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Systems, methods, and devices having databases for electronic spectrum management

Abstract

Systems, methods, and apparatus are provided for automated identification of baseline data and changes in state in a wireless communications spectrum, by identifying sources of signal emission in the spectrum by automatically detecting signals, analyzing signals, comparing signal data to historical and reference data, creating corresponding signal profiles, and determining information about the baseline data and changes in state based upon the measured and analyzed data in near real time, which is stored on each apparatus or device and/or on a remote server computer that aggregates data from each apparatus or device.

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11012340	12/2020	Ryan et al.	N/A	N/A
11035929	12/2020	Parker et al.	N/A	N/A
11063653	12/2020	Ottersten et al.	N/A	N/A
11190233	12/2020	Lo et al.	N/A	N/A
11223431	12/2021	Garcia et al.	N/A	N/A
11265652	12/2021	Kallai et al.	N/A	N/A
11321282	12/2021	Tran	N/A	N/A
11334807	12/2021	O'Shea et al.	N/A	N/A
11336011	12/2021	Tran et al.	N/A	N/A
11516071	12/2021	Karapantelakis et al.	N/A	N/A
11637641	12/2022	Garcia et al.	N/A	N/A
11663992	12/2022	Canberk et al.	N/A	N/A
11671839	12/2022	Guo et al.	N/A	N/A
11700304	12/2022	Brown, Jr. et al.	N/A	N/A
11757185	12/2022	Tran et al.	N/A	N/A
11777783	12/2022	Meirosu et al.	N/A	N/A
11791913	12/2022	Garcia et al.	N/A	N/A
11871103	12/2023	Kleinbeck	N/A	N/A
11874674	12/2023	Groden et al.	N/A	N/A
11880888	12/2023	Gold et al.	N/A	N/A
11889351	12/2023	Tagg	N/A	N/A
11910305	12/2023	Buyukdura	N/A	N/A
12095518	12/2023	Garcia et al.	N/A	N/A
12156037	12/2023	Montalvo	N/A	N/A
12183213	12/2023	Kleinbeck et al.	N/A	N/A
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2001/0005423	12/2000	Rhoads	N/A	N/A
2001/0016503	12/2000	Kang	N/A	N/A
2001/0020220	12/2000	Kurosawa	N/A	N/A
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2002/0173341	12/2001	Abdelmonem et al.	N/A	N/A
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2003/0040277	12/2002	Deats	N/A	N/A
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2003/0144601	12/2002	Prichep	N/A	N/A
2003/0145008	12/2002	Burrell	N/A	N/A
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2009/0143019	12/2008	Shellhammer	N/A	N/A
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2011/0122855	12/2010	Henry	N/A	N/A
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2011/0273328	12/2010	Parker	N/A	N/A
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Attorney, Agent or Firm: NEO IP

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims priority from one or more U.S. patent applications: it is a continuation of U.S. application Ser. No. 18/936,487, filed Nov. 4, 2024, which is a continuation of U.S. application Ser. No. 18/633,977, filed Apr. 12, 2024, which is a continuation of U.S. application Ser. No. 18/620,267, filed Mar. 28, 2024, which is a continuation of U.S. application Ser. No. 18/201,284, filed May 24, 2023, which is a continuation of U.S. application Ser. No. 18/082,180, filed Dec. 15, 2022, which is a continuation of U.S. application Ser. No. 17/388,822, filed Jul. 29, 2021, which is a continuation of U.S. application Ser. No. 16/821,472, filed Mar. 17, 2020, which is a continuation of U.S. application Ser. No. 16/371,547, filed Apr. 1, 2019, now U.S. Pat. No. 10,609,586, which is a continuation of U.S. application Ser. No. 15/622,173, filed Jun. 14, 2017, now U.S. Pat. No. 10,257,729, which is a continuation-in-part of U.S. application Ser. No. 15/412,982, filed Jan. 23, 2017, now U.S. Pat. No. 10,122,479, and a continuation-in-part of U.S. application Ser. No. 15/207,104 filed Jul. 11, 2016, which is a continuation-in-part of U.S. application Ser. No. 14/643,284 filed Mar. 10, 2015, which is a continuation of U.S. application Ser. No. 14/511,525 filed Oct. 10, 2014, now U.S. Pat. No. 9,008,587, which is a continuation of U.S. application Ser. No. 14/329,829 filed Jul. 11, 2014, now U.S. Pat. No. 8,868,005, which is a continuation of U.S. application Ser. No. 14/086,875 filed Nov. 21, 2013, now U.S. Pat. No. 8,798,548, which is a continuation-in-part of U.S. application Ser. No. 14/082,873 filed Nov. 18, 2013, now U.S. Pat. No. 8,805,291, which is a continuation of U.S. application Ser. No. 13/912,683 filed Jun. 7, 2013, now U.S. Pat. No. 9,288,683, which claims the benefit of U.S. Application 61/789,758 filed Mar. 15, 2013. U.S. application Ser. No. 14/086,875 is also a continuation-in-part of U.S. application Ser. No. 14/082,916 filed Nov. 18, 2013, now U.S. Pat. No. 8,780,968, which is a continuation of U.S. application Ser. No. 13/912,893 filed Jun. 7, 2013, now issued U.S. Pat. No. 9,078,162, which claims the benefit of U.S. Application 61/789,758 filed Mar. 15, 2013. U.S. application Ser. No. 14/086,875 is also a continuation-in-part of U.S. application Ser. No. 14/082,930 filed Nov. 18, 2013, now U.S. Pat. No. 8,824,536, which is a continuation of U.S. application Ser. No. 13/913,013 filed Jun. 7, 2013, which claims the benefit of U.S. Application 61/789,758 filed Mar. 15, 2013. Each of the U.S. Applications mentioned above is incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION
1. Field of the Invention
(1) The present invention relates to spectrum analysis and management for radio frequency signals, and

more particularly for automatically identifying baseline data and changes in state for signals from a multiplicity of devices in a wireless communications spectrum.

2. Description of the Prior Art

(2) Generally, it is known in the prior art to provide wireless communications spectrum management for detecting devices for managing the space. Spectrum management includes the process of regulating the use of radio frequencies to promote efficient use and gain net social benefit. A problem faced in effective spectrum management is the various numbers of devices emanating wireless signal propagations at different frequencies and across different technological standards. Coupled with the different regulations relating to spectrum usage around the globe effective spectrum management becomes difficult to obtain and at best can only be reached over a long period of time.

(3) Another problem facing effective spectrum management is the growing need from spectrum despite the finite amount of spectrum available. Wireless technologies have exponentially grown in recent years. Consequently, available spectrum has become a valuable resource that must be efficiently utilized. Therefore, systems and methods are needed to effectively manage and optimize the available spectrum that is being used.

(4) Most spectrum management devices may be categorized into two primary types. The first type is a spectral analyzer where a device is specifically fitted to run a ‘scanner’ type receiver that is tailored to provide spectral information for a narrow window of frequencies related to a specific and limited type of communications standard, such as cellular communication standard. Problems arise with these narrowly tailored devices as cellular standards change and/or spectrum use changes impact the spectrum space of these technologies. Changes to the software and hardware for these narrowly tailored devices become too complicated, thus necessitating the need to purchase a totally different and new device. Unfortunately, this type of device is only for a specific use and cannot be used to alleviate the entire needs of the spectrum management community.

(5) The second type of spectral management device employs a methodology that requires bulky, extremely difficult to use processes, and expensive equipment. In order to attain a broad spectrum management view and complete all the necessary tasks, the device ends up becoming a conglomerate of software and hardware devices that is both hard to use and difficult to maneuver from one location to another.

(6) While there may be several additional problems associated with current spectrum management devices, at least four major problems exist overall: 1) most devices are built to inherently only handle specific spectrum technologies such as 900 MHz cellular spectrum while not being able to mitigate other technologies that may be interfering or competing with that spectrum, 2) the other spectrum management devices consist of large spectrum analyzers, database systems, and spectrum management software that is expensive, too bulky, and too difficult to manage for a user's basic needs, 3) other spectrum management devices in the prior art require external connectivity to remote databases to perform analysis and provide results or reports with analytics to aid in management of spectrum and/or devices, and 4) other devices of the prior art do not function to provide real-time or near real-time data and analysis to allow for efficient management of the space and/or devices and signals therein.

(7) Examples of relevant prior art documents include the following:

(8) U.S. Pat. No. 8,326,313 for “Method and system for dynamic spectrum access using detection periods” by inventors McHenry, et al., filed Aug. 14, 2009, discloses methods and systems for dynamic spectrum access (DSA) in a wireless network. A DSA-enabled device may sense spectrum use in a region and, based on the detected spectrum use, select one or more communication channels for use. The devices also may detect one or more other DSA-enabled devices with which they can form DSA networks. A DSA network may monitor spectrum use by cooperative and non-cooperative devices, to dynamically select one or more channels to use for communication while avoiding or reducing interference with other devices. Classification results can be used to “learn” classifications to reduce future errors.

(9) U.S. Publication No. 2013/0005240 for “System and Method for Dynamic Coordination of Radio Resources Usage in a Wireless Network Environment” by inventors Novak, et al., filed Sep. 12, 2012, discloses an architecture, system and associated method for dynamic coordination of radio resource usage in a network environment. In one aspect, a relay communication method comprises detecting, by a first wireless mobile device, sensory data associated with multiple radio channels relative to at least one radio element in a sensing area of the first wireless mobile device. If the first wireless mobile device is out of range of a wide area cellular network, a short-range wireless communication path is established with a

second wireless mobile device having a wide area cellular communication connection. The sensory data is transmitted by the first wireless mobile device to the second wireless mobile device for reporting to a network element via a wide area cellular network serving the second wireless mobile device. The sensory data are processed by sensing elements and sent to a distributed channel occupancy and location database (COLD) system. The sensory data is updated dynamically to provide a real-time view of channel usage.

(10) U.S. Pat. No. 8,515,473 for “Cognitive radio methodology, physical layer policies and machine learning” by inventors Mody, et al., filed Mar. 6, 2008, discloses a method of cognitive communication for non-interfering transmission, wherein the improvement comprises the step of conducting radio scene analysis to find not just the spectrum holes or White spaces; but also to use the signal classification, machine learning, pattern-matching and prediction information to learn more things about the existing signals and its underlying protocols, to find the Gray space, hence utilizing the signal space, consisting of space, time, frequency (spectrum), code and location more efficiently.

(11) U.S. Publication 2013/0217450 for “Radiation Pattern Recognition System and Method for a Mobile Communications Device” by inventors Kanj, et al., filed Nov. 26, 2010, discloses a radiation pattern recognition system and method for a wireless user equipment (UE) device wherein a set of benchmark radiation patterns are matched based on the wireless UE device's usage mode. In one aspect, the wireless UE device includes one or more antennas adapted for radio communication with a telecommunications network. A memory is provided including a database of benchmark radiation patterns for each of the one or more antennas in one or more usage modes associated with the wireless UE device. A processor is configured to execute an antenna application process for optimizing performance of the wireless UE device based at least in part upon using the matched set of benchmark radiation patterns.

(12) U.S. Pat. No. 8,224,254 for “Operating environment analysis techniques for wireless communication systems” by inventor Simon Haykin, filed Oct. 13, 2005, describes methods and systems of analyzing an operating environment of wireless communication equipment in a wireless communication system. A stimulus in the operating environment at a location of the wireless communication equipment is sensed and linearly expanded in Slepian sequences using a multitaper spectral estimation procedure. A singular value decomposition is performed on the linearly expanded stimulus, and a singular value of the linearly expanded stimulus provides an estimate of interference at the location of the wireless communication equipment. The traffic model, which could be built on historical data, provides a basis for predicting future traffic patterns in that space which, in turn, makes it possible to predict the duration for which a spectrum hole vacated by the incumbent primary user is likely to be available for use by a cognitive radio operator. In a wireless environment, two classes of traffic data pattern are distinguished, including deterministic patterns and stochastic patterns.

(13) U.S. Pat. No. 5,393,713 for “Broadcast receiver capable of automatic station identification and format-scanning based on an internal database updatable over the airwaves with automatic receiver location determination” by inventor Pierre R. Schwob, filed Sep. 25, 1992, describes a broadcasting system capable of automatically or semi-automatically updating its database and using the database to identify received broadcasting stations, and search for stations according to user-chosen attributes and current data. The receiver is capable of receiving current location information within the received data stream, and also of determining the current location of the receiver by using a received station attribute. The invention provides an automatic or quasi-automatic data updating system based on subcarrier technology or other on-the-air data transmission techniques.

(14) U.S. Pat. No. 6,741,595 for “Device for enabling trap and trace of internet protocol communications” by inventors Maher, III, et al., filed Jun. 11, 2002, describes a network processing system for use in a network and operable to intercept communications flowing over the network, the network passing a plurality of data packets, which form a plurality of flows, the network processing system comprising: a learning state machine operable to identify characteristics of one or more of the flows and to compare the characteristics to a database of known signatures, one or more of the known signatures representing a search criteria, wherein when one or more characteristics of one or more of the flows matches the search criteria the learning state machine intercepts the flow and replicates the flow, redirecting the replication to a separate address.

(15) U.S. Pat. No. 7,676,192 for “Radio scanner programmed from frequency database and method” by inventor Wayne K. Wilson, filed Jan. 7, 2011, discloses a scanning radio and method using a receiver, a channel memory and a display in conjunction with a frequency-linked descriptor database. The frequency-

linked descriptor database is queried using a geographic reference to produce a list of local radio channels that includes a list of frequencies with linked descriptors. The list of radio channels is transferred into the channel memory of the scanner, and the receiver is sequentially tuned to the listed frequencies recalled from the list of radio channels while the corresponding linked descriptors are simultaneously displayed.
(16) U.S. Publication 2012/0148069 for “Coexistence of white space devices and wireless narrowband devices” by inventors Chandra, et al., filed Dec. 8, 2010, discloses architecture enabling wireless narrowband devices (e.g., wireless microphones) and white space devices to efficiently coexist on the same telecommunications channels, while not interfering with the usability of the wireless narrowband device. The architecture provides interference detection, strobe generation and detection and, power ramping and suppression (interference-free coexistence with spectrum efficiency). The architecture provides the ability of the white space device to learn about the presence of the microphone. This can be accomplished using a geolocation database, reactively via a strober device, and/or proactively via the strober device. The strober device can be positioned close to the microphone receiver and signals the presence of a microphone to white space devices on demand. The strober device takes into consideration the microphone's characteristics as well as the relative signal strength from the microphone transmitter versus the white space device, in order to enable maximum use of the available white space spectrum.
(17) U.S. Pat. No. 8,326,240 for “System for specific emitter identification” by inventors Kadambe, et al., filed Sep. 27, 2010, describes an apparatus for identifying a specific emitter in the presence of noise and/or interference including (a) a sensor configured to sense radio frequency signal and noise data, (b) a reference estimation unit configured to estimate a reference signal relating to the signal transmitted by one emitter, (c) a feature estimation unit configured to generate one or more estimates of one or more feature from the reference signal and the signal transmitted by that particular emitter, and (d) an emitter identifier configured to identify the signal transmitted by that particular emitter as belonging to a specific device (e.g., devices using Gaussian Mixture Models and the Bayesian decision engine). The apparatus may also include an SINR enhancement unit configured to enhance the SINR of the data before the reference estimation unit estimates the reference signal.
(18) U.S. Pat. No. 7,835,319 for “System and method for identifying wireless devices using pulse fingerprinting and sequence analysis” by inventor Sugar, filed May 9, 2007, discloses methods for identifying devices that are sources of wireless signals from received radio frequency (RF) energy, and, particularly, sources emitting frequency hopping spread spectrum (FHSS). Pulse metric data is generated from the received RF energy and represents characteristics associated thereto. The pulses are partitioned into groups based on their pulse metric data such that a group comprises pulses having similarities for at least one item of pulse metric data. Sources of the wireless signals are identified based on the partitioning process. The partitioning process involves iteratively subdividing each group into subgroups until all resulting subgroups contain pulses determined to be from a single source. At each iteration, subdividing is performed based on different pulse metric data than at a prior iteration. Ultimately, output data is generated (e.g., a device name for display) that identifies a source of wireless signals for any subgroup that is determined to contain pulses from a single source.
(19) U.S. Pat. No. 8,131,239 for “Method and apparatus for remote detection of radio-frequency devices” by inventors Walker, et al., filed Aug. 21, 2007, describes methods and apparatus for detecting the presence of electronic communications devices, such as cellular phones, including a complex RF stimulus is transmitted into a target area, and nonlinear reflection signals received from the target area are processed to obtain a response measurement. The response measurement is compared to a pre-determined filter response profile to detect the presence of a radio device having a corresponding filter response characteristic. In some embodiments, the pre-determined filter response profile comprises a pre-determined band-edge profile, so that comparing the response measurement to a pre-determined filter response profile comprises comparing the response measurement to the pre-determined band-edge profile to detect the presence of a radio device having a corresponding band-edge characteristic. Invention aims to be useful in detecting hidden electronic devices.
(20) U.S. Pat. No. 8,369,305 for “Correlating multiple detections of wireless devices without a unique identifier” by inventors Diener, et al., filed Jun. 30, 2008, describes at a plurality of first devices, wireless transmissions are received at different locations in a region where multiple target devices may be emitting, and identifier data is subsequently generated. Similar identifier data associated with received emissions at multiple first devices are grouped together into a cluster record that potentially represents the same target

device detected by multiple first devices. Data is stored that represents a plurality of cluster records from identifier data associated with received emissions made over time by multiple first devices. The cluster records are analyzed over time to correlate detections of target devices across multiple first devices. It aims to lessen disruptions caused by devices using the same frequency and to protect data.

