

INTELLIGENT CHANNEL ASSESSMENT AND CROSS-SPECTRUM COMMUNICATION

TECHNICAL FIELD

[0001] Various aspects of this disclosure generally relate to communication systems, and more particularly, to wireless ad hoc networks.

BACKGROUND

[0002] In many telecommunication systems, communications networks are used to exchange messages among several interacting spatially-separated devices. Networks may be classified according to geographic scope, which could be, for example, a metropolitan area, a local area, or a personal area. Such networks may be designated respectively as a wide area network (WAN), metropolitan area network (MAN), local area network (LAN), wireless local area network (WLAN), or personal area network (PAN). Networks also differ according to the switching/routing technique used to interconnect the various network nodes and devices (e.g., circuit switching vs. packet switching), the type of physical media employed for transmission (e.g., wired vs. wireless), and the set of communication protocols used (e.g., Internet protocol suite, Synchronous Optical Networking (SONET), Ethernet, etc.).

[0003] Wireless networks may be preferred when the network elements are mobile and may have dynamic connectivity needs, or if the network architecture is formed in an ad hoc, rather than fixed, topology. Wireless networks may employ intangible physical media in an unguided propagation mode using electromagnetic waves in the radio, microwave, infrared, optical, etc., frequency bands. Wireless networks may facilitate user mobility and rapid field deployment when compared to fixed wired networks.

[0004] A mesh network is a network topology in which each node relays data for the network. All mesh nodes cooperate in the distribution of data in the network. Wireless mesh networks can be considered a type of wireless ad hoc network. Wireless ad hoc networks may take any form of network topology.

[0005] Mesh protocols for long-range low-power wireless communication have been around for quite some time. Communication links extending for kilometres of lengths are feasible. It is possible for large amount of data generated by geographically distributed devices to be aggregated at a common gateway device, and be eventually pushed to the cloud. Unfortunately, while building a mesh network, CTI (cross-technology interference, i.e., interference from other radio access technologies that share the same spectrum) turns out to be the cause of unreliable data transmission.

[0006] There have been numerous traditional techniques employed to mitigate the impact of CTI like exploiting spatial diversity, channel diversity, packet redundancy, error correction capability, interference cancellation, etc. However, the fundamental issue with traditional solutions is that they stick to one single spectrum (e.g. 433 MHz, 2.4 GHz or 5 GHz) forever. As these frequencies are becoming more and more congested, interference rises and wireless communication link quality suffers. This lack of flexibility of the traditional techniques and the increasing utilization of the scarce shared spectrum limits the reliability that can be achieved.

[0007] Many industries (e.g., construction, manufacturing, petroleum, electrical power, transport, etc.) need real-time data from multiple deployed sensors despite signal obstructions, and are strictly regulated in terms of monitoring requirements. Therefore, a wireless technology that is highly reliable may be desirable.

SUMMARY

[0008] The following presents a simplified summary of one or more aspects in order to provide a basic understanding of such aspects. This summary is not an extensive overview of all contemplated aspects, and is intended to neither identify key or critical elements of all aspects nor delineate the scope of any or all aspects. Its sole purpose is to present some concepts of one or more aspects in a simplified form as a prelude to the more detailed description that is presented later.

[0009] In an aspect of the disclosure, a wireless technology (hereinafter referred to as SmartCast) that enables reliable and energy efficient cross-spectrum communication is provided. SmartCast may learn the cause of packet drops on-the-fly by looking at packet signatures and exploits the best spectrum opportunistically. SmartCast enables distributed radios to communicate across different spectrum technologies without a centralized controller.

[0010] In an aspect of the disclosure, a method, a computer-readable medium, and an apparatus (e.g., a station) for wireless communication are provided. The apparatus may use clear channel assessment to determine whether a first spectrum is busy. The apparatus may perform data transmission over the first spectrum in response to the first spectrum is determined to be not busy. In response to the first spectrum is determined to be busy, the apparatus may determine whether cross technology interference is detected in the first spectrum. The apparatus may switch data transmission from the first spectrum to a second spectrum when cross technology interference is detected in the first spectrum. The apparatus may perform exponential backoff when cross technology interference is not detected in the first spectrum.

[0011] To the accomplishment of the foregoing and related ends, the one or more aspects include the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative features of the one or more aspects. These features are indicative, however, of but a few of the various ways in which the principles of various aspects may be employed, and this description is intended to include all such aspects and their equivalents.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 shows an example wireless communication system in which aspects of the present disclosure may be employed.

[0013] FIG. 2 is a diagram illustrating an example of a system that utilizes SmartCast to achieve reliable and energy efficient cross-spectrum communication.

[0014] FIG. 3 is a diagram illustrating an example of a wireless mesh network with communication links of different quality.

[0015] FIG. 4 is a diagram illustrating an example of a wireless mesh network that utilizes SmartCast to achieve reliable and energy efficient cross-spectrum communication.

[0016] FIG. 5 shows an example functional block diagram of a wireless device that may utilize SmartCast to achieve reliable and energy efficient cross-spectrum communication.

[0017] FIG. 6 is a flowchart of an exemplary method for utilizing SmartCast to achieve reliable and energy efficient cross-spectrum communication.

[0018] FIG. 7 is a flowchart of another exemplary method for utilizing SmartCast to achieve reliable and energy efficient cross-spectrum communication.

