within a Jamming Information (JI) field, a payload portion, or within a reserved frame type or subtype of at least some of UE Wi-Fi frames.

12. The method of claim **1**, wherein each UE is configured to preferentially connect to an available WAP in response to entering a mobile network idle state.

13. A system for managing service provider network nodes in a converged network, the service provider network nodes comprising Citizens Broadband Radio Service Devices (CBSDs) configured for providing network services of the service provider to user equipment (UE) connected thereto, the system comprising:

a mobility management entity (MME) configured to manage user equipment (UE) connectivity to service provider nodes in a mobile network; and

the MME, in response to receiving from a Wi-Fi controller a message identifying UE associated with a Citizens Broadband Radio Service Device (CBSD) potential jamming condition, transmitting, toward at least a portion of the identified UE associated with the CBSD potential jamming condition, paging messages configured to cause receiving UE to connect to a respective proximate service provider node of the mobile network, the Wi-Fi controller being configured to manage a plurality of service provider wireless access points (WAPs) providing the network services to UE connected thereto.

14. The system of claim **13**, wherein MME transmitting of the paging messages toward the UE is responsive to receiving Home Subscriber Server (HSS) confirmation of mobile network subscription associated with the UE.

15. The system of claim **13**, further comprising:

responsive to determining that a jamming condition at one or more CBSD nodes exists, transmitting toward a Spectrum Access System (SAS) tracking area information of identified UE associated with each of the one or more CBSD nodes; and

determining that a jamming condition exists at a CBSD node associated with a potential jamming condition if an amount of UE connection failure at the CBSD node exceeds a threshold amount, or if there are currently no UE connected to the CBSD node.

16. The system of claim **13**, wherein the transmitted SAS tracking area information is configured to enable SAS mitigation of proximate CBSD node jamming conditions.

17. The system of claim **15**, wherein the respective proximate service provider node of the mobile network comprises a CBSD node identified by the SAS as having a location associated with the tracking area information of identified UE.

18. The system of claim **13**, wherein the UE associated with the CBSD potential jamming condition are identified via international mobile subscriber identifier (IMSI) values included within the message received from the Wi-Fi controller.

19. The system of claim **13**, wherein the CBSD potential jamming condition comprises an indication by a UE of a failure of the UE to connect to the CBSD node after a threshold number of attempts, the indication of the CBSD potential jamming condition being stored by the UE within a Jamming Information (JI) field, a payload portion, or within a reserved frame type or subtype of at least some of UE Wi-Fi frames.

20. A tangible and non-transitory computer readable storage medium storing instructions which, when executed by a computer, adapt operation of the computer to provide method for managing service provider network nodes at a mobility management entity (MME) configured to manage user equipment (UE) connectivity to the service provider network nodes, the method comprising:

in response to receiving from a Wi-Fi controller a message identifying UE associated with a Citizens Broadband Radio Service Device (CBSD) potential jamming condition, transmitting toward at least a portion of the identified UE associated with the CBSD potential jamming condition, paging messages configured to cause receiving UE to connect to a respective proximate service provider node of a mobile network.

21. The tangible and non-transitory computer readable storage medium of claim **20**, wherein the method further comprises:

responsive to determining that a jamming condition at one or more CBSD nodes exists, transmitting toward a Spectrum Access System (SAS) tracking area information of identified UE associated with each of the one or more CBSD nodes; and

determining that a jamming condition exists at a CBSD node associated with a potential jamming condition if an amount of UE connection failure at the CBSD node exceeds a threshold amount, or if there are currently no UE connected to the CBSD node.

22. The tangible and non-transitory computer readable storage medium of claim **21**, wherein the respective proximate service provider node of the mobile network comprises a CBSD node identified by the SAS as having a location associated with the tracking area information of identified UE.

23. The tangible and non-transitory computer readable storage medium of claim **21**, wherein the UE associated with the CBSD potential jamming condition are identified via international mobile subscriber identifier (IMSI) values included within the message received from the Wi-Fi controller.

24. The tangible and non-transitory computer readable storage medium of claim **21**, wherein the CBSD potential jamming condition comprises an indication by a UE of a failure of the UE to connect to the CBSD node after a threshold number of attempts, the indication of a potential jamming condition by a UE being stored within a Jamming Information (JI) field, a payload portion, or within a reserved frame type or subtype of at least some of UE Wi-Fi frames.

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