(21) U.S. Pat. No. 8,155,649 for “Method and system for classifying communication signals in a dynamic spectrum access system” by inventors McHenry, et al., filed Aug. 14, 2009, discloses methods and systems for dynamic spectrum access (DSA) in a wireless network wherein a DSA-enabled device may sense spectrum use in a region and, based on the detected spectrum use, select one or more communication channels for use. The devices also may detect one or more other DSA-enabled devices with which they can form DSA networks. A DSA network may monitor spectrum use by cooperative and non-cooperative devices, to dynamically select one or more channels to use for communication while avoiding or reducing interference with other devices. A DSA network may include detectors such as a narrow-band detector, wide-band detector, TV detector, radar detector, a wireless microphone detector, or any combination thereof.

(22) U.S. Pat. No. RE43,066 for “System and method for reuse of communications spectrum for fixed and mobile applications with efficient method to mitigate interference” by inventor Mark Allen McHenry, filed Dec. 2, 2008, describes a communications system network enabling secondary use of spectrum on a non-interference basis. The system uses a modulation method to measure the background signals that eliminates self-generated interference and also identifies the secondary signal to all primary users via on/off amplitude modulation, allowing easy resolution of interference claims. The system uses high-processing gain probe waveforms that enable propagation measurements to be made with minimal interference to the primary users. The system measures background signals and identifies the types of nearby receivers and modifies the local frequency assignments to minimize interference caused by a secondary system due to non-linear mixing interference and interference caused by out-of-band transmitted signals (phase noise, harmonics, and spurs). The system infers a secondary node's elevation and mobility (thus, its probability to cause interference) by analysis of the amplitude of background signals. Elevated or mobile nodes are given more conservative frequency assignments than stationary nodes.

(23) U.S. Pat. No. 7,424,268 for “System and Method for Management of a Shared Frequency Band” by inventors Diener, et al., filed Apr. 22, 2003, discloses a system, method, software and related functions for managing activity in an unlicensed radio frequency band that is shared, both in frequency and time, by signals of multiple types. Signal pulse energy in the band is detected and is used to classify signals according to signal type. Using knowledge of the types of signals occurring in the frequency band and other spectrum activity related statistics (referred to as spectrum intelligence), actions can be taken in a device or network of devices to avoid interfering with other signals, and in general to optimize simultaneous use of the frequency band with the other signals. The spectrum intelligence may be used to suggest actions to a device user or network administrator, or to automatically invoke actions in a device or network of devices to maintain desirable performance.

(24) U.S. Pat. No. 8,249,631 for “Transmission power allocation/control method, communication device and program” by inventor Ryo Sawai, filed Jul. 21, 2010, teaches a method for allocating transmission power to a second communication service making secondary usage of a spectrum assigned to a first communication service, in a node which is able to communicate with a secondary usage node. The method determines an interference power acceptable for two or more second communication services when the two or more second communication services are operated and allocates the transmission powers to the two or more second communication services.

(25) U.S. Pat. No. 8,094,610 for “Dynamic cellular cognitive system” by inventors Wang, et al., filed Feb. 25, 2009, discloses permitting high quality communications among a diverse set of cognitive radio nodes while minimizing interference to primary and other secondary users by employing dynamic spectrum access in a dynamic cellular cognitive system. Diverse device types interoperate, cooperate, and communicate with high spectrum efficiency and do not require infrastructure to form the network. The dynamic cellular cognitive system can expand to a wider geographical distribution via linking to existing infrastructure.

(26) U.S. Pat. No. 8,565,811 for “Software-defined radio using multi-core processor” by inventors Tan, et al., discloses a radio control board passing a plurality of digital samples between a memory of a computing device and a radio frequency (RF) transceiver coupled to a system bus of the computing device. Processing

of the digital samples is carried out by one or more cores of a multi-core processor to implement a software-defined radio.

(27) U.S. Pat. No. 8,064,840 for "Method and system for determining spectrum availability within a network" by inventors McHenry, et al., filed Jun. 18, 2009, discloses an invention which determines spectrum holes for a communication network by accumulating the information obtained from previous received signals to determine the presence of a larger spectrum hole that allows a reduced listening period, higher transmit power and a reduced probability of interference with other networks and transmitters.

(28) U.S. Publication No. 2009/0143019 for "Method and apparatus for distributed spectrum sensing for wireless communication" by inventor Stephen J. Shellhammer, filed Jan. 4, 2008, discloses methods and apparatus for determining if a licensed signal having or exceeding a predetermined field strength is present in a wireless spectrum. The signal of interest maybe a television signal or a wireless microphone signal using licensed television spectrum.

(29) U.S. Publication No. 2013/0090071 for "Systems and methods for communication in a white space" by inventors Abraham, et al., filed Apr. 3, 2012, discloses systems, methods, and devices to communicate in a white space. In some aspects, wireless communication transmitted in the white space authorizes an initial transmission by a device. The wireless communication may include power information for determining a power at which to transmit the initial transmission. The initial transmission may be used to request information identifying one or more channels in the white space available for transmitting data.

(30) U.S. Publication No. 2012/0072986 for "Methods for detecting and classifying signals transmitted over a radio frequency spectrum" by inventors Livsics, et al., filed Nov. 1, 2011, discloses a method to classify a signal as non-cooperative (NC) or a target signal. The percentage of power above a first threshold is computed for a channel. Based on the percentage, a signal is classified as a narrowband signal. If the percentage indicates the absence of a narrowband signal, then a lower second threshold is applied to confirm the absence according to the percentage of power above the second threshold. The signal is classified as a narrowband signal or pre-classified as a wideband signal based on the percentage. Pre-classified wideband signals are classified as a wideband NC signal or target signal using spectrum masks.

(31) U.S. Pat. No. 8,494,464 for "Cognitive networked electronic warfare" by inventors Kadambe, et al., filed Sep. 8, 2010, describes an apparatus for sensing and classifying radio communications including sensor units configured to detect RF signals, a signal classifier configured to classify the detected RF signals into a classification, the classification including at least one known signal type and an unknown signal type, a clustering learning algorithm capable of finding clusters of common signals among the previously seen unknown signals; it is then further configured to use these clusters to retrain the signal classifier to recognize these signals as a new signal type, aiming to provide signal identification to better enable electronic attacks and jamming signals.

(32) U.S. Publication No. 2011/0059747 for "Sensing Wireless Transmissions From a Licensed User of a Licensed Spectral Resource" by inventors Lindoff, et al., filed Sep. 7, 2009, describes sensing wireless transmissions from a licensed user of a licensed spectral resource includes obtaining information indicating a number of adjacent sensors that are concurrently sensing wireless transmissions from the licensed user of the licensed spectral resource. Such information can be obtained from a main node controlling the sensor and its adjacent sensors, or by the sensor itself (e.g., by means of short-range communication equipment targeting any such adjacent sensors). A sensing rate is then determined as a function, at least in part, of the information indicating the number of adjacent sensors that are concurrently sensing wireless transmissions from the licensed user of the licensed spectral resource. Receiver equipment is then periodically operated at the determined sensing rate, wherein the receiver equipment is configured to detect wireless transmissions from the licensed user of the licensed spectral resource.

(33) U.S. Pat. No. 8,463,195 for "Methods and apparatus for spectrum sensing of signal features in a wireless channel" by inventor Shellhammer, filed Nov. 13, 2009, discloses methods and apparatus for sensing features of a signal in a wireless communication system are disclosed. The disclosed methods and apparatus sense signal features by determining a number of spectral density estimates, where each estimate is derived based on reception of the signal by a respective antenna in a system with multiple sensing antennas. The spectral density estimates are then combined, and the signal features are sensed based on the combination of the spectral density estimates. Invention aims to increase sensing performance by addressing problems associated with Rayleigh fading, which causes signals to be less detectable.

(34) U.S. Pat. No. 8,151,311 for "System and method of detecting potential video traffic interference" by

inventors Huffman, et al., filed Nov. 30, 2007, describes a method of detecting potential video traffic interference at a video head-end of a video distribution network is disclosed and includes detecting, at a video head-end, a signal populating an ultra-high frequency (UHF) white space frequency. The method also includes determining that a strength of the signal is equal to or greater than a threshold signal strength. Further, the method includes sending an alert from the video head-end to a network management system. The alert indicates that the UHF white space frequency is populated by a signal having a potential to interfere with video traffic delivered via the video head-end. Cognitive radio technology, various sensing mechanisms (energy sensing, National Television System Committee signal sensing, Advanced Television Systems Committee sensing), filtering, and signal reconstruction are disclosed.

(35) U.S. Pat. No. 8,311,509 for "Detection, communication and control in multimode cellular, TDMA, GSM, spread spectrum, CDMA, OFDM, WiLAN, and WiFi systems" by inventor Feher, filed Oct. 31, 2007, teaches a device for detection of signals, with location finder or location tracker or navigation signal and with Modulation Demodulation (Modem) Format Selectable (MFS) communication signal. Processor for processing a digital signal into cross-correlated in-phase and quadrature-phase filtered signal and for processing a voice signal into Orthogonal Frequency Division Multiplexed (OFDM) or Orthogonal Frequency Division Multiple Access (OFDMA) signal. Each is used in a Wireless Local Area Network (WLAN) and in Voice over Internet Protocol (VOIP) network. Device and location finder with Time Division Multiple Access (TDMA), Global Mobile System (GSM) and spread spectrum Code Division Multiple Access (CDMA) is used in a cellular network. Polar and quadrature modulator and two antenna transmitter for transmission of provided processed signal. Transmitter with two amplifiers operated in separate radio frequency (RF) bands. One transmitter is operated as a Non-Linearly Amplified (NLA) transmitter and the other transmitter is operated as a linearly amplified or linearized amplifier transmitter.

(36) U.S. Pat. No. 8,514,729 for "Method and system for analyzing RF signals in order to detect and classify actively transmitting RF devices" by inventor Blackwell, filed Apr. 3, 2009, discloses methods and apparatuses to analyze RF signals in order to detect and classify RF devices in wireless networks are described. The method includes detecting one or more radio frequency (RF) samples; determining burst data by identifying start and stop points of the one or more RF samples; comparing time domain values for an individual burst with time domain values of one or more predetermined RF device profiles; generating a human-readable result indicating whether the individual burst should be assigned to one of the predetermined RF device profiles; and, classifying the individual burst if assigned to one of the predetermined RF device profiles as being a WiFi device or a non-WiFi device with the non-WiFi device being a RF interference source to a wireless network.

(37) However, none of the prior art references provide solutions to the limitations and longstanding unmet needs existing in this area for automatically identifying open space in a wireless communications spectrum. Thus, there remains a need for automated identification of open space in a wireless communications spectrum in near real time.

SUMMARY OF THE INVENTION

(38) The present invention addresses the longstanding, unmet needs existing in the prior art and commercial sectors to provide solutions to the at least four major problems existing before the present invention, each one that requires near real time results on a continuous scanning of the target environment for the spectrum.

(39) The present invention relates to systems, methods, and devices of the various embodiments enable spectrum management by identifying, classifying, and cataloging signals of interest based on radio frequency measurements. In an embodiment, signals and the parameters of the signals may be identified and indications of available frequencies may be presented to a user. In another embodiment, the protocols of signals may also be identified. In a further embodiment, the modulation of signals, data types carried by the signals, and estimated signal origins may be identified.

(40) It is an object of this invention is to provide an apparatus for identifying signal emitting devices including: a housing, at least one processor and memory, and sensors constructed and configured for sensing and measuring wireless communications signals from signal emitting devices in a spectrum associated with wireless communications; and wherein the apparatus is operable to automatically analyze the measured data to identify at least one signal emitting device in near real time from attempted detection and identification of the at least one signal emitting device, and then to identify open space available for wireless communications, based upon the information about the signal emitting device(s) operating in the

predetermined spectrum; furthermore, the present invention provides baseline data and changes in state for compressed data to enable near real time analytics and results for individual units and for aggregated units for making unique comparisons of data.

(41) The present invention further provides systems for identifying white space in wireless communications spectrum by detecting and analyzing signals from any signal emitting devices including at least one apparatus, wherein the at least one apparatus is operable for network-based communication with at least one server computer including a database, and/or with at least one other apparatus, but does not require a connection to the at least one server computer to be operable for identifying signal emitting devices; wherein each of the apparatus is operable for identifying signal emitting devices including: a housing, at least one processor and memory, and sensors constructed and configured for sensing and measuring wireless communications signals from signal emitting devices in a spectrum associated with wireless communications; and wherein the apparatus is operable to automatically analyze the measured data to identify at least one signal emitting device in near real time from attempted detection and identification of the at least one signal emitting device, and then to identify open space available for wireless communications, based upon the information about the signal emitting device(s) operating in the predetermined spectrum; all of the foregoing using baseline data and changes in state for compressed data to enable near real time analytics and results for individual units and for aggregated units for making unique comparisons of data.

(42) The present invention is further directed to a method for identifying baseline data and changes in state for compressed data to enable near real time analytics and results for individual units and for aggregated units for making unique comparisons of data in a wireless communications spectrum including the steps of: providing a device for measuring characteristics of signals from signal emitting devices in a spectrum associated with wireless communications, with measured data characteristics including frequency, power, bandwidth, duration, modulation, and combinations thereof; the device including a housing, at least one processor and memory, and sensors constructed and configured for sensing and measuring wireless communications signals within the spectrum; and further including the following steps performed within the device housing: assessing whether the measured data includes analog and/or digital signal(s); determining a best fit based on frequency, if the measured power spectrum is designated in an historical or a reference database(s) for frequency ranges; automatically determining a category for either analog or digital signals, based on power and sideband combined with frequency allocation; determining a TDM/FDM/CDM signal, based on duration and bandwidth; identifying at least one signal emitting device from the composite results of the foregoing steps; and then automatically identifying the open space available for wireless communications, based upon the information about the signal emitting device(s) operating in the predetermined spectrum; all using baseline data and changes in state for compressed data to enable near real time analytics and results for individual units and for aggregated units for making unique comparisons of data.

(43) Additionally, the present invention provides systems, apparatus, and methods for identifying open space in a wireless communications spectrum using an apparatus having a multiplicity of processors and memory, sensors, and communications transmitters and receivers, all constructed and configured within a housing for automated analysis of detected signals from signal emitting devices, determination of signal duration and other signal characteristics, and automatically generating information relating to device identification, open space, signal optimization, all using baseline data and changes in state for compressed data to enable near real time analytics and results for individual units and for aggregated units for making unique comparisons of data within the spectrum for wireless communication.