[0019] FIG. 8 is a functional block diagram of an example wireless communication device that may utilize SmartCast to achieve reliable and energy efficient cross-spectrum communication.

DETAILED DESCRIPTION

[0020] Various aspects of systems, apparatuses, computer-readable medium, and methods are described more fully hereinafter with reference to the accompanying drawings. The disclosure may, however, be embodied in many different forms and should not be construed as limited to any specific structure or function presented throughout the disclosure. Rather, the various aspects are provided so that the disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art. Based on the teachings herein one skilled in the art should appreciate that the scope of the disclosure is intended to cover any aspect of the systems, apparatuses, computer program products, and methods disclosed herein, whether implemented independently of, or combined with, any other aspect of the invention. For example, an apparatus may be implemented or a method may be practiced using any number of the aspects set forth herein. In addition, the scope of the invention is intended to cover such an apparatus or method, which is practiced using other structure, functionality, or structure and functionality in addition to or other than the various aspects of the invention set forth herein. It should be understood that any aspect disclosed herein may be embodied by one or more elements of a claim.

[0021] Although particular aspects are described herein, many variations and permutations of the particular aspects fall within the scope of the disclosure. Although some benefits and advantages of aspects may be mentioned, the scope of the disclosure is not intended to be limited to particular benefits, uses, or objectives. Rather, aspects of the disclosure are intended to be broadly applicable to different wireless technologies, system configurations, networks, and transmission protocols, some of which are illustrated by way of example in the figures and in the following description of aspects of the disclosure. The detailed description and drawings are merely illustrative of the disclosure rather than

limiting, the scope of the disclosure being defined by the appended claims and equivalents thereof.

[0022] Wireless network technologies may include various types of WLANs. A WLAN may be used to interconnect nearby devices together, employing networking protocols. The various aspects described herein may apply to various communication standards, e.g., a wireless protocol standard.

[0023] In some aspects, wireless signals may be transmitted according to an IEEE 802.11 protocol using orthogonal frequency-division multiplexing (OFDM), direct-sequence spread spectrum (DSSS) communications, a combination of OFDM and DSSS communications, or other schemes. Implementations of the IEEE 802.11 protocol may be used for sensors, metering, and smart grid networks. In an aspect, certain devices implementing the IEEE 802.11 protocol may consume less power than devices implementing other wireless protocols, and/or may be used to transmit wireless signals across a relatively long range, for example about one kilometer or longer. In some aspects, wireless signals may be transmitted accordingly to IEEE 802.15.4 protocol for low power communication.

[0024] In some implementations, a WLAN may include various devices, e.g., the components that access the wireless network. For example, there may be two types of devices: access points (APs) and clients (also referred to as stations or “STAs”). An AP may serve as a hub or base station for the WLAN and a STA may serve as a user of the WLAN. For example, a STA may be a laptop computer, a personal digital assistant (PDA), a mobile phone, etc. In an example, a STA may connect to an AP via a Wi-Fi™ (e.g., an IEEE 802.11 protocol) compliant wireless link to obtain connectivity to the Internet or to other wide area networks. In another example, a STA may connect to an AP via a wireless network that provides low power communication between devices (e.g., using IEEE 802.15.4 protocol). In some implementations, a STA may also be used as an AP.

[0025] An access point may also include, be implemented as, or known as a NodeB, Radio Network Controller (RNC), eNodeB, Base Station Controller (BSC), Base Transceiver Station (BTS), Base Station (BS), Transceiver Function (TF), Radio Router, Radio Transceiver, connection point, or some other terminology.

[0026] A station may also include, be implemented as, or known as an access terminal (AT), a subscriber station, a subscriber unit, a mobile station, a remote station, a remote terminal, a user terminal, a user agent, a user device, a user equipment, or some other

terminology. In some implementations, a station may include a cellular telephone, a cordless telephone, a Session Initiation Protocol (SIP) phone, a wireless local loop (WLL) station, a personal digital assistant (PDA), a handheld device having wireless connection capability, or some other suitable processing device connected to a wireless modem. Accordingly, one or more aspects taught herein may be incorporated into a phone (e.g., a cellular phone or smartphone), a computer (e.g., a laptop), a portable communication device, a headset, a portable computing device (e.g., a personal data assistant), an entertainment device (e.g., a music or video device, or a satellite radio), a gaming device or system, a global positioning system device, or any other suitable device that is configured to communicate via a wireless medium.

[0027] The term “associate,” or “association,” or any variant thereof should be given the broadest meaning possible within the context of the present disclosure. By way of example, when a first apparatus associates with a second apparatus, the two apparatuses may be directly associated or intermediate apparatuses may be present. For purposes of brevity, the process for establishing an association between two apparatuses will be described using a handshake protocol that employs an “association request” by one of the apparatus followed by an “association response” by the other apparatus. In some aspects, the handshake protocol may require other signaling, such as by way of example, signaling to provide authentication.

[0028] Any reference to an element herein using a designation such as “first,” “second,” and so forth does not limit the quantity or order of such elements. Rather, such designations are used herein as a convenient method of distinguishing between two or more elements or instances of an element. Thus, a reference to first and second elements does not mean that only two elements can be employed, or that the first element must precede the second element. In addition, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: A, B, or C” is intended to cover: A, or B, or C, or any combination thereof (e.g., A-B, A-C, B-C, and A-B-C).