(44) These and other aspects of the present invention will become apparent to those skilled in the art after a reading of the following description of the preferred embodiment when considered with the drawings, as they support the claimed invention.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate exemplary embodiments of the invention, and together with the general description given above

and the detailed description given below, serve to explain the features of the invention.
(2) FIG. **1** is a system block diagram of a wireless environment suitable for use with the various embodiments.
(3) FIG. **2**A is a block diagram of a spectrum management device according to an embodiment.
(4) FIG. **2**B is a schematic logic flow block diagram illustrating logical operations which may be performed by a spectrum management device according to an embodiment.
(5) FIG. **3** is a process flow diagram illustrating an embodiment method for identifying a signal.
(6) FIG. **4** is a process flow diagram illustrating an embodiment method for measuring sample blocks of a radio frequency scan.
(7) FIGS. **5**A-**5**C are a process flow diagram illustrating an embodiment method for determining signal parameters.
(8) FIG. **6** is a process flow diagram illustrating an embodiment method for displaying signal identifications.
(9) FIG. **7** is a process flow diagram illustrating an embodiment method for displaying one or more open frequency.
(10) FIG. **8**A is a block diagram of a spectrum management device according to another embodiment.
(11) FIG. **8**B is a schematic logic flow block diagram illustrating logical operations which may be performed by a spectrum management device according to another embodiment.
(12) FIG. **9** is a process flow diagram illustrating an embodiment method for determining protocol data and symbol timing data.
(13) FIG. **10** is a process flow diagram illustrating an embodiment method for calculating signal degradation data.
(14) FIG. **11** is a process flow diagram illustrating an embodiment method for displaying signal and protocol identification information.
(15) FIG. **12**A is a block diagram of a spectrum management device according to a further embodiment.
(16) FIG. **12**B is a schematic logic flow block diagram illustrating logical operations which may be performed by a spectrum management device according to a further embodiment.
(17) FIG. **13** is a process flow diagram illustrating an embodiment method for estimating a signal origin based on a frequency difference of arrival.
(18) FIG. **14** is a process flow diagram illustrating an embodiment method for displaying an indication of an identified data type within a signal.
(19) FIG. **15** is a process flow diagram illustrating an embodiment method for determining modulation type, protocol data, and symbol timing data.
(20) FIG. **16** is a process flow diagram illustrating an embodiment method for tracking a signal origin.
(21) FIG. **17** is a schematic diagram illustrating an embodiment for scanning and finding open space.
(22) FIG. **18** is a diagram of an embodiment wherein software defined radio nodes are in communication with a master transmitter and device sensing master.
(23) FIG. **19** is a process flow diagram of an embodiment method of temporally dividing up data into intervals for power usage analysis.
(24) FIG. **20** is a flow diagram illustrating an embodiment wherein frequency to license matching occurs.
(25) FIG. **21** is a flow diagram illustrating an embodiment method for reporting power usage information.
(26) FIG. **22** is a flow diagram illustrating an embodiment method for creating frequency arrays.
(27) FIG. **23** is a flow diagram illustrating an embodiment method for reframe and aggregating power when producing frequency arrays.
(28) FIG. **24** is a flow diagram illustrating an embodiment method of reporting license expirations.
(29) FIG. **25** is a flow diagram illustrating an embodiment method of reporting frequency power use.
(30) FIG. **26** is a flow diagram illustrating an embodiment method of connecting devices.
(31) FIG. **27** is a flow diagram illustrating an embodiment method of addressing collisions.
(32) FIG. **28** is a schematic diagram of an embodiment of the invention illustrating a virtualized computing network and a plurality of distributed devices.
(33) FIG. **29** is a schematic diagram of an embodiment of the present invention.
(34) FIG. **30** is a schematic diagram illustrating the present invention in a virtualized or cloud computing system with a network and a mobile computer or mobile communications device.
(35) FIGS. **31-34** show screen shot illustrations for automatic signal detection indications on displays

associated with the present invention.
(36) FIG. **35** is an example of a receiver that has marked variations on baseline behavior across a wide spectrum (9 MHz-6 GHz).
(37) FIG. **36** shows a normal spectrum from 700 MHz to 790 MHz in one embodiment.
(38) FIG. **37** shows the same spectrum as in FIG. **36** at a different time.
(39) FIG. **38** illustrates a spectrum from 1.9 GHz to 2.0 GHz, along with some additional lines that indicate the functions of the new algorithm.
(40) FIG. **39** is a close up view of the first part of the overall spectrum in FIG. **38**.
(41) FIG. **40** illustrates a knowledge map obtained by a TFE process.
(42) FIG. **41** illustrates an interpretation operation based on a knowledge map.
(43) FIG. **42** shows the identification of signals, which are represented by the black brackets above the knowledge display.
(44) FIG. **43** shows more details of the narrow band signals at the left of the spectrum around 400 MHz in FIG. **42**.
(45) FIG. **44** shows more details of the wide band signals and narrow band signals between 735 MHz and 790 MHz in FIG. **42**.
(46) FIG. **45** illustrates an operation of the ASD in the present invention.
(47) FIG. **46** provides a flow diagram for geolocation in the present invention.
(48) FIG. **47** illustrates a local small diversity array with North-South/East-West orientation.
(49) FIG. **48** illustrates a synthetic aperture for a bearing from the midpoint of two monitoring units.
(50) FIG. **49** illustrates the use of another component to establish a synthetic aperture yielding another bearing.

DETAILED DESCRIPTION

(51) Referring now to the drawings in general, the illustrations are for the purpose of describing at least one preferred embodiment and/or examples of the invention and are not intended to limit the invention thereto. Various embodiments are described in detail with reference to the accompanying drawings. Wherever possible, the same reference numbers are used throughout the drawings to refer to the same or like parts. References made to particular examples and implementations are for illustrative purposes, and are not intended to limit the scope of the invention or the claims.
(52) The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any implementation described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other implementations.
(53) The present invention provides systems, methods, and devices for spectrum analysis and management by identifying, classifying, and cataloging at least one or a multiplicity of signals of interest based on radio frequency measurements and location and other measurements, and using near real-time parallel processing of signals and their corresponding parameters and characteristics in the context of historical and static data for a given spectrum, and more particularly, all using baseline data and changes in state for compressed data to enable near real time analytics and results for individual units and for aggregated units for making unique comparisons of data.
(54) The systems, methods and apparatus according to the present invention preferably have the ability to detect in near real time, and more preferably to detect, sense, measure, and/or analyze in near real time, and more preferably to perform any near real time operations within about 1 second or less. Advantageously, the present invention and its real time functionality described herein uniquely provide and enable the apparatus units to compare to historical data, to update data and/or information, and/or to provide more data and/or information on the open space, on the device that may be occupying the open space, and combinations, in the near real time compared with the historically scanned (15 min to 30 days) data, or historical database information.
(55) The systems, methods, and devices of the various embodiments enable spectrum management by identifying, classifying, and cataloging signals of interest based on radio frequency measurements. In an embodiment, signals and the parameters of the signals may be identified and indications of available frequencies may be presented to a user. In another embodiment, the protocols of signals may also be identified. In a further embodiment, the modulation of signals, data types carried by the signals, and estimated signal origins may be identified.
(56) Embodiments are directed to a spectrum management device that may be configurable to obtain

spectrum data over a wide range of wireless communication protocols. Embodiments may also provide for the ability to acquire data from and send data to database depositories that may be used by a plurality of spectrum management customers.

(57) In one embodiment, a spectrum management device may include a signal spectrum analyzer that may be coupled with a database system and spectrum management interface. The device may be portable or may be a stationary installation and may be updated with data to allow the device to manage different spectrum information based on frequency, bandwidth, signal power, time, and location of signal propagation, as well as modulation type and format and to provide signal identification, classification, and geo-location. A processor may enable the device to process spectrum power density data as received and to process raw I/Q complex data that may be used for further signal processing, signal identification, and data extraction.

(58) In an embodiment, a spectrum management device may comprise a low noise amplifier that receives a radio frequency (RF) energy from an antenna. The antenna may be any antenna structure that is capable of receiving RF energy in a spectrum of interest. The low noise amplifier may filter and amplify the RF energy. The RF energy may be provided to an RF translator. The RF translator may perform a fast Fourier transform (FFT) and either a square magnitude or a fast convolution spectral periodogram function to convert the RF measurements into a spectral representation. In an embodiment, the RF translator may also store a timestamp to facilitate calculation of a time of arrival and an angle of arrival. The In-Phase and Quadrature (I/Q) data may be provided to a spectral analysis receiver or it may be provided to a sample data store where it may be stored without being processed by a spectral analysis receiver. The input RF energy may also be directly digital down-converted and sampled by an analog to digital converter (ADC) to generate complex I/Q data. The complex I/Q data may be equalized to remove multipath, fading, white noise and interference from other signaling systems by fast parallel adaptive filter processes. This data may then be used to calculate modulation type and baud rate. Complex sampled I/Q data may also be used to measure the signal angle of arrival and time of arrival. Such information as angle of arrival and time of arrival may be used to compute more complex and precise direction finding. In addition, they may be used to apply geo-location techniques. Data may be collected from known signals or unknown signals and time spaced in order to provide expedient information. I/Q sampled data may contain raw signal data that may be used to demodulate and translate signals by streaming them to a signal analyzer or to a real-time demodulator software defined radio that may have the newly identified signal parameters for the signal of interest. The inherent nature of the input RF allows for any type of signal to be analyzed and demodulated based on the reconfiguration of the software defined radio interfaces.

(59) A spectral analysis receiver may be configured to read raw In-Phase (I) and Quadrature (Q) data and either translate directly to spectral data or down convert to an intermediate frequency (IF) up to half the Nyquist sampling rate to analyze the incoming bandwidth of a signal. The translated spectral data may include measured values of signal energy, frequency, and time. The measured values provide attributes of the signal under review that may confirm the detection of a particular signal of interest within a spectrum of interest. In an embodiment, a spectral analysis receiver may have a referenced spectrum input of 0 Hz to 12.4 GHz with capability of fiber optic input for spectrum input up to 60 GHz.

(60) In an embodiment, the spectral analysis receiver may be configured to sample the input RF data by fast analog down-conversion of the RF signal. The down-converted signal may then be digitally converted and processed by fast convolution filters to obtain a power spectrum. This process may also provide spectrum measurements including the signal power, the bandwidth, the center frequency of the signal as well as a Time of Arrival (TOA) measurement. The TOA measurement may be used to create a timestamp of the detected signal and/or to generate a time difference of arrival iterative process for direction finding and fast triangulation of signals. In an embodiment, the sample data may be provided to a spectrum analysis module. In an embodiment, the spectrum analysis module may evaluate the sample data to obtain the spectral components of the signal.

(61) In an embodiment, the spectral components of the signal may be obtained by the spectrum analysis module from the raw I/Q data as provided by an RF translator. The I/Q data analysis performed by the spectrum analysis module may operate to extract more detailed information about the signal, including by way of example, modulation type (e.g., FM, AM, QPSK, 16QAM, etc.) and/or protocol (e.g., GSM, CDMA, OFDM, LTE, etc.). In an embodiment, the spectrum analysis module may be configured by a user to obtain specific information about a signal of interest. In an alternate embodiment, the spectral

components of the signal may be obtained from power spectral component data produced by the spectral analysis receiver.

(62) In an embodiment, the spectrum analysis module may provide the spectral components of the signal to a data extraction module. The data extraction module may provide the classification and categorization of signals detected in the RF spectrum. The data extraction module may also acquire additional information regarding the signal from the spectral components of the signal. For example, the data extraction module may provide modulation type, bandwidth, and possible system in use information. In another embodiment, the data extraction module may select and organize the extracted spectral components in a format selected by a user.

(63) The information from the data extraction module may be provided to a spectrum management module. The spectrum management module may generate a query to a static database to classify a signal based on its components. For example, the information stored in static database may be used to determine the spectral density, center frequency, bandwidth, baud rate, modulation type, protocol (e.g., GSM, CDMA, OFDM, LTE, etc.), system or carrier using licensed spectrum, location of the signal source, and a timestamp of the signal of interest. These data points may be provided to a data store for export. In an embodiment and as more fully described below, the data store may be configured to access mapping software to provide the user with information on the location of the transmission source of the signal of interest. In an embodiment, the static database includes frequency information gathered from various sources including, but not limited to, the Federal Communication Commission, the International Telecommunication Union, and data from users. As an example, the static database may be an SQL database. The data store may be updated, downloaded or merged with other devices or with its main relational database. Software API applications may be included to allow database merging with third-party spectrum databases that may only be accessed securely.

(64) In the various embodiments, the spectrum management device may be configured in different ways. In an embodiment, the front end of system may comprise various hardware receivers that may provide In-Phase and Quadrature complex data. The front end receiver may include API set commands via which the system software may be configured to interface (i.e., communicate) with a third party receiver. In an embodiment, the front end receiver may perform the spectral computations using FFT (Fast Fourier Transform) and other DSP (Digital Signal Processing) to generate a fast convolution periodogram that may be re-sampled and averaged to quickly compute the spectral density of the RF environment.

(65) In an embodiment, cyclic processes may be used to average and correlate signal information by extracting the changes inside the signal to better identify the signal of interest that is present in the RF space. A combination of amplitude and frequency changes may be measured and averaged over the bandwidth time to compute the modulation type and other internal changes, such as changes in frequency offsets, orthogonal frequency division modulation, changes in time (e.g., Time Division Multiplexing), and/or changes in I/Q phase rotation used to compute the baud rate and the modulation type. In an embodiment, the spectrum management device may have the ability to compute several processes in parallel by use of a multi-core processor and along with several embedded field programmable gate arrays (FPGA). Such multi-core processing may allow the system to quickly analyze several signal parameters in the RF environment at one time in order to reduce the amount of time it takes to process the signals. The amount of signals computed at once may be determined by their bandwidth requirements. Thus, the capability of the system may be based on a maximum frequency Fs/2. The number of signals to be processed may be allocated based on their respective bandwidths. In another embodiment, the signal spectrum may be measured to determine its power density, center frequency, bandwidth and location from which the signal is emanating and a best match may be determined based on the signal parameters based on information criteria of the frequency.

(66) In another embodiment, a GPS and direction finding location (DF) system may be incorporated into the spectrum management device and/or available to the spectrum management device. Adding GPS and DF ability may enable the user to provide a location vector using the National Marine Electronics Association's (NMEA) standard form. In an embodiment, location functionality is incorporated into a specific type of GPS unit, such as a U.S. government issued receiver. The information may be derived from the location presented by the database internal to the device, a database imported into the device, or by the user inputting geo-location parameters of longitude and latitude which may be derived as degrees, minutes and seconds, decimal minutes, or decimal form and translated to the necessary format with the

default being 'decimal' form. This functionality may be incorporated into a GPS unit. The signal information and the signal classification may then be used to locate the signaling device as well as to provide a direction finding capability.

(67) A type of triangulation using three units as a group antenna configuration performs direction finding by using multilateration. Commonly used in civil and military surveillance applications, multilateration is able to accurately locate an aircraft, vehicle, or stationary emitter by measuring the "Time Difference of Arrival" (TDOA) of a signal from the emitter at three or more receiver sites. If a pulse is emitted from a platform, it will arrive at slightly different times at two spatially separated receiver sites, the TDOA being due to the different distances of each receiver from the platform. This location information may then be supplied to a mapping process that utilizes a database of mapping images that are extracted from the database based on the latitude and longitude provided by the geo-location or direction finding device. The mapping images may be scanned in to show the points of interest where a signal is either expected to be emanating from based on the database information or from an average taken from the database information and the geo-location calculation performed prior to the mapping software being called. The user can control the map to maximize or minimize the mapping screen to get a better view which is more fit to provide information of the signal transmissions. In an embodiment, the mapping process does not rely on outside mapping software. The mapping capability has the ability to generate the map image and to populate a mapping database that may include information from third party maps to meet specific user requirements.

(68) In an embodiment, triangulation and multilateration may utilize a Bayesian type filter that may predict possible movement and future location and operation of devices based on input collected from the TDOA and geolocation processes and the variables from the static database pertaining to the specified signal of interest. The Bayesian filter takes the input changes in time difference and its inverse function (i.e., frequency difference) and takes an average change in signal variation to detect and predict the movement of the signals. The signal changes are measured within 1 ns time difference and the filter may also adapt its gradient error calculation to remove unwanted signals that may cause errors due to signal multipath, inter-symbol interference, and other signal noise.

(69) In an embodiment the changes within a 1 ns time difference for each sample for each unique signal may be recorded. The spectrum management device may then perform the inverse and compute and record the frequency difference and phase difference between each sample for each unique signal. The spectrum management device may take the same signal and calculates an error based on other input signals coming in within the 1 ns time and may average and filter out the computed error to equalize the signal. The spectrum management device may determine the time difference and frequency difference of arrival for that signal and compute the odds of where the signal is emanating from based on the frequency band parameters presented from the spectral analysis and processor computations, and determines the best position from which the signal is transmitted (i.e., origin of the signal).

(70) FIG. **1** illustrates a wireless environment **100** suitable for use with the various embodiments. The wireless environment **100** may include various sources **104**, **106**, **108**, **110**, **112**, and **114** generating various radio frequency (RF) signals **116**, **118**, **120**, **122**, **124**, **126**. As an example, mobile devices **104** may generate cellular RF signals **116**, such as CDMA, GSM, 3G signals, etc. As another example, wireless access devices **106**, such as Wi-Fi® routers, may generate RF signals **118**, such as Wi-Fi® signals. As a further example, satellites **108**, such as communication satellites or GPS satellites, may generate RF signals **120**, such as satellite radio, television, or GPS signals. As a still further example, base stations **110**, such as a cellular base station, may generate RF signals **122**, such as CDMA, GSM, 3G signals, etc. As another example, radio towers **112**, such as local AM or FM radio stations, may generate RF signals **124**, such as AM or FM radio signals. As another example, government service provides **114**, such as police units, fire fighters, military units, air traffic control towers, etc. may generate RF signals **126**, such as radio communications, tracking signals, etc. The various RF signals **116**, **118**, **120**, **122**, **124**, **126** may be generated at different frequencies, power levels, in different protocols, with different modulations, and at different times. The various sources **104**, **106**, **108**, **110**, **112**, and **114** may be assigned frequency bands, power limitations, or other restrictions, requirements, and/or licenses by a government spectrum control entity, such as the FCC. However, with so many different sources **104**, **106**, **108**, **110**, **112**, and **114** generating so many different RF signals **116**, **118**, **120**, **122**, **124**, **126**, overlaps, interference, and/or other problems may occur. A spectrum management device **102** in the wireless environment **100** may measure

the RF energy in the wireless environment **100** across a wide spectrum and identify the different RF signals **116**, **118**, **120**, **122**, **124**, **126** which may be present in the wireless environment **100**. The identification and cataloging of the different RF signals **116**, **118**, **120**, **122**, **124**, **126** which may be present in the wireless environment **100** may enable the spectrum management device **102** to determine available frequencies for use in the wireless environment **100**. In addition, the spectrum management device **102** may be able to determine if there are available frequencies for use in the wireless environment **100** under certain conditions (i.e., day of week, time of day, power level, frequency band, etc.). In this manner, the RF spectrum in the wireless environment **100** may be managed.
(71) FIG. **2**A is a block diagram of a spectrum management device **202** according to an embodiment. The spectrum management device **202** may include an antenna structure **204** configured to receive RF energy expressed in a wireless environment. The antenna structure **204** may be any type antenna, and may be configured to optimize the receipt of RF energy across a wide frequency spectrum. The antenna structure **204** may be connected to one or more optional amplifiers and/or filters **208** which may boost, smooth, and/or filter the RF energy received by antenna structure **204** before the RF energy is passed to an RF receiver **210** connected to the antenna structure **204**. In an embodiment, the RF receiver **210** may be configured to measure the RF energy received from the antenna structure **204** and/or optional amplifiers and/or filters **208**. In an embodiment, the RF receiver **210** may be configured to measure RF energy in the time domain and may convert the RF energy measurements to the frequency domain. In an embodiment, the RF receiver **210** may be configured to generate spectral representation data of the received RF energy. The RF receiver **210** may be any type RF receiver, and may be configured to generate RF energy measurements over a range of frequencies, such as 0 kHz to 24 GHz, 9 kHz to 6 GHz, etc. In an embodiment, the frequency scanned by the RF receiver **210** may be user selectable. In an embodiment, the RF receiver **210** may be connected to a signal processor **214** and may be configured to output RF energy measurements to the signal processor **214**. As an example, the RF receiver **210** may output raw In-Phase (I) and Quadrature (Q) data to the signal processor **214**. As another example, the RF receiver **210** may apply signals processing techniques to output complex In-Phase (I) and Quadrature (Q) data to the signal processor **214**. In an embodiment, the spectrum management device may also include an antenna **206** connected to a location receiver **212**, such as a GPS receiver, which may be connected to the signal processor **214**. The location receiver **212** may provide location inputs to the signal processor **214**.
(72) The signal processor **214** may include a signal detection module **216**, a comparison module **222**, a timing module **224**, and a location module **225**. Additionally, the signal processor **214** may include an optional memory module **226** which may include one or more optional buffers **228** for storing data generated by the other modules of the signal processor **214**.
(73) In an embodiment, the signal detection module **216** may operate to identify signals based on the RF energy measurements received from the RF receiver **210**. The signal detection module **216** may include a Fast Fourier Transform (FFT) module **217** which may convert the received RF energy measurements into spectral representation data. The signal detection module **216** may include an analysis module **221** which may analyze the spectral representation data to identify one or more signals above a power threshold. A power module **220** of the signal detection module **216** may control the power threshold at which signals may be identified. In an embodiment, the power threshold may be a default power setting or may be a user selectable power setting. A noise module **219** of the signal detection module **216** may control a signal threshold, such as a noise threshold, at or above which signals may be identified. The signal detection module **216** may include a parameter module **218** which may determine one or more signal parameters for any identified signals, such as center frequency, bandwidth, power, number of detected signals, frequency peak, peak power, average power, signal duration, etc. In an embodiment, the signal processor **214** may include a timing module **224** which may record time information and provide the time information to the signal detection module **216**. Additionally, the signal processor **214** may include a location module **225** which may receive location inputs from the location receiver **212** and determine a location of the spectrum management device **202**. The location of the spectrum management device **202** may be provided to the signal detection module **216**.
(74) In an embodiment, the signal processor **214** may be connected to one or more memory **230**. The memory **230** may include multiple databases, such as a history or historical database **232** and characteristics listing **236**, and one or more buffers **240** storing data generated by signal processor **214**. While illustrated as connected to the signal processor **214** the memory **230** may also be on chip memory

residing on the signal processor **214** itself. In an embodiment, the history or historical database **232** may include measured signal data **234** for signals that have been previously identified by the spectrum management device **202**. The measured signal data **234** may include the raw RF energy measurements, time stamps, location information, one or more signal parameters for any identified signals, such as center frequency, bandwidth, power, number of detected signals, frequency peak, peak power, average power, signal duration, etc., and identifying information determined from the characteristics listing **236**. In an embodiment, the history or historical database **232** may be updated as signals are identified by the spectrum management device **202**. In an embodiment, the characteristic listing **236** may be a database of static signal data **238**. The static signal data **238** may include data gathered from various sources including by way of example and not by way of limitation the Federal Communication Commission, the International Telecommunication Union, telecom providers, manufacture data, and data from spectrum management device users. Static signal data **238** may include known signal parameters of transmitting devices, such as center frequency, bandwidth, power, number of detected signals, frequency peak, peak power, average power, signal duration, geographic information for transmitting devices, and any other data that may be useful in identifying a signal. In an embodiment, the static signal data **238** and the characteristic listing **236** may correlate signal parameters and signal identifications. As an example, the static signal data **238** and characteristic listing **236** may list the parameters of the local fire and emergency communication channel correlated with a signal identification indicating that signal is the local fire and emergency communication channel.

(75) In an embodiment, the signal processor **214** may include a comparison module **222** which may match data generated by the signal detection module **216** with data in the history or historical database **232** and/or characteristic listing **236**. In an embodiment the comparison module **222** may receive signal parameters from the signal detection module **216**, such as center frequency, bandwidth, power, number of detected signals, frequency peak, peak power, average power, signal duration, and/or receive parameter from the timing module **224** and/or location module **225**. The parameter match module **223** may retrieve data from the history or historical database **232** and/or the characteristic listing **236** and compare the retrieved data to any received parameters to identify matches. Based on the matches the comparison module may identify the signal. In an embodiment, the signal processor **214** may be optionally connected to a display **242**, an input device **244**, and/or network transceiver **246**. The display **242** may be controlled by the signal processor **214** to output spectral representations of received signals, signal characteristic information, and/or indications of signal identifications on the display **242**. In an embodiment, the input device **244** may be any input device, such as a keyboard and/or knob, mouse, virtual keyboard or even voice recognition, enabling the user of the spectrum management device **202** to input information for use by the signal processor **214**. In an embodiment, the network transceiver **246** may enable the spectrum management device **202** to exchange data with wired and/or wireless networks, such as to update the characteristic listing **236** and/or upload information from the history or historical database **232**.

(76) FIG. **2**B is a schematic logic flow block diagram illustrating logical operations which may be performed by a spectrum management device **202** according to an embodiment. A receiver **210** may output RF energy measurements, such as I and Q data to an FFT module **252** which may generate a spectral representation of the RF energy measurements which may be output on a display **242**. The I and Q data may also be buffered in a buffer **256** and sent to a signal detection module **216**. The signal detection module **216** may receive location inputs from a location receiver **212** and use the received I and Q data to detect signals. Data from the signal detection module **216** may be buffered in a buffer **262** and written into a history or historical database **232**. Additionally, data from the historical database may be used to aid in the detection of signals by the signal detection module **216**. The signal parameters of the detected signals may be determined by a signal parameters module **218** using information from the history or historical database **232** and/or a static database **238** listing signal characteristics through a buffer **268**. Data from the signal parameters module **218** may be stored in the history or historical database **232** and/or sent to the signal detection module **216** and/or display **242**. In this manner, signals may be detected and indications of the signal identification may be displayed to a user of the spectrum management device.

(77) FIG. **3** illustrates a process flow of an embodiment method **300** for identifying a signal. In an embodiment the operations of method **300** may be performed by the processor **214** of a spectrum management device **202**. In block **302** the processor **214** may determine the location of the spectrum management device **202**. In an embodiment, the processor **214** may determine the location of the spectrum

management device **202** based on a location input, such as GPS coordinates, received from a location receiver, such as a GPS receiver **212**. In block **304** the processor **214** may determine the time. As an example, the time may be the current clock time as determined by the processor **214** and may be a time associated with receiving RF measurements. In block **306** the processor **214** may receive RF energy measurements. In an embodiment, the processor **214** may receive RF energy measurements from an RF receiver **210**. In block **308** the processor **214** may convert the RF energy measurements to spectral representation data. As an example, the processor may apply a Fast Fourier Transform (FFT) to the RF energy measurements to convert them to spectral representation data. In optional block **310** the processor **214** may display the spectral representation data on a display **242** of the spectrum management device **202**, such as in a graph illustrating amplitudes across a frequency spectrum.

(78) In block **312** the processor **214** may identify one or more signal above a threshold. In an embodiment, the processor **214** may analyze the spectral representation data to identify a signal above a power threshold. A power threshold may be an amplitude measure selected to distinguish RF energies associated with actual signals from noise. In an embodiment, the power threshold may be a default value. In another embodiment, the power threshold may be a user selectable value. In block **314** the processor **214** may determine signal parameters of any identified signal or signals of interest. As examples, the processor **214** may determine signal parameters such as center frequency, bandwidth, power, number of detected signals, frequency peak, peak power, average power, signal duration for the identified signals. In block **316** the processor **214** may store the signal parameters of each identified signal, a location indication, and time indication for each identified signal in a history database **232**. In an embodiment, a history database **232** may be a database resident in a memory **230** of the spectrum management device **202** which may include data associated with signals actually identified by the spectrum management device.

(79) In block **318** the processor **214** may compare the signal parameters of each identified signal to signal parameters in a signal characteristic listing. In an embodiment, the signal characteristic listing may be a static database **238** stored in the memory **230** of the spectrum management device **202** which may correlate signal parameters and signal identifications. In determination block **320** the processor **214** may determine whether the signal parameters of the identified signal or signals match signal parameters in the characteristic listing **236**. In an embodiment, a match may be determined based on the signal parameters being within a specified tolerance of one another. As an example, a center frequency match may be determined when the center frequencies are within plus or minus 1 kHz of each other. In this manner, differences between real world measured conditions of an identified signal and ideal conditions listed in a characteristics listing may be accounted for in identifying matches. If the signal parameters do not match (i.e., determination block **320**=“No”), in block **326** the processor **214** may display an indication that the signal is unidentified on a display **242** of the spectrum management device **202**. In this manner, the user of the spectrum management device may be notified that a signal is detected, but has not been positively identified. If the signal parameters do match (i.e., determination block **320**=“Yes”), in block **324** the processor **214** may display an indication of the signal identification on the display **242**. In an embodiment, the signal identification displayed may be the signal identification correlated to the signal parameter in the signal characteristic listing which matched the signal parameter for the identified signal. Upon displaying the indications in blocks **324** or **326** the processor **214** may return to block **302** and cyclically measure and identify further signals of interest.

(80) FIG. **4** illustrates an embodiment method **400** for measuring sample blocks of a radio frequency scan. In an embodiment the operations of method **400** may be performed by the processor **214** of a spectrum management device **202**. As discussed above, in blocks **306** and **308** the processor **214** may receive RF energy measurements and convert the RF energy measurements to spectral representation data. In block **402** the processor **214** may determine a frequency range at which to sample the RF spectrum for signals of interest. In an embodiment, a frequency range may be a frequency range of each sample block to be analyzed for potential signals. As an example, the frequency range may be 240 kHz. In an embodiment, the frequency range may be a default value. In another embodiment, the frequency range may be a user selectable value. In block **404** the processor **214** may determine a number (N) of sample blocks to measure. In an embodiment, each sample block may be sized to the determined of default frequency range, and the number of sample blocks may be determined by dividing the spectrum of the measured RF energy by the frequency range. In block **406** the processor **214** may assign each sample block a respective frequency range. As an example, if the determined frequency range is 240 kHz, the first sample block may be

assigned a frequency range from 0 kHz to 240 kHz, the second sample block may be assigned a frequency range from 240 kHz to 480 kHz, etc. In block **408** the processor **214** may set the lowest frequency range sample block as the current sample block. In block **409** the processor **214** may measure the amplitude across the set frequency range for the current sample block. As an example, at each frequency interval (such as 1 Hz) within the frequency range of the sample block the processor **214** may measure the received signal amplitude. In block **410** the processor **214** may store the amplitude measurements and corresponding frequencies for the current sample block. In determination block **414** the processor **214** may determine if all sample blocks have been measured. If all sample blocks have not been measured (i.e., determination block **414**="No"), in block **416** the processor **214** may set the next highest frequency range sample block as the current sample block. As discussed above, in blocks **409**, **410**, and **414** the processor **214** may measure and store amplitudes and determine whether all blocks are sampled. If all blocks have been sampled (i.e., determination block **414**="Yes"), the processor **214** may return to block **306** and cyclically measure further sample blocks.

(81) FIGS. **5**A, **5**B, and **5**C illustrate the process flow for an embodiment method **500** for determining signal parameters. In an embodiment the operations of method **500** may be performed by the processor **214** of a spectrum management device **202**. Referring to FIG. **5**A, in block **502** the processor **214** may receive a noise floor average setting. In an embodiment, the noise floor average setting may be an average noise level for the environment in which the spectrum management device **202** is operating. In an embodiment, the noise floor average setting may be a default setting and/or may be user selectable setting. In block **504** the processor **214** may receive the signal power threshold setting. In an embodiment, the signal power threshold setting may be an amplitude measure selected to distinguish RF energies associated with actual signals from noise. In an embodiment the signal power threshold may be a default value and/or may be a user selectable setting. In block **506** the processor **214** may load the next available sample block. In an embodiment, the sample blocks may be assembled according to the operations of method **400** described above with reference to FIG. **4**. In an embodiment, the next available sample block may be an oldest in time sample block which has not been analyzed to determine whether signals of interest are present in the sample block. In block **508** the processor **214** may average the amplitude measurements in the sample block. In determination block **510** the processor **214** may determine whether the average for the sample block is greater than or equal to the noise floor average set in block **502**. In this manner, sample blocks including potential signals may be quickly distinguished from sample blocks which may not include potential signals reducing processing time by enabling sample blocks without potential signals to be identified and ignored. If the average for the sample block is lower than the noise floor average (i.e., determination block **510**="No"), no signals of interest may be present in the current sample block. In determination block **514** the processor **214** may determine whether a cross block flag is set. If the cross block flag is not set (i.e., determination block **514**="No"), in block **506** the processor **214** may load the next available sample block and in block **508** average the sample block **508**.

(82) If the average of the sample block is equal to or greater than the noise floor average (i.e., determination block **510**="Yes"), the sample block may potentially include a signal of interest and in block **512** the processor **214** may reset a measurement counter (C) to 1. The measurement counter value indicating which sample within a sample block is under analysis. In determination block **516** the processor **214** may determine whether the RF measurement of the next frequency sample (C) is greater than the signal power threshold. In this manner, the value of the measurement counter (C) may be used to control which sample RF measurement in the sample block is compared to the signal power threshold. As an example, when the counter (C) equals 1, the first RF measurement may be checked against the signal power threshold and when the counter (C) equals 2 the second RF measurement in the sample block may be checked, etc. If the C RF measurement is less than or equal to the signal power threshold (i.e., determination block **516**="No"), in determination block **517** the processor **214** may determine whether the cross block flag is set. If the cross block flag is not set (i.e., determination block **517**="No"), in determination block **522** the processor **214** may determine whether the end of the sample block is reached. If the end of the sample block is reached (i.e., determination block **522**="Yes"), in block **506** the processor **214** may load the next available sample block and proceed in blocks **508**, **510**, **514**, and **512** as discussed above. If the end of the sample block is not reached (i.e., determination block **522**="No"), in block **524** the processor **214** may increment the measurement counter (C) so that the next sample in the sample block is analyzed.

(83) If the C RF measurement is greater than the signal power threshold (i.e., determination block **516**="Yes"), in block **518** the processor **214** may check the status of the cross block flag to determine whether the cross block flag is set. If the cross block flag is not set (i.e., determination block **518**="No"), in block **520** the processor **214** may set a sample start. As an example, the processor **214** may set a sample start by indicating a potential signal of interest may be discovered in a memory by assigning a memory location for RF measurements associated with the sample start. Referring to FIG. **5**B, in block **526** the processor **214** may store the C RF measurement in a memory location for the sample currently under analysis. In block **528** the processor **214** may increment the measurement counter (C) value.

(84) In determination block **530** the processor **214** may determine whether the C RF measurement (e.g., the next RF measurement because the value of the RF measurement counter was incremented) is greater than the signal power threshold. If the C RF measurement is greater than the signal power threshold (i.e., determination block **530**="Yes"), in determination block **532** the processor **214** may determine whether the end of the sample block is reached. If the end of the sample block is not reached (i.e., determination block **532**="No"), there may be further RF measurements available in the sample block and in block **526** the processor **214** may store the C RF measurement in the memory location for the sample. In block **528** the processor may increment the measurement counter (C) and in determination block **530** determine whether the C RF measurement is above the signal power threshold and in block **532** determine whether the end of the sample block is reached. In this manner, successive sample RF measurements may be checked against the signal power threshold and stored until the end of the sample block is reached and/or until a sample RF measurement falls below the signal power threshold. If the end of the sample block is reached (i.e., determination block **532**="Yes"), in block **534** the processor **214** may set the cross block flag. In an embodiment, the cross block flag may be a flag in a memory available to the processor **214** indicating the signal potential spans across two or more sample blocks. In a further embodiment, prior to setting the cross block flag in block **534**, the slope of a line drawn between the last two RF measurement samples may be used to determine whether the next sample block likely contains further potential signal samples. A negative slope may indicate that the signal of interest is fading and may indicate the last sample was the final sample of the signal of interest. In another embodiment, the slope may not be computed and the next sample block may be analyzed regardless of the slope.