[0029] As discussed above, certain devices described herein may implement the IEEE 802.11 standard, for example. Such devices, whether used as a STA or AP or other device, may be used for smart metering or in a smart grid network. Such devices may provide sensor applications or be used in home automation. The devices may instead of or in addition to be used in a healthcare context, for example for personal healthcare. The

devices may also be used for surveillance, to enable extended-range Internet connectivity (e.g. for use with hotspots), or to implement machine-to-machine communications. The device may also be used to collect real time data from multiple deployed sensors in industries like construction, manufacturing, petroleum, electrical power, transport, etc.

[0030] FIG. 1 shows an example wireless communication system 100 in which aspects of the present disclosure may be employed. The wireless communication system 100 may operate pursuant to a wireless standard, for example the IEEE 802.11 standard. The wireless communication system 100 may include an AP 104, which communicates with STAs (e.g., STAs 112, 114, 116, and 118).

[0031] A variety of processes and methods may be used for transmissions in the wireless communication system 100 between the AP 104 and the STAs. For example, signals may be sent and received between the AP 104 and the STAs in accordance with OFDM/OFDMA techniques, in which case, the wireless communication system 100 may be referred to as an OFDM/OFDMA system. Alternatively, signals may be sent and received between the AP 104 and the STAs in accordance with CDMA techniques, in which case, the wireless communication system 100 may be referred to as a CDMA system.

[0032] A communication link that facilitates transmission from the AP 104 to one or more of the STAs may be referred to as a downlink (DL) 108, and a communication link that facilitates transmission from one or more of the STAs to the AP 104 may be referred to as an uplink (UL) 110. Alternatively, a downlink 108 may be referred to as a forward link or a forward channel, and an uplink 110 may be referred to as a reverse link or a reverse channel. In some aspects, DL communications may include unicast or multicast traffic indications.

[0033] The AP 104 may suppress adjacent channel interference (ACI) in some aspects so that the AP 104 may receive UL communications on more than one channel simultaneously/concurrently without causing significant analog-to-digital conversion (ADC) clipping noise. The AP 104 may improve suppression of ACI, for example, by having separate finite impulse response (FIR) filters for each channel or having a longer ADC backoff period with increased bit widths.

[0034] The AP 104 may act as a base station and may provide wireless communication coverage for a basic service area (BSA) 102. A BSA (e.g., the BSA 102) may be the coverage area of an AP (e.g., the AP 104). The AP 104 along with the STAs

associated with the AP 104 and that use the AP 104 for communication may be referred to as a basic service set (BSS). In an aspect, the wireless communication system 100 may not have a central AP (e.g., AP 104), but rather may function as a peer-to-peer network between the STAs. Accordingly, the functions of the AP 104 described herein may alternatively be performed by one or more of the STAs.

[0035] The AP 104 may transmit a beacon signal (or simply a “beacon”) on one or more channels (e.g., multiple narrowband channels, each channel including a frequency bandwidth) via a communication link such as the downlink 108, to other nodes (STAs) of the wireless communication system 100, which may help the other nodes (STAs) synchronize their timing with the AP 104, or which may provide other information or functionality. Such beacons may be transmitted periodically. In one aspect, the period between successive transmissions may be referred to as a superframe. Transmission of a beacon may be divided into a number of groups or intervals. In one aspect, the beacon may include, but is not limited to, such information as timestamp information to set a common clock, a peer-to-peer network identifier, a device identifier, capability information, a superframe duration, transmission direction information, reception direction information, a neighbor list, and/or an extended neighbor list, some of which are described in additional detail below. Thus, a beacon may include information that is both common (e.g., shared) amongst several devices and specific to a given device.

[0036] In some aspects, a STA (e.g., STA 114) may associate with the AP 104 in order to send communications to and/or to receive communications from the AP 104. In one aspect, information for associating may be included in a beacon broadcast by the AP 104. To receive such a beacon, the STA 114 may, for example, perform a broad coverage search over a coverage region. A search may also be performed by the STA 114 by sweeping a coverage region in a lighthouse fashion, for example. After receiving the information for associating, either from the beacon or from probe response frames, the STA 114 may transmit a reference signal, such as an association probe or request, to the AP 104. In some aspects, the AP 104 may use backhaul services, for example, to communicate with a larger network, such as the Internet or a public switched telephone network (PSTN).

[0037] In an aspect, the STA 114 may include one or more components for performing various functions. For example, the STA 114 may include a carrier sensing component 124. The carrier sensing component 124 may be configured to determine, via clear

channel assessment, whether a first spectrum is busy. In response to the first spectrum is determined to be busy, the carrier sensing component 124 may be configured to determine whether cross technology interference is detected in the first spectrum. The carrier sensing component 124 may be configured to switch data transmission from the first spectrum to a second spectrum when cross technology interference is detected in the first spectrum.

[0038] In one aspect of the disclosure, SmartCast, a low-power mesh networking protocol, is introduced to exploit multiple low-power communication technologies across different spectrum to achieve extremely high reliability despite strong interference and occlusion of signals from various sources. The SmartCast scheme may include two key components: smart channel assessment and cross-spectrum communication, which will be further described below.