(85) If the end of the sample block is reached (i.e., determination block **532**="Yes") and in block **534** the cross block flag is set, referring to FIG. **5**A, in block **506** the processor **214** may load the next available sample block, in block **508** may average the sample block, and in block **510** determine whether the average of the sample block is greater than or equal to the noise floor average. If the average is equal to or greater than the noise floor average (i.e., determination block **510**="Yes"), in block **512** the processor **214** may reset the measurement counter (C) to 1. In determination block **516** the processor **214** may determine whether the C RF measurement for the current sample block is greater than the signal power threshold. If the C RF measurement is greater than the signal power threshold (i.e., determination block **516**="Yes"), in determination block **518** the processor **214** may determine whether the cross block flag is set. If the cross block flag is set (i.e., determination block **518**="Yes"), referring to FIG. **5**B, in block **526** the processor **214** may store the C RF measurement in the memory location for the sample and in block **528** the processor may increment the measurement counter (C). As discussed above, in blocks **530** and **532** the processor **214** may perform operations to determine whether the C RF measurement is greater than the signal power threshold and whether the end of the sample block is reached until the C RF measurement is less than or equal to the signal power threshold (i.e., determination block **530**="No") or the end of the sample block is reached (i.e., determination block **532**="Yes"). If the end of the sample block is reached (i.e., determination block **532**="Yes"), as discussed above in block **534** the cross block flag may be set (or verified and remain set if already set) and in block **535** the C RF measurement may be stored in the sample.

(86) If the end of the sample block is reached (i.e., determination block **532**="Yes") and in block **534** the cross block flag is set, referring to FIG. **5**A, the processor may perform operations of blocks **506**, **508**, **510**, **512**, **516**, and **518** as discussed above. If the average of the sample block is less than the noise floor average (i.e., determination block **510**="No") and the cross block flag is set (i.e., determination block **514**="Yes"), the C RF measurement is less than or equal to the signal power threshold (i.e., determination block **516**="No") and the cross block flag is set (i.e., determination block **517**="Yes"), or the C RF measurement is less than or equal to the signal power threshold (i.e., determination block **516**="No"),

referring to FIG. 5B, in block **538** the processor **214** may set the sample stop. As an example, the processor **214** may indicate that a sample end is reached in a memory and/or that a sample is complete in a memory. In block **540** the processor **214** may compute and store complex I and Q data for the stored measurements in the sample. In block **542** the processor **214** may determine a mean of the complex I and Q data. Referring to FIG. 5C, in determination block **544** the processor **214** may determine whether the mean of the complex I and Q data is greater than a signal threshold. If the mean of the complex I and Q data is less than or equal to the signal threshold (i.e., determination block **544**="No"), in block **550** the processor **214** may indicate the sample is noise and discard data associated with the sample from memory.

(87) If the mean is greater than the signal threshold (i.e., determination block **544**="Yes"), in block **546** the processor **214** may identify the sample as a signal of interest. In an embodiment, the processor **214** may identify the sample as a signal of interest by assigning a signal identifier to the signal, such as a signal number or sample number. In block **548** the processor **214** may determine and store signal parameters for the signal. As an example, the processor **214** may determine and store a frequency peak of the identified signal, a peak power of the identified signal, an average power of the identified signal, a signal bandwidth of the identified signal, and/or a signal duration of the identified signal. In block **552** the processor **214** may clear the cross block flag (or verify that the cross block flag is unset). In block **556** the processor **214** may determine whether the end of the sample block is reached. If the end of the sample block is not reached (i.e., determination block **556**="No") in block **558** the processor **214** may increment the measurement counter (C), and referring to FIG. **5**A in determination block **516** may determine whether the C RF measurement is greater than the signal power threshold. Referring to FIG. **5**C, if the end of the sample block is reached (i.e., determination block **556**="Yes"), referring to FIG. **5**A, in block **506** the processor **214** may load the next available sample block.

(88) FIG. **6** illustrates a process flow for an embodiment method **600** for displaying signal identifications. In an embodiment, the operations of method **600** may be performed by a processor **214** of a spectrum management device **202**. In determination block **602** the processor **214** may determine whether a signal is identified. If a signal is not identified (i.e., determination block **602**="No"), in block **604** the processor **214** may wait for the next scan. If a signal is identified (i.e., determination block **602**="Yes"), in block **606** the processor **214** may compare the signal parameters of an identified signal to signal parameters in a history database **232**. In determination block **608** the processor **214** may determine whether signal parameters of the identified signal match signal parameters in the history database **232**. If there is no match (i.e., determination block **608**="No"), in block **610** the processor **214** may store the signal parameters as a new signal in the history database **232**. If there is a match (i.e., determination block **608**="Yes"), in block **612** the processor **214** may update the matching signal parameters as needed in the history database **232**.

(89) In block **614** the processor **214** may compare the signal parameters of the identified signal to signal parameters in a signal characteristic listing **236**. In an embodiment, the characteristic listing **236** may be a static database separate from the history database **232**, and the characteristic listing **236** may correlate signal parameters with signal identifications. In determination block **616** the processor **214** may determine whether the signal parameters of the identified signal match any signal parameters in the signal characteristic listing **236**. In an embodiment, the match in determination **616** may be a match based on a tolerance between the signal parameters of the identified signal and the parameters in the characteristic listing **236**. If there is a match (i.e., determination block **616**="Yes"), in block **618** the processor **214** may indicate a match in the history database **232** and in block **622** may display an indication of the signal identification on a display **242**. As an example, the indication of the signal identification may be a display of the radio call sign of an identified FM radio station signal. If there is not a match (i.e., determination block **616**="No"), in block **620** the processor **214** may display an indication that the signal is an unidentified signal. In this manner, the user may be notified a signal is present in the environment, but that the signal does not match to a signal in the characteristic listing.

(90) FIG. **7** illustrates a process flow of an embodiment method **700** for displaying one or more open frequency. In an embodiment, the operations of method **700** may be performed by the processor **214** of a spectrum management device **202**. In block **702** the processor **214** may determine a current location of the spectrum management device **202**. In an embodiment, the processor **214** may determine the current location of the spectrum management device **202** based on location inputs received from a location receiver **212**, such as GPS coordinates received from a GPS receiver **212**. In block **704** the processor **214** may compare the current location to the stored location value in the historical database **232**. As discussed

above, the historical or history database **232** may be a database storing information about signals previously actually identified by the spectrum management device **202**. In determination block **706** the processor **214** may determine whether there are any matches between the location information in the historical database **232** and the current location. If there are no matches (i.e., determination block **706**="No"), in block **710** the processor **214** may indicate incomplete data is available. In other words the spectrum data for the current location has not previously been recorded.

(91) If there are matches (i.e., determination block **706**="Yes"), in optional block **708** the processor **214** may display a plot of one or more of the signals matching the current location. As an example, the processor **214** may compute the average frequency over frequency intervals across a given spectrum and may display a plot of the average frequency over each interval. In block **712** the processor **214** may determine one or more open frequencies at the current location. As an example, the processor **214** may determine one or more open frequencies by determining frequency ranges in which no signals fall or at which the average is below a threshold. In block **714** the processor **214** may display an indication of one or more open frequency on a display **242** of the spectrum management device **202**.

(92) FIG. **8**A is a block diagram of a spectrum management device **802** according to an embodiment. Spectrum management device **802** is similar to spectrum management device **202** described above with reference to FIG. **2**A, except that spectrum management device **802** may include symbol module **816** and protocol module **806** enabling the spectrum management device **802** to identify the protocol and symbol information associated with an identified signal as well as protocol match module **814** to match protocol information. Additionally, the characteristic listing **236** of spectrum management device **802** may include protocol data **804**, hardware data **808**, environment data **810**, and noise data **812** and an optimization module **818** may enable the signal processor **214** to provide signal optimization parameters.

(93) The protocol module **806** may identify the communication protocol (e.g., LTE, CDMA, etc.) associated with a signal of interest. In an embodiment, the protocol module **806** may use data retrieved from the characteristic listing, such as protocol data **804** to help identify the communication protocol. The symbol detector module **816** may determine symbol timing information, such as a symbol rate for a signal of interest. The protocol module **806** and/or symbol module **816** may provide data to the comparison module **222**. The comparison module **222** may include a protocol match module **814** which may attempt to match protocol information for a signal of interest to protocol data **804** in the characteristic listing to identify a signal of interest. Additionally, the protocol module **806** and/or symbol module **816** may store data in the memory module **226** and/or history database **232**. In an embodiment, the protocol module **806** and/or symbol module **816** may use protocol data **804** and/or other data from the characteristic listing **236** to help identify protocols and/or symbol information in signals of interest.

(94) The optimization module **818** may gather information from the characteristic listing, such as noise figure parameters, antenna hardware parameters, and environmental parameters correlated with an identified signal of interest to calculate a degradation value for the identified signal of interest. The optimization module **818** may further control the display **242** to output degradation data enabling a user of the spectrum management device **802** to optimize a signal of interest.

(95) FIG. **8**B is a schematic logic flow block diagram illustrating logical operations which may be performed by a spectrum management device according to an embodiment. Only those logical operations illustrated in FIG. **8**B different from those described above with reference to FIG. **2**B will be discussed. As illustrated in FIG. **8**B, as received time tracking **850** may be applied to the I and Q data from the receiver **210**. An additional buffer **851** may further store the I and Q data received and a symbol detector **852** may identify the symbols of a signal of interest and determine the symbol rate. A multiple access scheme identifier module **854** may identify whether the signal is part of a multiple access scheme (e.g., CDMA), and a protocol identifier module **856** may attempt to identify the protocol the signal of interested is associated with. The multiple access scheme identifier module **854** and protocol identifier module **856** may retrieve data from the static database **238** to aid in the identification of the access scheme and/or protocol. The symbol detector module **852** may pass data to the signal parameter and protocol module **858** which may store protocol and symbol information in addition to signal parameter information for signals of interest.

(96) FIG. **9** illustrates a process flow of an embodiment method **900** for determining protocol data and symbol timing data. In an embodiment, the operations of method **900** may be performed by the processor **214** of a spectrum management device **802**. In determination block **902** the processor **214** may determine

whether two or more signals are detected. If two or more signals are not detected (i.e., determination block **902**=“No”), in determination block **902** the processor **214** may continue to determine whether two or more signals are detected. If two or more signals are detected (i.e., determination block **902**=“Yes”), in determination block **904** the processor **214** may determine whether the two or more signals are interrelated. In an embodiment, a mean correlation value of the spectral decomposition of each signal may indicate the two or more signals are interrelated. As an example, a mean correlation of each signal may generate a value between 0.0 and 1, and the processor **214** may compare the mean correlation value to a threshold, such as a threshold of 0.75. In such an example, a mean correlation value at or above the threshold may indicate the signals are interrelated while a mean correlation value below the threshold may indicate the signals are not interrelated and may be different signals. In an embodiment, the mean correlation value may be generated by running a full energy bandwidth correlation of each signal, measuring the values of signal transition for each signal, and for each signal transition running a spectral correlation between signals to generate the mean correlation value. If the signals are not interrelated (i.e., determination block **904**=“No”), the signals may be two or more different signals, and in block **907** processor **214** may measure the interference between the two or more signals. In an optional embodiment, in optional block **909** the processor **214** may generate a conflict alarm indicating the two or more different signals interfere. In an embodiment, the conflict alarm may be sent to the history database and/or a display. In determination block **902** the processor **214** may continue to determine whether two or more signals are detected. If the two signals are interrelated (i.e., determination block **904**=“Yes”), in block **905** the processor **214** may identify the two or more signals as a single signal. In block **906** the processor **214** may combine signal data for the two or more signals into a signal single entry in the history database. In determination block **908** the processor **214** may determine whether the signals mean averages. If the mean averages (i.e., determination block **908**=“Yes”), the processor **214** may identify the signal as having multiple channels **910**. If the mean does not average (i.e., determination block **908**=“Yes”) or after identifying the signal as having multiple channels **910**, in block **914** the processor **214** may determine and store protocol data for the signal. In block **916** the processor **214** may determine and store symbol timing data for the signal, and the method **900** may return to block **902**.
(97) FIG. **10** illustrates a process flow of an embodiment method **1000** for calculating signal degradation data. In an embodiment, the operations of method **1000** may be performed by the processor **214** of a spectrum management device **202**. In block **1002** the processor may detect a signal. In block **1004** the processor **214** may match the signal to a signal in a static database. In block **1006** the processor **214** may determine noise figure parameters based on data in the static database **236** associated with the signal. As an example, the processor **214** may determine the noise figure of the signal based on parameters of a transmitter outputting the signal according to the static database **236**. In block **1008** the processor **214** may determine hardware parameters associated with the signal in the static database **236**. As an example, the processor **214** may determine hardware parameters such as antenna position, power settings, antenna type, orientation, azimuth, location, gain, and equivalent isotropically radiated power (EIRP) for the transmitter associated with the signal from the static database **236**. In block **1010** processor **214** may determine environment parameters associated with the signal in the static database **236**. As an example, the processor **214** may determine environment parameters such as rain, fog, and/or haze based on a delta correction factor table stored in the static database and a provided precipitation rate (e.g., mm/hr). In block **1012** the processor **214** may calculate and store signal degradation data for the detected signal based at least in part on the noise figure parameters, hardware parameters, and environmental parameters. As an example, based on the noise figure parameters, hardware parameters, and environmental parameters free space losses of the signal may be determined. In block **1014** the processor **214** may display the degradation data on a display **242** of the spectrum management device **202**. In a further embodiment, the degradation data may be used with measured terrain data of geographic locations stored in the static database to perform pattern distortion, generate propagation and/or next neighbor interference models, determine interference variables, and perform best fit modeling to aide in signal and/or system optimization.
(98) FIG. **11** illustrates a process flow of an embodiment method **1100** for displaying signal and protocol identification information. In an embodiment, the operations of method **1100** may be performed by a processor **214** of a spectrum management device **202**. In block **1102** the processor **214** may compare the signal parameters and protocol data of an identified signal to signal parameters and protocol data in a history database **232**. In an embodiment, a history database **232** may be a database storing signal

parameters and protocol data for previously identified signals. In block **1104** the processor **214** may determine whether there is a match between the signal parameters and protocol data of the identified signal and the signal parameters and protocol data in the history database **232**. If there is not a match (i.e., determination block **1104**="No"), in block **1106** the processor **214** may store the signal parameters and protocol data as a new signal in the history database **232**. If there is a match (i.e., determination block **1104**="Yes"), in block **1108** the processor **214** may update the matching signal parameters and protocol data as needed in the history database **232**.

(99) In block **1110** the processor **214** may compare the signal parameters and protocol data of the identified signal to signal parameters and protocol data in the signal characteristic listing **236**. In determination block **1112** the processor **214** may determine whether the signal parameters and protocol data of the identified signal match any signal parameters and protocol data in the signal characteristic listing **236**. If there is a match (i.e., determination block **1112**="Yes"), in block **1114** the processor **214** may indicate a match in the history database and in block **1118** may display an indication of the signal identification and protocol on a display. If there is not a match (i.e., determination block **1112**="No"), in block **1116** the processor **214** may display an indication that the signal is an unidentified signal. In this manner, the user may be notified a signal is present in the environment, but that the signal does not match to a signal in the characteristic listing.

(100) FIG. **12**A is a block diagram of a spectrum management device **1202** according to an embodiment. Spectrum management device **1202** is similar to spectrum management device **802** described above with reference to FIG. **8**A, except that spectrum management device **1202** may include TDOA/FDOA module **1204** and modulation module **1206** enabling the spectrum management device **1202** to identify the modulation type employed by a signal of interest and calculate signal origins. The modulation module **1206** may enable the signal processor to determine the modulation applied to signal, such as frequency modulation (e.g., FSK, MSK, etc.) or phase modulation (e.g., BPSK, QPSK, QAM, etc.) as well as to demodulate the signal to identify payload data carried in the signal. The modulation module **1206** may use payload data **1221** from the characteristic listing to identify the data types carried in a signal. As examples, upon demodulating a portion of the signal the payload data may enable the processor **214** to determine whether voice data, video data, and/or text based data is present in the signal. The TDOA/FDOA module **1204** may enable the signal processor **214** to determine time difference of arrival for signals or interest and/or frequency difference of arrival for signals of interest. Using the TDOA/FDOA information estimates of the origin of a signal may be made and passed to a mapping module **1225** which may control the display **242** to output estimates of a position and/or direction of movement of a signal.

(101) FIG. **12**B is a schematic logic flow block diagram illustrating logical operations which may be performed by a spectrum management device according to an embodiment. Only those logical operations illustrated in FIG. **12**B different from those described above with reference to FIG. **8**B will be discussed. Time tracking **850** may additionally include TDOA and/or FDOA (see **1250**). A magnitude squared **1252** operation may be performed on data from the symbol detector **852** to identify whether frequency or phase modulation is present in the signal. Phase modulated signals may be identified by the phase modulation **1254** processes and frequency modulated signals may be identified by the frequency modulation processes **1256**. The modulation information may be passed to a signal parameters, protocols, and modulation module **1258**.