[0039] FIG. 2 is a diagram illustrating an example of a system 200 that utilizes SmartCast to achieve reliable and energy efficient cross-spectrum communication. In the example, the system 200 may include wireless devices 204, 206, a communication hub 202, a cloud storage 208, and a server 214.

[0040] In one embodiment, each of the wireless devices 204, 206 may be an STA (e.g., the STA 114). In one embodiment, one or more of the wireless devices 204, 206 may include wireless-enabled sensors. In one embodiment, one or more of the wireless devices 204, 206 may be interfaced with industrial sensors for wireless monitoring. In one embodiment, the wireless devices 204, 206 may implement SmartCast to send sensor data to the communication hub 202 in real time.

[0041] The communication hub 202 may aggregate sensor data received from the wireless devices 204, 206, and stream the aggregated sensor data to the cloud storage 208. In one embodiment, the communication hub 202 may be an STA (e.g., the STA 114). In one embodiment, the communication hub 202 may implement SmartCast to send the aggregated sensor data to the cloud storage 208.

[0042] The cloud storage 208 may store the aggregated sensor data. The server 214 may organize and/or analyze the aggregated sensor data. In one embodiment, the server 214 may be part of the cloud storage 208. In another embodiment, the sever 214 may be separate from the cloud storage 208. The server 214 may output the result of processing the aggregated sensor data to a mobile device 210 and/or a computing device 212 to visualize the sensor data, as well providing alerts and insights about the sensor data.

[0043] FIG. 3 is a diagram illustrating an example of a wireless mesh network 300 with communication links of different quality. In the example, the wireless mesh network 300 may include multiple wireless devices 304 and a communication hub 302, which form the nodes of the wireless mesh network 300. In one embodiment, the communication hub 302 may be the communication hub 202 described above with reference to FIG. 2. In one embodiment, each of the wireless devices 304 may be the wireless device 204 or 206 described above with reference to FIG. 2. In one embodiment, the wireless devices 304 may send sensor data to the communication hub 302 through communication links between nodes of the wireless mesh network 300.

[0044] The quality of different communication links in the wireless mesh network 300 may be different. For example, the communication link 306 may experience interference, from the same radio access technology (RAT) and/or from different RATs. The communication link 308 may be weak due to obstructions by physical objects (e.g., walls between the two wireless devices). The communication link 310 may be strong with limited interference or obstruction. Moreover, the quality of communication links may change dynamically.

[0045] In one embodiment, SmartCast protocol may enable reliable, cost-effective, long-range, wireless data collection. The wireless devices 304 may use SmartCast to stream their data to the communication hub 302 in real time. In one embodiment, the wireless mesh network 300 may jump across multiple frequencies on a per-hop basis when links are experiencing interference. Each wireless device 304 may perform opportunistic routing, where paths in the wireless mesh network 300 may be selected dynamically depending on availability. In one embodiment, a wireless device 304 may sleep for extended time periods to prolong battery life. These techniques may make the SmartCast mesh network protocol more reliable and energy efficient than traditional mesh network protocols.

[0046] FIG. 4 is a diagram illustrating an example of a wireless mesh network 400 that utilizes SmartCast to achieve reliable and energy efficient cross-spectrum communication. In one embodiment, the wireless mesh network 400 may be the wireless mesh network 300 described above with reference to FIG. 3. In the example, the wireless mesh network 400 may include multiple wireless devices 402-422 and a communication hub 424. In one embodiment, the communication hub 424 may be the communication hub 202 or 302 described above. In one embodiment, each of the wireless devices 402-422 may be the

wireless device 204, 206, 304 described above. In one embodiment, the wireless devices 402-422 may send sensor data to the communication hub 424 through communication links between nodes of the wireless mesh network 400. In the example, the nodes in the wireless mesh network 400 may communicate with each other over either the 868 MHz spectrum or the 2.4 GHz spectrum. Even though 868 MHz spectrum and 2.4 GHz spectrum are used in this example, one of ordinary skill in the art would recognize that, instead of or in conjunction with at least one of 868 MHz spectrum and 2.4 GHz spectrum, other spectrums (e.g., one or more of 433 MHz spectrum, 915 MHz spectrum, or any other unlicensed industrial, scientific and medical (ISM) radio band) may also be used to achieve cross-spectrum communication.

[0047] Clear channel assessment (CCA) has been around for a long time as a fundamental wireless network media access control (MAC) technique. In a low power sensor network, CCA may be used by carrier-sense multiple access with collision avoidance (CSMA/CA) to avoid collisions. Moreover, CCA may be used to enable energy efficient duty cycling. In one embodiment, CCA may involve sampling of energy in the spectrum and interpreting it as activity if the energy exceeds a specified threshold. Although simple to implement, this simple threshold-based scheme may lead to false positives, especially in a noisy environment.

[0048] As described above, SmartCast may include smart channel assessment and cross-spectrum communication. In one embodiment, smart channel assessment may involve a two-stage approach. Before any transmission, every wireless device may perform CCA, and depending on the outcome of CCA, decide to switch to what may be referred to as the CTI identification mode (CIM) or proceed with communication.

[0049] In one embodiment, to perform smart channel assessment, a wireless device may perform CCA on a selected spectrum/channel. If no activity is detected in the channel, the wireless device may proceed with communication. However, if activity detected in the channel by CCA, the wireless device may enter into CTI identification mode.