(102) FIG. **13** illustrates a process flow of an embodiment method **1300** for estimating a signal origin based on a frequency difference of arrival. In an embodiment, the operations of method **1300** may be performed by a processor **214** of a spectrum management device **1202**. In block **1302** the processor **214** may compute frequency arrivals and phase arrivals for multiple instances of an identified signal. In block **1304** the processor **214** may determine frequency difference of arrival for the identified signal based on the computed frequency difference and phase difference. In block **1306** the processor may compare the determined frequency difference of arrival for the identified signal to data associated with known emitters in the characteristic listing to estimate an identified signal origin. In block **1308** the processor **214** may indicate the estimated identified signal origin on a display of the spectrum management device. As an example, the processor **214** may overlay the estimated origin on a map displayed by the spectrum management device.

(103) FIG. **14** illustrates a process flow of an embodiment method for displaying an indication of an identified data type within a signal. In an embodiment, the operations of method **1400** may be performed

by a processor **214** of a spectrum management device **1202**. In block **1402** the processor **214** may determine the signal parameters for an identified signal of interest. In block **1404** the processor **214** may determine the modulation type for the signal of interest. In block **1406** the processor **214** may determine the protocol data for the signal of interest. In block **1408** the processor **214** may determine the symbol timing for the signal of interest. In block **1410** the processor **214** may select a payload scheme based on the determined signal parameters, modulation type, protocol data, and symbol timing. As an example, the payload scheme may indicate how data is transported in a signal. For example, data in over the air television broadcasts may be transported differently than data in cellular communications and the signal parameters, modulation type, protocol data, and symbol timing may identify the applicable payload scheme to apply to the signal. In block **1412** the processor **214** may apply the selected payload scheme to identify the data type or types within the signal of interest. In this manner, the processor **214** may determine what type of data is being transported in the signal, such as voice data, video data, and/or text based data. In block **1414** the processor may store the data type or types. In block **1416** the processor **214** may display an indication of the identified data types.

(104) FIG. **15** illustrates a process flow of an embodiment method **1500** for determining modulation type, protocol data, and symbol timing data. Method **1500** is similar to method **900** described above with reference to FIG. **9**, except that modulation type may also be determined. In an embodiment, the operations of method **1500** may be performed by a processor **214** of a spectrum management device **1202**. In blocks **902**, **904**, **905**, **906**, **908**, and **910** the processor **214** may perform operations of like numbered blocks of method **900** described above with reference to FIG. **9**. In block **1502** the processor may determine and store a modulation type. As an example, a modulation type may be an indication that the signal is frequency modulated (e.g., FSK, MSK, etc.) or phase modulated (e.g., BPSK, QPSK, QAM, etc.). As discussed above, in block **914** the processor may determine and store protocol data and in block **916** the processor may determine and store timing data.

(105) In an embodiment, based on signal detection, a time tracking module, such as a TDOA/FDOA module **1204**, may track the frequency repetition interval at which the signal is changing. The frequency repetition interval may also be tracked for a burst signal. In an embodiment, the spectrum management device may measure the signal environment and set anchors based on information stored in the historic or static database about known transmitter sources and locations. In an embodiment, the phase information about a signal be extracted using a spectral decomposition correlation equation to measure the angle of arrival ("AOA") of the signal. In an embodiment, the processor of the spectrum management device may determine the received power as the Received Signal Strength ("RSS") and based on the AOA and RSS may measure the frequency difference of arrival. In an embodiment, the frequency shift of the received signal may be measured and aggregated over time. In an embodiment, after an initial sample of a signal, known transmitted signals may be measured and compared to the RSS to determine frequency shift error. In an embodiment, the processor of the spectrum management device may compute a cross ambiguity function of aggregated changes in arrival time and frequency of arrival. In an additional embodiment, the processor of the spectrum management device may retrieve FFT data for a measured signal and aggregate the data to determine changes in time of arrival and frequency of arrival. In an embodiment, the signal components of change in frequency of arrival may be averaged through a Kalman filter with a weighted tap filter from 2 to 256 weights to remove measurement error such as noise, multipath interference, etc. In an embodiment, frequency difference of arrival techniques may be applied when either the emitter of the signal or the spectrum management device are moving or when then emitter of the signal and the spectrum management device are both stationary. When the emitter of the signal and the spectrum management device are both stationary the determination of the position of the emitter may be made when at least four known other known signal emitters positions are known and signal characteristics may be available. In an embodiment, a user may provide the four other known emitters and/or may use already in place known emitters, and may use the frequency, bandwidth, power, and distance values of the known emitters and their respective signals. In an embodiment, where the emitter of the signal or spectrum management device may be moving, frequency difference of arrival techniques may be performed using two known emitters.

(106) FIG. **16** illustrates an embodiment method for tracking a signal origin. In an embodiment, the operations of method **1600** may be performed by a processor **214** of a spectrum management device **1202**. In block **1602** the processor **214** may determine a time difference of arrival for a signal of interest. In block **1604** the processor **214** may determine a frequency difference of arrival for the signal interest. As an

example, the processor **214** may take the inverse of the time difference of arrival to determine the frequency difference of arrival of the signal of interest. In block **1606** the processor **214** may identify the location. As an example, the processor **214** may determine the location based on coordinates provided from a GPS receiver. In determination block **1608** the processor **214** may determine whether there are at least four known emitters present in the identified location. As an example, the processor **214** may compare the geographic coordinates for the identified location to a static database and/or historical database to determine whether at least four known signals are within an area associated with the geographic coordinates. If at least four known emitters are present (i.e., determination block **1608**="Yes"), in block **1612** the processor **214** may collect and measure the RSS of the known emitters and the signal of interest. As an example, the processor **214** may use the frequency, bandwidth, power, and distance values of the known emitters and their respective signals and the signal of interest. If less than four known emitters are present (i.e., determination block **1608**="No"), in block **1610** the processor **214** may measure the angle of arrival for the signal of interest and the known emitter. Using the RSS or angle or arrival, in block **1614** the processor **214** may measure the frequency shift and in block **1616** the processor **214** may obtain the cross ambiguity function. In determination block **1618** the processor **214** may determine whether the cross ambiguity function converges to a solution. If the cross ambiguity function does converge to a solution (i.e., determination block **1618**="Yes"), in block **1620** the processor **214** may aggregate the frequency shift data. In block **1622** the processor **214** may apply one or more filter to the aggregated data, such as a Kalman filter. Additionally, the processor **214** may apply equations, such as weighted least squares equations and maximum likelihood equations, and additional filters, such as a non-line-of-sight ("NLOS") filters to the aggregated data. In an embodiment, the cross ambiguity function may resolve the position of the emitter of the signal of interest to within 3 meters. If the cross ambiguity function does not converge to a solution (i.e., determination block **1618**="No"), in block **1624** the processor **214** may determine the time difference of arrival for the signal and in block **1626** the processor **214** may aggregate the time shift data. Additionally, the processor may filter the data to reduce interference. Whether based on frequency difference of arrival or time difference of arrival, the aggregated and filtered data may indicate a position of the emitter of the signal of interest, and in block **1628** the processor **214** may output the tracking information for the position of the emitter of the signal of interest to a display of the spectrum management device and/or the historical database. In an additional embodiment, location of emitters, time and duration of transmission at a location may be stored in the history database such that historical information may be used to perform and predict movement of signal transmission. In a further embodiment, the environmental factors may be considered to further reduce the measured error and generate a more accurate measurement of the location of the emitter of the signal of interest.

(107) The processor **214** of spectrum management devices **202**, **802** and **1202** may be any programmable microprocessor, microcomputer or multiple processor chip or chips that can be configured by software instructions (applications) to perform a variety of functions, including the functions of the various embodiments described above. In some devices, multiple processors may be provided, such as one processor dedicated to wireless communication functions and one processor dedicated to running other applications. Typically, software applications may be stored in the internal memory **226** or **230** before they are accessed and loaded into the processor **214**. The processor **214** may include internal memory sufficient to store the application software instructions. In many devices the internal memory may be a volatile or nonvolatile memory, such as flash memory, or a mixture of both. For the purposes of this description, a general reference to memory refers to memory accessible by the processor **214** including internal memory or removable memory plugged into the device and memory within the processor **214** itself.

(108) Identifying Devices in White Space.

(109) The present invention provides for systems, methods, and apparatus solutions for device sensing in white space, which improves upon the prior art by identifying sources of signal emission by automatically detecting signals and creating unique signal profiles. Device sensing has an important function and applications in military and other intelligence sectors, where identifying the emitter device is crucial for monitoring and surveillance, including specific emitter identification (SEI).

(110) At least two key functions are provided by the present invention: signal isolation and device sensing. Signal Isolation according to the present invention is a process whereby a signal is detected, isolated through filtering and amplification, amongst other methods, and key characteristics extracted. Device Sensing according to the present invention is a process whereby the detected signals are matched to a

device through comparison to device signal profiles and may include applying a confidence level and/or rating to the signal-profile matching. Further, device sensing covers technologies that permit storage of profile comparisons such that future matching can be done with increased efficiency and/or accuracy. The present invention systems, methods, and apparatus are constructed and configured functionally to identify any signal emitting device, including by way of example and not limitation, a radio, a cell phone, etc.

(111) Regarding signal isolation, the following functions are included in the present invention: amplifying, filtering, detecting signals through energy detection, waveform-based, spectral correlation-based, radio identification-based, or matched filter method, identifying interference, identifying environmental baseline(s), and/or identify signal characteristics.

(112) Regarding device sensing, the following functions are included in the present invention: using signal profiling and/or comparison with known database(s) and previously recorded profile(s), identifying the expected device or emitter, stating the level of confidence for the identification, and/or storing profiling and sensing information for improved algorithms and matching. In preferred embodiments of the present invention, the identification of the at least one signal emitting device is accurate to a predetermined degree of confidence between about 80 and about 95 percent, and more preferably between about 80 and about 100 percent. The confidence level or degree of confidence is based upon the amount of matching measured data compared with historical data and/or reference data for predetermined frequency and other characteristics.

(113) The present invention provides for wireless signal-emitting device sensing in the white space based upon a measured signal, and considers the basis of license(s) provided in at least one reference database, preferably the federal communication commission (FCC) and/or other defined database including license listings. The methods include the steps of providing a device for measuring characteristics of signals from signal emitting devices in a spectrum associated with wireless communications, the characteristics of the measured data from the signal emitting devices including frequency, power, bandwidth, duration, modulation, and combinations thereof; making an assessment or categorization on analog and/or digital signal(s); determining the best fit based on frequency if the measured power spectrum is designated in historical and/or reference data, including but not limited to the FCC or other database(s) for select frequency ranges; determining analog or digital, based on power and sideband combined with frequency allocation; determining a TDM/FDM/CDM signal, based on duration and bandwidth; determining best modulation fit for the desired signal, if the bandwidth and duration match the signal database(s); adding modulation identification to the database; listing possible modulations with best percentage fit, based on the power, bandwidth, frequency, duration, database allocation, and combinations thereof; and identifying at least one signal emitting device from the composite results of the foregoing steps. Additionally, the present invention provides that the phase measurement of the signal is calculated between the difference of the end frequency of the bandwidth and the peak center frequency and the start frequency of the bandwidth and the peak center frequency to get a better measurement of the sideband drop off rate of the signal to help determine the modulation of the signal.

(114) In embodiments of the present invention, an apparatus is provided for automatically identifying devices in a spectrum, the apparatus including a housing, at least one processor and memory, and sensors constructed and configured for sensing and measuring wireless communications signals from signal emitting devices in a spectrum associated with wireless communications; and wherein the apparatus is operable to automatically analyze the measured data to identify at least one signal emitting device in near real time from attempted detection and identification of the at least one signal emitting device. The characteristics of signals and measured data from the signal emitting devices include frequency, power, bandwidth, duration, modulation, and combinations thereof.

(115) The present invention systems including at least one apparatus, wherein the at least one apparatus is operable for network-based communication with at least one server computer including a database, and/or with at least one other apparatus, but does not require a connection to the at least one server computer to be operable for identifying signal emitting devices; wherein each of the apparatus is operable for identifying signal emitting devices including: a housing, at least one processor and memory, and sensors constructed and configured for sensing and measuring wireless communications signals from signal emitting devices in a spectrum associated with wireless communications; and wherein the apparatus is operable to automatically analyze the measured data to identify at least one signal emitting device in near real time from attempted detection and identification of the at least one signal emitting device.

(116) Identifying Open Space in a Wireless Communication Spectrum.
(117) The present invention provides for systems, methods, and apparatus solutions for automatically identifying open space, including open space in the white space of a wireless communication spectrum. Importantly, the present invention identifies the open space as the space that is unused and/or seldomly used (and identifies the owner of the licenses for the seldomly used space, if applicable), including unlicensed spectrum, white space, guard bands, and combinations thereof. Method steps of the present invention include: automatically obtaining a listing or report of all frequencies in the frequency range; plotting a line and/or graph chart showing power and bandwidth activity; setting frequencies based on a frequency step and/or resolution so that only user-defined frequencies are plotted; generating files, such as by way of example and not limitation, .csv or .pdf files, showing average and/or aggregated values of power, bandwidth and frequency for each derived frequency step; and showing an activity report over time, over day vs. night, over frequency bands if more than one, in white space if requested, in Industrial, Scientific, and Medical (ISM) band or space if requested; and if frequency space is seldomly in that area, then identify and list frequencies and license holders.
(118) Additional steps include: automatically scanning the frequency span, wherein a default scan includes a frequency span between about 54 MHz and about 804 MHz; an ISM scan between about 900 MHz and about 2.5 GHz; an ISM scan between about 5 GHz and about 5.8 GHz; and/or a frequency range based upon inputs provided by a user. Also, method steps include scanning for an allotted amount of time between a minimum of about 15 minutes up to about 30 days; preferably scanning for allotted times selected from the following: a minimum of about 15 minutes; about 30 minutes; about 1 hour increments; about 5 hour increments; about 10 hour increments; about 24 hours; about 1 day; and about up to 30 days; and combinations thereof. In preferred embodiments, if the apparatus is configured for automatically scanning for more than about 15 minutes, then the apparatus is preferably set for updating results, including updating graphs and/or reports for an approximately equal amount of time (e.g., every 15 minutes).
(119) The systems, methods, and apparatus also provide for automatically calculating a percent activity associated with the identified open space on predetermined frequencies and/or ISM bands.
(120) Signal Database.
(121) Preferred embodiments of the present invention provide for sensed and/or measured data received by the at least one apparatus of the present invention, analyzed data, historical data, and/or reference data, change-in-state data, and any updates thereto, are storable on each of the at least one apparatus. In systems of the present invention, each apparatus further includes transmitters for sending the sensed and/or measured data received by the at least one apparatus of the present invention, analyzed data, historical data, and/or reference data, change-in-state data, and any updates thereto, are communicated via the network to the at least one remote server computer and its corresponding database(s). Preferably, the server(s) aggregate the data received from the multiplicity of apparatus or devices to produce a composite database for each of the types of data indicated. Thus, while each of the apparatus or devices is fully functional and self-contained within the housing for performing all method steps and operations without network-based communication connectivity with the remote server(s), when connected, as illustrated in FIG. **29**, the distributed devices provide the composite database, which allows for additional analytics not possible for individual, isolated apparatus or device units (when not connected in network-based communication), which solves a longstanding, unmet need.
(122) In particular, the aggregation of data from distributed, different apparatus or device units allow for comparison of sample sets of data to compare signal data or information for similar factors, including time(s), day(s), venues, geographic locations or regions, situations, activities, etc., as well as for comparing various signal characteristics with the factors, wherein the signal characteristics and their corresponding sensed and/or measured data, including raw data and change-in-state data, and/or analyzed data from the signal emitting devices include frequency, power, bandwidth, duration, modulation, and combinations thereof. Preferably, the comparisons are conducted in near real time. The aggregation of data may provide for information about the same or similar mode from apparatus to apparatus, scanning the same or different frequency ranges, with different factors and/or signal characteristics received and stored in the database(s), both on each apparatus or device unit, and when they are connected in network-based communication for transmission of the data to the at least one remote server.
(123) The aggregation of data from a multiplicity of units also advantageously provide for continuous, 24

hours/7 days per week scanning, and allows the system to identify sections that exist as well as possibly omitted information or lost data, which may still be considered for comparisons, even if it is incomplete. From a time standpoint, there may not be a linearity with respect to when data is collected or received by the units; rather, the systems and methods of the present invention provide for automated matching of time, i.e., matching timeframes and relative times, even where the environment, activities, and/or context may be different for different units. By way of example and not limitation, different units may sense and/or measure the same signal from the same signal emitting device in the spectrum, but interference, power, environmental factors, and other factors may present identification issues that preclude one of the at last one apparatus or device units from determining the identity of the signal emitting device with the same degree of certainty or confidence. The variation in this data from a multiplicity of units measuring the same signals provides for aggregation and comparison at the remote server using the distributed databases from each unit to generate a variance report in near real time. Thus, the database(s) provide repository database in memory on the apparatus or device units, and/or data from a multiplicity of units are aggregated on at least one remote server to provide an active network with distributed nodes over a region that produce an active or dynamic database of signals, identified devices, identified open space, and combinations thereof, and the nodes may report to or transmit data via network-based communication to a central hub or server. This provides for automatically comparing signal emitting devices or their profiles and corresponding sensed or measured data, situations, activities, geographies, times, days, and/or environments, which provides unique composite and comparison data that may be continuously updated, and includes in the near real time reports automatically generated at predetermined times, at user-specified times, on-demand, and/or when data changes occur beyond an expected range. Other reports data may include sample size, power usage, average power levels, and interference.