[0050] In one embodiment of CIM, the wireless device may log the power present in the received radio signal (e.g., by measuring received signal strength indicator (RSSI)) at high sampling rate (e.g., greater than a threshold sampling rate). In one embodiment, the wireless device may feed the logged signal strength measurements into a classifier to identify whether the interference in the channel is self-interference or cross-technology interference. If the interference is CTI, a local spectrum switch may be triggered, which

may be referred to as cross-spectrum communication. However, if the interference is self-interference (e.g., interference by signal of the same RAT), the wireless device may perform an exponential back-off and then perform CCA again on the channel.

[0051] For example, the wireless device 406 may choose to use the 868 MHz spectrum to transmit data (e.g., sensor data) to the wireless device 404. Before transmission, the wireless device 406 may perform CCA on the 868 MHz spectrum. Since there is no activity/interference in the 868 MHz spectrum link between the wireless devices 406 and 404 (as illustrated in FIG. 4), the wireless device 406 may proceed to transmit data to the wireless device 404 over the 868 MHz spectrum.

[0052] In another example, the wireless device 410 may choose to use the 868 MHz spectrum to transmit data (e.g., sensor data) to the wireless device 416. Before transmission, the wireless device 410 may perform CCA on the 868 MHz spectrum. If there is activity/interference in the 868 MHz spectrum link between the wireless devices 410 and 416, the wireless device 410 may enter CIM. Under CIM, the wireless device 410 may log the power present in the received radio signal at high sampling rate. In one embodiment, the wireless device 410 may feed the logged signal strength measurements into a classifier to identify whether the interference in the channel is self-interference or cross-technology interference. If the interference is CTI, the wireless device 410 may switch to the 2.4 GHz spectrum for data transmission. Since there is no activity/interference in the 2.4 GHz spectrum link between the wireless device 410 and 416 (as illustrated in FIG. 4), CCA on the 2.4 GHz spectrum would be successful. The wireless device 410 may then proceed to transmit data to the wireless device 416 over the 2.4 GHz spectrum.

[0053] In one embodiment, in the event of cross-spectrum switches, the network nodes may identify the best data carrier/spectrum towards the given destination. The nodes may maintain per-spectrum network topology. In one embodiment, the link qualities may be measured using packet reception rate (PRR) and/or expected transmission count (ETX). The link qualities may be used to identify the shortest reliable routing path. In one embodiment, SmartCast may allow multiple network links to be operating on multiple technologies or spectrums without causing network partitioning despite there is no centralized controller.

[0054] The CTI classification algorithm may be based on the premise that every CTI exhibits a different time domain signal strength pattern. This may be used to train a

classifier that identifies an interference be a self-interference or a cross-technology interference based on a time domain signal strength pattern corresponding to the interference. In one embodiment, the classifier may be a neural network. In one embodiment, the classifier may perform supervised training based on a set of time domain signal strength patterns of known instances of self-interference and CTI.

[0055] In one embodiment, SmartCast may allow each individual communication link between wireless devices to operate on different low-power RATs. For example, the smart channel assessment may provide soft hints that may be used by the wireless devices to decide whether to use the 2.4 GHz spectrum or a sub-1 GHz spectrum (e.g., the 868 MHz spectrum) for data transmission. In one embodiment, the decision may also depend on the application requirements. For example, if low data rate of few hundreds of bits per second is sufficient for data transmission, the sub-1 GHz spectrum may be selected to exploit the long-range communication benefits. However, if the application demands a data rate of hundreds of kilobits per second, the wireless devices may make local decision to switch to the 2.4 GHz spectrum.

[0056] In one embodiment, SmartCast may employ low-power probing MAC (LPP-MAC). In such an embodiment, every different probe may be sent out on a different RAT that is used for distributed neighbor discovery and cross-spectrum communication. In one embodiment, SmartCast may provide reliable wireless communication despite the presence of obstructions and interferences caused by self and cross-technology communications. In one embodiment, SmartCast may enable cross-spectrum communication, where each link of a wireless mesh network may independently decide the best communication technology to use depending on the level of interference in its vicinity. In one embodiment, SmartCast may look beyond threshold-based clear channel assessment and perform cross-technology interference identification. In one embodiment, SmartCast may be able to have different links of a wireless mesh network operate on a different technology without the need of a centralized scheduler.

[0057] FIG. 5 shows an example functional block diagram of a wireless device 502 that may utilize SmartCast to achieve reliable and energy efficient cross-spectrum communication. The wireless device 502 is an example of a device that may be configured to implement the various methods described herein. For example, the wireless device 502 may be one of the STAs 114, 204, 206, 304, 402-422.

[0058] The wireless device 502 may include a processor 504, which controls operation of the wireless device 502. The processor 504 may also be referred to as a central processing unit (CPU). Memory 506, which may include both read-only memory (ROM) and random access memory (RAM), may provide instructions and data to the processor 504. A portion of the memory 506 may also include non-volatile random access memory (NVRAM). The processor 504 typically performs logical and arithmetic operations based on program instructions stored within the memory 506. The instructions in the memory 506 may be executable (by the processor 504, for example) to implement the methods described herein.

[0059] The processor 504 may include or be a component of a processing system implemented with one or more processors. The one or more processors may be implemented with any combination of general-purpose microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate array (FPGAs), programmable logic devices (PLDs), controllers, state machines, gated logic, discrete hardware components, dedicated hardware finite state machines, or any other suitable entities that can perform calculations or other manipulations of information.

[0060] The processing system may also include a machine-readable medium for storing software. Software shall be construed broadly to mean any type of instructions, whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. Instructions may include code (e.g., in source code format, binary code format, executable code format, or any other suitable format of code). The instructions, when executed by the one or more processors, cause the processing system to perform the various functions described herein.

[0061] The wireless device 502 may also include a housing 508, and the wireless device 502 that may include a transmitter 510 and/or a receiver 512 to allow transmission and reception of data between the wireless device 502 and a remote device. The transmitter 510 and the receiver 512 may be combined into a transceiver 514. An antenna 516 may be attached to the housing 508 and electrically coupled to the transceiver 514. The wireless device 502 may also include multiple transmitters, multiple receivers, multiple transceivers, and/or multiple antennas.

[0062] The wireless device 502 may also include a signal detector 518 that may be used to detect and quantify the level of signals received by the transceiver 514 or the receiver 512. The signal detector 518 may detect such signals as total energy, energy per

subcarrier per symbol, power spectral density, and other signals. The wireless device 502 may also include a DSP 520 for use in processing signals. The DSP 520 may be configured to generate a packet for transmission. In some aspects, the packet may include a physical layer convergence procedure (PLCP) protocol data unit (PPDU).

[0063] In some aspects, the wireless device 502 may further include a user interface 522. The user interface 522 may include a keypad, a microphone, a speaker, and/or a display. The user interface 522 may include any element or component that conveys information to a user of the wireless device 502 and/or receives input from the user.

[0064] When the wireless device 502 is implemented as a STA (e.g., the STA 114), the wireless device 502 may also include a carrier sensing component 524. The carrier sensing component 524 may be configured to perform each of the functions and/or steps recited in disclosure with respect to FIGS. 1-4.

[0065] The various components of the wireless device 502 may be coupled together by a bus system 526. The bus system 526 may include a data bus, for example, as well as a power bus, a control signal bus, and a status signal bus in addition to the data bus. Components of the wireless device 502 may be coupled together or accept or provide inputs to each other using some other mechanism.

[0066] Although a number of separate components are illustrated in FIG. 5, one or more of the components may be combined or commonly implemented. For example, the processor 504 may be used to implement not only the functionality described above with respect to the processor 504, but also to implement the functionality described above with respect to the signal detector 518, the DSP 520, the user interface 522, and/or the carrier sensing component 524. Further, each of the components illustrated in FIG. 5 may be implemented using a plurality of separate elements.

[0067] FIG. 6 is a flowchart of an exemplary method 600 for utilizing SmartCast to achieve reliable and energy efficient cross-spectrum communication. The method 600 may be performed using an apparatus (e.g., the STA 114, 402-422). Although the method 600 is described below with respect to the elements of wireless device 502 of FIG. 5, other components may be used to implement one or more of the steps described herein. In one embodiment, operations performed in method 600 may be the operations described above with reference to FIG. 4.

[0068] At 602, the apparatus may create a timer for periodic smart carrier sensing. At 604, the apparatus may determine whether a timer event associated with the timer is

triggered. If a timer event is triggered, the apparatus may proceed to 606. Otherwise, the apparatus may loop back to 604 to check the timer event again.

[0069] At 606, the apparatus may select a spectrum for data transmission. In one embodiment, the spectrum may be selected based on application requirements. In one embodiment, the spectrum may be selected by a default configuration.

[0070] At 608, the apparatus may initiate carrier sensing in the selected spectrum. In one embodiment, the carrier sensing may involve performing CCA in the selected spectrum.

[0071] At 610, the apparatus may determine whether noise is detected in the spectrum based on the result of carrier sensing. If noise is detected, the apparatus may proceed to 614. Otherwise, the apparatus may proceed to 612. At 612, the apparatus may transmit data over the selected spectrum.

[0072] At 614, the apparatus may determine whether CTI is detected. If CTI is detected, the apparatus may proceed to 618. If CTI is not detected, which may mean self-interference is detected, the apparatus may proceed to 616.

[0073] At 616, the apparatus may perform exponential backoff. The apparatus may then loop back to 608.

[0074] At 618, the apparatus may update spectrum statistics regarding CTI. At 620, the apparatus may select the best spectrum available for data transmission. In one embodiment, the spectrum may be selected based on application requirements. In one embodiment, the spectrum may be selected by a default rule or configuration.

[0075] At 622, the apparatus may switch to the newly selected spectrum to transmit data. The apparatus may then loop back to 608.

[0076] FIG. 7 is a flowchart of another exemplary method 700 for utilizing SmartCast to achieve reliable and energy efficient cross-spectrum communication. The method 700 may be performed using an apparatus (e.g., the STA 114, 402-422). Although the method 700 is described below with respect to the elements of wireless device 502 of FIG. 5, other components may be used to implement one or more of the steps described herein. In one embodiment, operations performed in method 700 may be the operations described above with reference to FIG. 4.

[0077] At 702, the apparatus may optionally select a first spectrum for data transmission. In one embodiment, the first spectrum may be selected based on application

requirements. In one embodiment, the first spectrum may be selected by a default configuration.