(124) Overall, the significant benefits provided by the present invention automatically generated reports in near real time is that the RF environment may be readily analyzed and communicated using real time or near real time data, so that the reports information is actionable to make changes to improve or optimize signals or to modify the environment for the signals and their corresponding devices. This solves a longstanding unmet need from the prior art.

(125) FIG. **29** shows a schematic diagram illustrating aspects of the systems, methods and apparatus according to the present invention. Each node includes an apparatus or device unit, referenced in the FIG. **29** as “SigSet Device A”, “SigSet Device B”, “SigSet Device C”, and through “SigSet Device N” that are constructed and configured for selective exchange, both transmitting and receiving information over a network connection, either wired or wireless communications, with the master SigDB or database at a remote server location from the units.

(126) Furthermore, the database aggregating nodes of the apparatus or device units provide a baseline compared with new data, which provide for near real time analysis and results within each of the at least one apparatus or device unit, which calculates and generates results such as signal emitting device identification, identification of open space, signal optimization, and combinations thereof, based upon the particular settings of each of the at least one apparatus or device unit. The settings include frequency ranges, location and distance from other units, difference in propagation from one unit to another unit, and combinations thereof, which factor into the final results.

(127) The present invention systems, methods, and apparatus embodiments provide for leveraging the use of deltas or differentials from the baseline, as well as actual data, to provide onsite sensing, measurement, and analysis for a given environment and spectrum, for each of the at least one apparatus or device unit. Because the present invention provides the at least one processor on each unit to compare signals and signal characteristic differences using compressed data for deltas to provide near real time results, the database storage may further be optimized by storing compressed data and/or deltas, and then decompressing and/or reconstructing the actual signals using the deltas and the baseline. Analytics are also provided using this approach. So then the signals database(s) provide for reduced data storage to the smallest sample set that still provides at least the baseline and the deltas to enable signal reconstruction and analysis to produce the results described according to the present invention.

(128) Preferably, the modeling and virtualization analytics enabled by the databases on each of the at least one apparatus or device units independently of the remote server computer, and also provided on the remote server computer from aggregated data, provide for “gap filling” for omitted or absent data, and or for reconstruction from deltas. A multiplicity of deltas may provide for signal identification, interference

identification, neighboring band identification, device identification, signal optimization, and combinations, all in near real time. Significantly, the deltas approach of the present invention which provide for minimization of data sets or sample data sets required for comparisons and/or analytics, i.e., the smallest range of time, frequency, etc. that captures all representative signals and/or deltas associated with the signals, environment conditions, noise, etc.

(129) The signal database(s) may be represented with visual indications including diagrams, graphs, plots, tables, and combinations thereof, which may be presented directly by the apparatus or device unit to its corresponding display contained within the housing. Also, the signals database(s) provide each apparatus or device unit to receive a first sample data set in a first time period, and receive a second sample data set in a second time period, and receive a N sample data set in a corresponding N time period; to save or store each of the at least two distinct sample data sets; to automatically compare the at least two sample data sets to determine a change-in-state or “delta”. Preferably, the database receives and stores at least the first of the at least two data sets and also stores the delta. The stored delta values provide for quick analytics and regeneration of the actual values of the sample sets from the delta values, which advantageously contributes to the near real time results of the present invention.

(130) In preferred embodiments of the present invention, the at least one apparatus is continuously scanning the environment for signals, deltas from prior at least one sample data set, and combinations, which are categorized, classified, and stored in memory.

(131) The systems, methods and apparatus embodiments of the present invention include hardware and software components and requirements to provide for each of the apparatus units to connect and communicate different data they sense, measure, analyze, and/or store on local database(s) in memory on each of the units with the remote server computer and database. Thus the master database or “SigDB” is operable to be applied and connect to the units, and may include hardware and software commercially available, for example SQL Server 2012, and to be applied to provide a user the criteria to upgrade/update their current sever network to the correct configuration that is required to operate and access the SigDB. Also, the SigDB is preferably designed, constructed and as a full hardware and software system configuration for the user, including load testing and network security and configuration. Other exemplary requirements include that the SigDB will include a database structure that can sustain a multiplicity of apparatus units' information; provide a method to update the FCC database and/or historical database according a set time (every month/quarter/week, etc.), and in accordance with changes to the FCC.gov databases that are integrated into the database; operable to receive and to download unit data from a remote location through a network connection; be operable to query apparatus unit data stored within the SigDB database server and to query apparatus unit data in ‘present’ time to a particular apparatus unit device for a given ‘present’ time not available in the current SigDB server database; update this information into its own database structure; to keep track of Device Identifications and the information each apparatus unit is collecting including its location; to query the apparatus units based on Device ID or location of device or apparatus unit; to connect to several devices and/or apparatus units on a distributed communications network; to partition data from each apparatus unit or device and differentiate the data from each based on its location and Device ID; to join queries from several devices if a user wants to know information acquired from several remote apparatus units at a given time; to provide ability for several users (currently up to 5 per apparatus unit or device) to query information from the SigDB database or apparatus unit or device; to grant access permissions to records for each user based on device ID, pertinent information or tables/location; to connect to a user GUI from a remote device such as a workstation or tablet PC from a Web App application; to retrieve data queries based on user information and/or jobs; to integrate database external database information from the apparatus units; and combinations thereof.

(132) Also, in preferred embodiments, a GUI interface based on a Web Application software is provided; in one embodiment, the SigDB GUI is provided in any appropriate software, such as by way of example, in Visual Studio using .Net/Asp.Net technology or JavaScript. In any case, the SigDB GUI preferably operates across cross platform systems with correct browser and operating system (OS) configuration; provides the initial requirements of a History screen in each apparatus unit to access sever information or query a remote apparatus unit containing the desired user information; and, generates .csv and .pdf reports that are useful to the user.

(133) Automated Reports and Visualization of Analytics.

(134) Various reports for describing and illustrating with visualization the data and analysis of the device,

system and method results from spectrum management activities include at least reports on power usage, RF survey, and/or variance, as well as interference detection, intermodulation detection, uncorrelated licenses, and/or open space identification.
(135) The systems, methods, and devices of the various embodiments enable spectrum management by identifying, classifying, and cataloging signals of interest based on radio frequency measurements. In an embodiment, signals and the parameters of the signals may be identified and indications of available frequencies may be presented to a user. In another embodiment, the protocols of signals may also be identified. In a further embodiment, the modulation of signals, devices or device types emitting signals, data types carried by the signals, and estimated signal origins may be identified.
(136) Reporting features of the present invention preferably include and support all of the sensing, measurements, analytics, and/or data for each of the at least one apparatus units in systems and methods, including SigDB databases and its advanced analytics. By way of example and not limitation, the reporting features include: frequency, power, bandwidth, time, and combinations thereof. In one embodiment of the present invention, the reports are selected from the group consisting essentially of: variance reports, power usage reports, RF survey reports, signal optimization reports, and combinations thereof. Variance reports provide information about the changes in spectrum usage between time periods, between locations, and/or between changes in state. Power usage reports provide information about power variables, including but not limited to amplitude, bandwidth, and time, for one or more frequency channels within the spectrum. RF survey reports provide detailed information about the spectrum usage and interference for particular signals and/or sites or locations. Signal optimization reports include information about interference and options for actions to take to optimize the signal(s) of focus.
(137) Variance reports provide information on variations within the spectrum. In one example of a report and methods for generating it, consider finding Open Space based upon frequency range and time; the at least one apparatus unit of the system is operable to automatically generate the report following the steps of: after sensing, measuring and/or analyzing the data, group all frequencies by at least one specific frequency range of the measured value collected; automatically check frequencies, and if more than one of the same frequency exists then use the highest and lowest frequency in the group and generate an average frequency, use the highest and lowest power in the group and generate an average power, use highest and lowest bandwidth in the group and generate average bandwidth; group frequencies in order of least to greatest (e.g., ascending order); automatically generate a diagram of Plot Line Graph of Frequency (x-axis) vs Power (y-axis) use FreqAvg and PwrAvg; where multiple same values exist, then automatically apply a smoothing filter and average the graph; set timer and average over time; take a new scan of frequencies and add additional new frequencies that have appeared; average existing same frequencies and update graph; and repeat after each time.
(138) In preferred embodiments of the present invention, the at least one apparatus is continuously scanning the environment for signals, deltas from prior at least one sample data set, and combinations, which are categorized, classified, and stored in memory, which are used in automatically generating reports at predetermined times, when specified by a user, and/or at times when updates or deltas are detected or determined. Any and all data, including deltas data, sample data and corresponding sample size, are preferably selectively available for inclusion in the automatically generated reports for near real time data reporting.
(139) Referring again to the drawings, FIG. **17** is a schematic diagram illustrating an embodiment for scanning and finding open space. A plurality of nodes are in wireless or wired communication with a software defined radio, which receives information concerning open channels following real-time scanning and access to external database frequency information.
(140) FIG. **18** is a diagram of an embodiment of the invention wherein software defined radio nodes are in wireless or wired communication with a master transmitter and device sensing master.
(141) FIG. **19** is a process flow diagram of an embodiment method of temporally dividing up data into intervals for power usage analysis and comparison. The data intervals are initially set to seconds, minutes, hours, days and weeks, but can be adjusted to account for varying time periods (e.g., if an overall interval of data is only a week, the data interval divisions would not be weeks). In one embodiment, the interval slicing of data is used to produce power variance information and reports.
(142) FIG. **20** is a flow diagram illustrating an embodiment wherein frequency to license matching occurs. In such an embodiment the center frequency and bandwidth criteria can be checked against a database to

check for a license match. Both licensed and unlicensed bands can be checked against the frequencies, and, if necessary, non-correlating factors can be marked when a frequency is uncorrelated.
(143) FIG. **21** is a flow diagram illustrating an embodiment method for reporting power usage information, including locational data, data broken down by time intervals, frequency and power usage information per band, average power distribution, propagation models, atmospheric factors, which is capable of being represented graphical, quantitatively, qualitatively, and overlaid onto a geographic or topographic map.
(144) FIG. **22** is a flow diagram illustrating an embodiment method for creating frequency arrays. For each initialization, an embodiment of the invention will determine a center frequency, bandwidth, peak power, noise floor level, resolution bandwidth, power and date/time. Start and end frequencies are calculated using the bandwidth and center frequency and like frequencies are aggregated and sorted in order to produce a set of frequency arrays matching power measurements captured in each band.
(145) FIG. **23** is a flow diagram illustrating an embodiment method for reframe and aggregating power when producing frequency arrays.
(146) FIG. **24** is a flow diagram illustrating an embodiment method of reporting license expirations by accessing static or FCC databases.
(147) FIG. **25** is a flow diagram illustrating an embodiment method of reporting frequency power use in graphical, chart, or report format, with the option of adding frequencies from FCC or other databases.
(148) FIG. **26** is a flow diagram illustrating an embodiment method of connecting devices. After acquiring a GPS location, static and FCC databases are accessed to update license information, if available. A frequency scan will find open spaces and detect interferences and/or collisions. Based on a master device ID, set a random generated token to select channel from available channel model and continually transmit ID channel token. If a node device reads ID, it will set itself to channel based on token and the node device will attempt to connect to the master device. The master device will then set frequency and bandwidth channel. For each device connected to a master device, a frequency, a bandwidth, and a time slot in which to transmit is set. In one embodiment, these steps can be repeated until the max number of devices is connected. As new devices are connected, the device list is updated with channel model and the device is set as active. Disconnected devices are set as inactive. If collision occurs, update channel model and get new token channel. Active scans will search for new or lost devices and update devices list, channel model, and status accordingly. Channel model IDs are actively sent out for new or lost devices.
(149) FIG. **27** is a flow diagram illustrating an embodiment method of addressing collisions. A first node device acquires its GPS location, scans frequencies for a master device, and get a first channel based on a first ID channel token. Then, the first node device gets assigned frequency and bandwidth rate and Transmit/Receive (Tx/Rx) time slot. Further, the first node device attempts to transmit a signal to and/or receive a signal from the master device. If there is a second node device also transmitting signals to and/or receiving signals from the master device over the first channel, the first node device is operable to wait for a time period t0, and then try another attempt. If there is no other device transmitting to or receiving from the master device over the first channel, the first device then transmits to and/or receives from the master device over the first channel. If there is no collision detected and the transmission and/or reception is done successfully, the process of connecting the first device to the first channel is done. If the transmission and/or reception is not done, the first device is operable to transmit or receive again until it is done successfully. If there is collision detected during the transmission and/or reception process, the process will check if the attempt number exceeds a maximum attempt number set by the master device. If the attempt number is smaller than the maximum attempt number, the first device will wait for a time period to and try another attempt. If the attempt number exceeds the maximum attempt number, the process will log the collision. In this case, no transmission or reception is possible for the first node device over the first channel. The master device will generate a second channel token for a second available channel with new frequency, bandwidth rate, and Tx/Rx time slot for the first device, and repeat the attempting process over the second available channel.
(150) FIG. **28** is a schematic diagram of an embodiment of the invention illustrating a virtualized computing network and a plurality of distributed devices. FIG. **28** is a schematic diagram of one embodiment of the present invention, illustrating components of a cloud-based computing system and network for distributed communication therewith by mobile communication devices. FIG. **28** illustrates an exemplary virtualized computing system for embodiments of the present invention loyalty and rewards platform. As illustrated in FIG. **28**, a basic schematic of some of the key components of a virtualized

computing (or cloud-based) system according to the present invention are shown. The system **2800** comprises at least one remote server computer **2810** with a processing unit **2811** and memory. The server **2810** is constructed, configured and coupled to enable communication over a network **2850**. The server provides for user interconnection with the server over the network with the at least one apparatus as described hereinabove **2840** positioned remotely from the server. Apparatus **2840** includes a memory **2846**, a CPU **2844**, an operating system **2847**, a bus **2842**, an input/output module **2848**, and an output or display **2849**. Furthermore, the system is operable for a multiplicity of devices or apparatus embodiments **2860**, **2870** for example, in a client/server architecture, as shown, each having outputs or displays **2869** and **2979**, respectively. Alternatively, interconnection through the network **2850** using the at least one device or apparatus for measuring signal emitting devices, each of the at least one apparatus is operable for network-based communication. Also, alternative architectures may be used instead of the client/server architecture. For example, a computer communications network, or other suitable architecture may be used. The network **2850** may be the Internet, an intranet, or any other network suitable for searching, obtaining, and/or using information and/or communications. The system of the present invention further includes an operating system **2812** installed and running on the at least one remote server **2810**, enabling the server **2810** to communicate through network **2850** with the remote, distributed devices or apparatus embodiments as described hereinabove, the server **2810** having a memory **2820**. The operating system may be any operating system known in the art that is suitable for network communication.

(151) FIG. **29** shows a schematic diagram of aspects of the systems, methods and apparatus according to the present invention. Each node includes an apparatus or device unit, referenced in the FIG. **29** as "SigSet Device A", "SigSet Device B", "SigSet Device C", and through "SigSet Device N" that are constructed and configured for selective exchange, both transmitting and receiving information over a network connection, either wired or wireless communications, with the master SigDB or database at a remote server location from the units.

(152) FIG. **30** is a schematic diagram of an embodiment of the invention illustrating a computer system, generally described as **3800**, having a network **3810** and a plurality of computing devices **3820**, **3830**, **3840**. In one embodiment of the invention, the computer system **3800** includes a cloud-based network **3810** for distributed communication via the network's wireless communication antenna **3812** and processing by a plurality of mobile communication computing devices **3830**. In another embodiment of the invention, the computer system **3800** is a virtualized computing system capable of executing any or all aspects of software and/or application components presented herein on the computing devices **3820**, **3830**, **3840**. In certain aspects, the computer system **3800** may be implemented using hardware or a combination of software and hardware, either in a dedicated computing device, or integrated into another entity, or distributed across multiple entities or computing devices.

(153) By way of example, and not limitation, the computing devices **3820**, **3830**, **3840** are intended to represent various forms of digital devices and mobile devices, such as a server, blade server, mainframe, mobile phone, a personal digital assistant (PDA), a smart phone, a desktop computer, a netbook computer, a tablet computer, a workstation, a laptop, and other similar computing devices. The components shown here, their connections and relationships, and their functions, are meant to be exemplary only, and are not meant to limit implementations of the invention described and/or claimed in this document.