[0078] At 704, the apparatus may determine whether the first spectrum is busy. In one embodiment, the apparatus may perform CCA to determine whether the first spectrum is busy. In one embodiment, the first spectrum may be determined to be busy if the average energy received over a time interval is above an energy detection threshold. In such an embodiment, the first spectrum may be determined to be not busy if the average energy received over the time interval is below or equal to the energy detection threshold. If the first spectrum is busy, the apparatus may proceed to 706. Otherwise, the apparatus may proceed to 708. At 708, the apparatus may optionally perform data transmission over the first spectrum. The method 700 may then terminate.

[0079] At 706, the apparatus may determine whether CTI is detected in the first spectrum. In one embodiment, to determine whether CTI is detected in the first spectrum, the apparatus may measure received signal strength in the first spectrum at a sampling rate that is greater than a threshold sampling rate to obtain a plurality of signal strength values, and detect CTI in the first spectrum based on the plurality of signal strength values. In one embodiment, to detect CTI in the first spectrum based on the plurality of signal strength values, the apparatus may provide the plurality of signal strength values to a classifier. The output of the classifier may indicate whether CTI exists in the first spectrum. In one embodiment, the classifier may be trained with signal strength patterns of cross technology interferences. In one embodiment, the classifier may include a neural network. If CTI is detected, the apparatus may proceed to 712. If CTI is not detected, which may mean self-interference is detected, the apparatus may proceed to 710.

[0080] At 710, the apparatus may optionally perform exponential backoff. The apparatus may then loop back to 704.

[0081] At 712, the apparatus may optionally select a second spectrum from a plurality of spectrums available for data transmission. In one embodiment, the second spectrum may be selected based on application requirements. In one embodiment, the second spectrum may be selected by a default rule or configuration.

[0082] At 714, the apparatus may switch data transmission from the first spectrum to the second spectrum. The apparatus may then loop back to 704.

[0083] FIG. 8 is a functional block diagram of an example wireless communication device 800 that may utilize SmartCast to achieve reliable and energy efficient cross-

spectrum communication. The wireless communication device 800 may include a receiver 805, a processing system 810, and a transmitter 815. The processing system 810 may include a carrier sensing component 824.

[0084] The receiver 805, the processing system 810, the carrier sensing component 824, and/or the transmitter 815 may be configured to perform one or more functions discussed above with respect to FIGS. 1-7. The receiver 805 may correspond to the receiver 512. The processing system 810 may correspond to the processor 504. The transmitter 815 may correspond to the transmitter 510. The carrier sensing component 824 may correspond to the carrier sensing component 124, and/or the carrier sensing component 524.

[0085] The various operations of methods described above may be performed by any suitable means capable of performing the operations, such as various hardware and/or software component(s), circuits, and/or component(s). Generally, any operations illustrated in the Figures may be performed by corresponding functional means capable of performing the operations.

[0086] The various illustrative logical blocks, components and circuits described in connection with the present disclosure may be implemented or performed with a general purpose processor, a DSP, an application specific integrated circuit (ASIC), an FPGA or other PLD, discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any commercially available processor, controller, microcontroller or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0087] In one or more aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable medium includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable medium can include RAM, ROM, EEPROM, compact disc (CD) ROM

(CD-ROM) or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes CD, laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Thus, computer readable medium includes a non-transitory computer readable medium (e.g., tangible media).

[0088] The methods disclosed herein include one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

[0089] Thus, certain aspects may include a computer program product for performing the operations presented herein. For example, such a computer program product may include a computer readable medium having instructions stored (and/or encoded) thereon, the instructions being executable by one or more processors to perform the operations described herein. For certain aspects, the computer program product may include packaging material.

[0090] Further, it should be appreciated that components and/or other appropriate means for performing the methods and techniques described herein may be downloaded and/or otherwise obtained by a user terminal and/or base station as applicable. For example, such a device can be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via storage means (e.g., RAM, ROM, a physical storage medium such as a CD or floppy disk, etc.), such that a user terminal and/or base station can obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other

suitable technique for providing the methods and techniques described herein to a device can be utilized.

[0091] In the following, various aspects of this disclosure will be illustrated:

[0092] Example 1 is a method or apparatus for wireless communication. The method or apparatus may determine, via clear channel assessment, whether a first spectrum is busy. In response to the first spectrum is determined to be busy, the method or apparatus may determine whether a cross technology interference is detected in the first spectrum. The method or apparatus may switch data transmission from the first spectrum to a second spectrum when the cross technology interference is detected in the first spectrum.

[0093] In Example 2, the subject matter of Example 1 may optionally include that, in response to the first spectrum is determined to be not busy, the method or apparatus may further perform the data transmission over the first spectrum.

[0094] In Example 3, the subject matter of any one of Examples 1 to 2 may optionally include that the first spectrum may be determined to be busy when average energy received over a time interval is above an energy detection threshold.

[0095] In Example 4, the subject matter of any one of Examples 1 to 3 may optionally include that the first spectrum may be determined to be not busy when the average energy received over the time interval is below or equal to the energy detection threshold.

[0096] In Example 5, the subject matter of any one of Examples 1 to 4 may optionally include that the method or apparatus may perform an exponential backoff when the cross technology interference is not detected in the first spectrum.

[0097] In Example 6, the subject matter of any one of Examples 1 to 5 may optionally include that, to determining whether the cross technology interference is detected in the first spectrum, the method or apparatus may measure received signal strength in the first spectrum at a sampling rate that is greater than a threshold sampling rate to obtain a plurality of signal strength values, and detect the cross technology interference in the first spectrum based on the plurality of signal strength values.

[0098] In Example 7, the subject matter of Example 6 may optionally include that, to detect the cross technology interference in the first spectrum based on the plurality of signal strength values, the method or apparatus may provide the plurality of signal strength values to a classifier, where an output of the classifier indicates whether the cross technology interference exists in the first spectrum.

[0099] In Example 8, the subject matter of Example 7 may optionally include that the classifier is trained with signal strength patterns of cross technology interferences.

[00100] In Example 9, the subject matter of any one of Examples 7 to 8 may optionally include that the classifier may include a neural network.

[00101] In Example 10, the subject matter of any one of Examples 1 to 9 may optionally include that the method or apparatus may select the second spectrum from a plurality of spectrums based on application requirements before the switching of the data transmission.

[00102] It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the methods and apparatus described above without departing from the scope of the claims.

[00103] While the foregoing is directed to aspects of the present disclosure, other and further aspects of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

[00104] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” Unless specifically stated otherwise, the term “some” refers to one or more. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112(f), unless the element is expressly recited using the phrase “means for” or, in the case of a method claim, the element is recited using the phrase “step for.”

CLAIMS

WHAT IS CLAIMED IS:

1. A method of wireless communication, comprising:
determining, via a clear channel assessment, whether a first spectrum is busy;
in response to the first spectrum is determined to be busy, determining whether a cross technology interference is detected in the first spectrum; and
switching data transmission from the first spectrum to a second spectrum when the cross technology interference is detected in the first spectrum.
2. The method of claim 1, further comprising:
in response to the first spectrum is determined to be not busy, performing the data transmission over the first spectrum.
3. The method of claim 1, wherein the first spectrum is determined to be busy when average energy received over a time interval is above an energy detection threshold.
4. The method of claim 3, wherein the first spectrum is determined to be not busy when the average energy received over the time interval is below or equal to the energy detection threshold.
5. The method of claim 1, further comprising performing an exponential backoff when the cross technology interference is not detected in the first spectrum.
6. The method of claim 1, wherein the determining whether the cross technology interference is detected in the first spectrum comprises:
measuring received signal strength in the first spectrum at a sampling rate that is greater than a threshold sampling rate to obtain a plurality of signal strength values; and
detecting the cross technology interference in the first spectrum based on the plurality of signal strength values.
7. The method of claim 6, wherein the detecting the cross technology interference in the first spectrum based on the plurality of signal strength values comprises:

providing the plurality of signal strength values to a classifier, wherein an output of the classifier indicates whether the cross technology interference exists in the first spectrum.

8. The method of claim 7, wherein the classifier is trained with signal strength patterns of cross technology interferences.

9. The method of claim 7, wherein the classifier comprises a neural network.

10. The method of claim 1, further comprising selecting the second spectrum from a plurality of spectrums based on application requirements before the switching the data transmission.

11. An apparatus for wireless communication, comprising:

a memory; and

at least one processor coupled to the memory and configured to:

determine, via a clear channel assessment, whether a first spectrum is busy;

in response to the first spectrum is determined to be busy, determine whether a cross technology interference is detected in the first spectrum; and

switch data transmission from the first spectrum to a second spectrum when the cross technology interference is detected in the first spectrum.

12. The apparatus of claim 11, wherein the at least one processor is further configured to:

in response to the first spectrum is determined to be not busy, perform the data transmission over the first spectrum.

13. The apparatus of claim 11, wherein the first spectrum is determined to be busy when average energy received over a time interval is above an energy detection threshold.

14. The apparatus of claim 13, wherein the first spectrum is determined to be not busy when the average energy received over the time interval is below or equal to the energy detection threshold.

15. The apparatus of claim 11, wherein the at least one processor is further configured to perform an exponential backoff when the cross technology interference is not detected in the first spectrum.

16. The apparatus of claim 11, wherein, to determine whether the cross technology interference is detected in the first spectrum, the at least one processor is configured to:

measure received signal strength in the first spectrum at a sampling rate that is greater than a threshold sampling rate to obtain a plurality of signal strength values; and

detect the cross technology interference in the first spectrum based on the plurality of signal strength values.

17. The apparatus of claim 16, wherein, to detect the cross technology interference in the first spectrum based on the plurality of signal strength values, the at least one processor is configured to:

provide the plurality of signal strength values to a classifier, wherein an output of the classifier indicates whether the cross technology interference exists in the first spectrum.

18. The apparatus of claim 17, wherein the classifier is trained with signal strength patterns of cross technology interferences.

19. The apparatus of claim 11, wherein the at least one processor is further configured to select the second spectrum from a plurality of spectrums based on application requirements before switching the data transmission.

20. A computer-readable medium storing computer executable code, comprising instructions for:

determining, via a clear channel assessment, whether a first spectrum is busy;

in response to the first spectrum is determined to be busy, determining whether a cross technology interference is detected in the first spectrum; and

switching data transmission from the first spectrum to a second spectrum when the cross technology interference is detected in the first spectrum.