(154) In one embodiment, the computing device **3820** includes components such as a processor **3860**, a system memory **3862** having a random access memory (RAM) **3864** and a read-only memory (ROM) **3866**, and a system bus **3868** that couples the memory **3862** to the processor **3860**. In another embodiment, the computing device **3830** may additionally include components such as a storage device **3890** for storing the operating system **3892** and one or more application programs **3894**, a network interface unit **3896**, and/or an input/output controller **3898**. Each of the components may be coupled to each other through at least one bus **3868**. The input/output controller **3898** may receive and process input from, or provide output to, a number of other devices **3899**, including, but not limited to, alphanumeric input devices, mice, electronic styluses, display units, touch screens, signal generation devices (e.g., speakers) or printers.

(155) By way of example, and not limitation, the processor **3860** may be a general-purpose microprocessor (e.g., a central processing unit (CPU)), a graphics processing unit (GPU), a microcontroller, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), a Programmable Logic Device (PLD), a controller, a state machine, gated or transistor logic, discrete hardware components, or any other suitable entity or combinations thereof that can perform

calculations, process instructions for execution, and/or other manipulations of information.
(156) In another implementation, shown in FIG. **30**, a computing device **3840** may use multiple processors **3860** and/or multiple buses **3868**, as appropriate, along with multiple memories **3862** of multiple types (e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core).
(157) Also, multiple computing devices may be connected, with each device providing portions of the necessary operations (e.g., a server bank, a group of blade servers, or a multi-processor system). Alternatively, some steps or methods may be performed by circuitry that is specific to a given function.
(158) According to various embodiments, the computer system **3800** may operate in a networked environment using logical connections to local and/or remote computing devices **3820**, **3830**, **3840** through a network **3810**. A computing device **3820** may connect to a network **3810** through a network interface unit **3896** connected to the bus **3868**. Computing devices may communicate communication media through wired networks, direct-wired connections or wirelessly such as acoustic, RF or infrared through a wireless communication antenna **3897** in communication with the network's wireless communication antenna **3812** and the network interface unit **3896**, which may include digital signal processing circuitry when necessary. The network interface unit **3896** may provide for communications under various modes or protocols.
(159) In one or more exemplary aspects, the instructions may be implemented in hardware, software, firmware, or any combinations thereof. A computer readable medium may provide volatile or non-volatile storage for one or more sets of instructions, such as operating systems, data structures, program modules, applications or other data embodying any one or more of the methodologies or functions described herein. The computer readable medium may include the memory **3862**, the processor **3860**, and/or the storage device **3890** and may be a single medium or multiple media (e.g., a centralized or distributed computer system) that store the one or more sets of instructions **3900**. Non-transitory computer readable media includes all computer readable media, with the sole exception being a transitory, propagating signal per se. The instructions **3900** may further be transmitted or received over the network **3810** via the network interface unit **3896** as communication media, which may include a modulated data signal such as a carrier wave or other transport mechanism and includes any delivery media. The term “modulated data signal” means a signal that has one or more of its characteristics changed or set in a manner as to encode information in the signal.
(160) Storage devices **3890** and memory **3862** include, but are not limited to, volatile and non-volatile media such as cache, RAM, ROM, EPROM, EEPROM, FLASH memory, or other solid state memory technology; discs (e.g., digital versatile discs (DVD), HD-DVD, BLU-RAY, compact disc (CD), or CD-ROM) or other optical storage; magnetic cassettes, magnetic tape, magnetic disk storage, floppy disks, or other magnetic storage devices; or any other medium that can be used to store the computer readable instructions and which can be accessed by the computer system **3800**.
(161) It is also contemplated that the computer system **3800** may not include all of the components shown in FIG. **30**, may include other components that are not explicitly shown in FIG. **30**, or may utilize an architecture completely different than that shown in FIG. **30**. The various illustrative logical blocks, modules, elements, circuits, and algorithms described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application (e.g., arranged in a different order or partitioned in a different way), but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.
(162) The present invention further provides for aggregating data from at least two apparatus units by at least one server computer and storing the aggregated data in a database and/or in at least one database in a cloud-based computing environment or virtualized computing environment, as illustrated in FIG. **28** or FIG. **30**. The present invention further provides for remote access to the aggregated data and/or data from any of the at least one apparatus unit, by distributed remote user(s) from corresponding distributed remote device(s), such as by way of example and not limitation, desktop computers, laptop computers, tablet computers, mobile computers with wireless communication operations, smartphones, mobile

communications devices, and combinations thereof. The remote access to data is provided by software applications operable on computers directly (as a “desktop” application) and/or as a web service that allows user interface to the data through a secure, network-based website access.
(163) In other embodiments of the present invention, which include the base invention described hereinabove, and further including the functions of machine “learning”, modulation detection, automatic signal detection, FFT replay, and combinations thereof.
(164) Automatic modulation detection and machine “learning” includes automatic signal variance determination by at least one of the following methods: date and time from location set, and remote access to the apparatus unit to determine variance from different locations and times, in addition to the descriptions of automatic signal detection and threshold determination and setting. Environments vary, especially where there are many signals, noise, interference, variance, etc., so tracking signals automatically is difficult, and a longstanding, unmet need in the prior art. The present invention provides for automatic signal detection using a sample of measured and sensed data associated with signals over time using the at least one apparatus unit of the present invention to provide an automatically adjustable and adaptable system. For each spectrum scan, the data is automatically subdivided into “windows”, which are sections or groups of data within a frequency space. Real-time processing of the measured and sensed data on the apparatus unit(s) or devices combined with the windowing effect provides for automatic comparison of signal versus noise within the window to provide for noise approximation, wherein both signals and noise are measured and sensed, recorded, analyzed compared with historical data to identify and output signals in a high noise environment. It is adaptive and iterative to include focused windows and changes in the window or frequency ranges grouped. The resulting values for all data are squared in the analysis, which results in signals identified easily by the apparatus unit as having significantly larger power values compared with noise; additional analytics provide for selection of the highest power value signals and review of the original data corresponding thereto. Thus, the at least one apparatus automatically determines and identifies signals compared to noise in the RF spectrum.
(165) The apparatus unit or device of the present invention further includes a temporal anomaly detector (or “learning channel”). The first screen shot illustrated in FIG. **31** shows the blank screen, the second screen shot illustrated in FIG. **32** shows several channels that the system has “learned”. This table can be saved to disk as a spreadsheet and reused on subsequent surveys at the same location. The third screen shot shown in FIG. **33** displays the results when run with the “Enable OOB Signals” button enabled. In this context OOB means “Out Of Band” or rogue or previously unidentified signals. Once a baseline set of signals has been learned by the system, it can be used with automatic signal detection to clearly show new, unknown signals that were not present when the initial learning was done, as shown in FIG. **34**.
(166) In a similar capacity, the user can load a spreadsheet that they have constructed on their own to describe the channels that they expect to see in a given environment, as illustrated in FIG. **34**. When run with OOB detection, the screen shot shows the detection of signals that were not in the user configuration. These rogue signals could be a possible source of interference, and automatic detection of them can greatly assist the job of an RF Manager.
(167) FIGS. **31-34** illustrate the functions and features of the present invention for automatic or machine “learning” as described hereinabove.
(168) Automatic signal detection of the present invention eliminates the need for a manual setting of a power threshold line or bar, as with the prior art. The present invention does not require a manual setting of power threshold bar or flat line to identify signals instead of noise, instead it uses information on the hardware parameters of the apparatus unit or device, environment parameters, and terrain data to derive the threshold bar or flatline, which are stored in the static database of the apparatus unit or device. Thus, the apparatus unit or device may be activated and left unattended to collect data continuously without the need for manual interaction with the device directly. Furthermore, the present invention allows remote viewing of live data in real time on a display of a computer or communications device in network-based connection but remotely positioned from the apparatus unit or device, and/or remote access to device settings, controls, data, and combinations thereof. The network-based communication may be selected from mobile, satellite, Ethernet, and functional equivalents or improvements with security including firewalls, encryption of data, and combinations thereof.
(169) Regarding FFT replay, the present invention apparatus units are operable to replay data and to review and/or replay data saved based upon an unknown event, such as for example and not limitation, reported

alarms and/or unique events, wherein the FFT replay is operable to replay stored sensed and measured data to the section of data nearest the reported alarm and/or unique event. By contrast, prior art provides for recording signals on RF spectrum measurement devices, which transmit or send the raw data to an external computer for analysis, so then it is impossible to replay or review specific sections of data, as they are not searchable, tagged, or otherwise sectioned into subgroups of data or stored on the device.
(170) Automatic Signal Detection
(171) The previous approach to ASD was to subtract a calibration vector from each FFT sample set (de-bias), then square each resulting value and look for concentrations of energy that would differentiate a signal from random baseline noise. The advantages of this approach are that, by the use of the calibration vector (which was created using the receiver itself with no antenna), we are able to closely track variations in the baseline noise that are due to the characteristics of the receiver, front end filtering, attenuation and A/D converter hardware. On most modern equipment, the designers take steps to keep the overall response flat, but there are those that do not. FIG. **35** is an example of a receiver that has marked variations on baseline behavior across a wide spectrum (9 MHz-6 GHz).
(172) The drawbacks to this approach are: 1) It requires the use of several “tuning” variables which often require the user to adjust and fiddle with in order to achieve good signal recognition. A fully automatic signal detection system should be able to choose values for these parameters without the intervention of an operator. 2) It does not take into account variations in the baseline noise floor that are introduced by RF energy in a live environment. Since these variations were not present during calibration, they are not part of the calibration vector and cannot be “canceled out” during the de-bias phase. Instead they remain during the square and detect phase, often being mistakenly classified as signal. An example of this is FIG. **36**, a normal spectrum from 700 MHz to 790 MHz. The threshold line (baby blue) indicates the level where we would differentiate signal from noise. FIG. **37** illustrates the same spectrum at a different time where an immensely powerful signal at about 785 MHz has caused undulations in the noise floor all the way down to 755 MHz. It is clear to see by the placement of the threshold line large blocks of the noise are now going to be recognized as signal. Not only are the 4 narrow band signals now going to be mistakenly seen as one large signal, there is an additional lump of noise around 760 MHz that represents no signal at all, but will be classified as such.
(173) In order to solve these two problems, and provide a fully automatic signal detection system, a new approach has been taken to prepare the calibration vector. The existing square and detect algorithm works well if the data are de-biased properly with a cleverly chosen calibration vector, it's just that the way we were creating the calibration vector was not sufficient.
(174) FIG. **38** illustrates a spectrum from 1.9 GHz to 2.0 GHz, along with some additional lines that indicate the functions of the new algorithm. Line 1 (brown) at the bottom displays the existing calibration vector created by running the receiver with no antenna. It is clear to see that, if used as is, it is too low to be used to de-bias the data shown as line 2 (dark blue). Also, much of the elevations in noise floor will wind up being part of the signals that are detected. In order to compensate for this, the user was given a control (called “Bias”) that allowed them to raise or lower the calibration vector to hopefully achieve a more reasonable result. But, as illustrated in FIG. **37**, no adjustment will suffice when the noise floor has been distorted due to the injection of large amounts of energy.
(175) So, rather than attempt to make the calibration vector fit the data, the new approach examines the data itself in an attempt to use parts of it as the correction vector. This is illustrated by the light purple and baby blue lines in the FIG. **38**. Line 3 (light purple) in FIG. **38** is the result of using a 60 sample smoothing filter to average the raw data. It clearly follows the data, but it removes the “jumpiness”. This can be better seen in FIG. **39** which is a close up view of the first part of the overall spectrum. The difference between the smoothed data shown as line 3 (light purple) and the original data shown as line 2 (dark blue) is displayed clearly.
(176) The new Gradient Detection algorithm is applied to the smoothed data to detect locations where the slope of the line changes quickly. In places where the slope changes quickly in a positive direction, the algorithm marks the start of a signal. On the other side of the signal the gradient again changes quickly to become more horizontal. At that point the algorithm determines it is the end of a signal. A second smoothing pass is performed on the smoothed data, but this time, those values that fall between the proposed start and end of signal are left out of the average. The result is line 4 (baby blue) in FIGS. **38** and **39**, which is then used as the new calibration vector. This new calibration vector shown as line 4 (baby

blue) is then used to de-bias the raw data which is then passed to the existing square and detect ASD algorithm.

(177) One of the other user-tunable parameters in the existing ASD system was called “Sensitivity”. This was a parameter that essentially set a threshold of energy, above which each FFT bin in a block of bins averaged together must exceed in order for that block of bins to be considered a signal. In this way, rather than a single horizontal line to divide signal from noise, each signal can be evaluated individually, based on its average power. The effect of setting this value too low was that tiny fluctuations of energy that are actually noise would sometimes appear to be signals. Setting the value too high would result in the algorithm missing a signal. In order to automatically choose a value for this parameter, the new system uses a “Quality of Service” feedback from the Event Compositor, a module that processes the real-time events from the ASD system and writes signal observations into a database. When the sensitivity value is too low, the random bits of energy that ASD mistakenly sees as signal are very transient. This is due to the random nature of noise. The Event Compositor has a parameter called a “Pre-Recognition Delay” that sets the minimum number of consecutive scans that it must see a signal in order for it to be considered a candidate for a signal observation database entry (in order to catch large fast signals, an exception is made for large transients that are either high in peak power, or in bandwidth). Since the random fluctuations seldom persist for more than 1 or 2 sweeps, the Event Compositor ignores them, essentially filtering them out. If there are a large number of these transients, the Event Compositor provides feedback to the ASD module to inform it that its sensitivity is too low. Likewise, if there are no transients at all, the feedback indicates the sensitivity is too high. Eventually, the system arrives at an optimal setting for the sensitivity parameter.

(178) The result is a fully automated signal detection system that requires no user intervention or adjustment. The black brackets at the top of FIG. **38** illustrate the signals recognized by the system, clearly indicating its accuracy.

(179) Because the system relies heavily upon averaging, a new algorithm was created that performs an N sample average in fixed time; i.e. regardless of the width of the average, N, each bin requires 1 addition, 1 subtraction, and 1 division. A simpler algorithm would require N additions and 1 division per bin of data. A snippet of the code is probably the best description:

(180) TABLE-US-00001 public double [ ] smoothingFilter(double [ ] dataSet, int filterSize) {   double [ ] resultSet = new double[dataSet.length];   double temp = 0.0;   int i=0;   int halfSize = filterSize/2;   for(i=0 ; i < filterSize ; i++) { temp += dataSet[i]; // load accumulator with the first N/2 values. if(i < halfSize)   resultSet[i] = dataSet[i];   } for(i=halfSize ; i < (dataSet.length − halfSize) ; i++) { resultSet[i] = temp / filterSize; // Compute the average and store it temp −= dataSet[i−halfSize]; // take out the oldest value temp += dataSet[i+halfSize]; // add in the newest value   }   while(i < dataSet.length) { resultSet[i] = dataSet[i]; i++;   }   return(resultSet); }

Automatic Signal Detection (ASD) with Temporal Feature Extraction (TFE)

(181) The system in the present invention uses statistical learning techniques to observe and learn an RF environment over time and identify temporal features of the RF environment (e.g., signals) during a learning period. The learning period is a predetermined period of time or a period of time required to reach a settled percent.

(182) A knowledge map is formed based on learning data from a learning period. Real-time signal events are detected by an ASD system and scrubbed against the knowledge map to determine if the real-time signal events are typical and expected for the environment, or if there is any event not typical nor expected.

(183) The knowledge map consists of an array of normal distributions, where each distribution column is for each frequency bin of the FFT result set provided by a software defined radio (SDR). Each vertical column corresponds to a bell-shaped curve for that frequency. Each pixel represents a count of how many times that frequency was seen at that power level.

(184) A learning routine takes power levels of each frequency bin, uses the power levels as an index into each distribution column corresponding to each frequency bin, and increments the counter in a location corresponding to a power level.

(185) FIG. **40** illustrates a knowledge map obtained by a TFE process. The top window shows the result of real-time spectrum sweep of an environment. The bottom window shows a knowledge map, which color codes the values in each column (normal distribution) based on how often the power level of that frequency (column) has been at a particular level.

(186) The TFE function monitors its operation and produces a “settled percent.” The settled percent is the percentage of the values of the incoming FFT result set that the system has seen before. In this way, the system can know if it is ready to interpret the statistical data that it has obtained. Once it reaches a point where most of the FFT values have been seen before (99.95% or better), it can then perform an interpretation operation.
(187) FIG. **41** illustrates an interpretation operation based on a knowledge map. During the interpretation operation, the system extracts valuable signal identification from the knowledge map. Some statistical quantities are identified. For each column, the power level at which a frequency is seen the most is determined (peak of the distribution curve), which is represented by line a (red) in FIG. **41**. A desired percentage of power level values is located between the high and low boundaries of the power levels (shoulders of the curve), which are represented by lines b (white) in FIG. **41**. The desired percentage is adjustable. In FIG. **41**, the desired percentage is set at 42% based on the learning data. In one embodiment, a statistical method is used to obtain a desirable percentage that provides the highest degree of “smoothness”—lowest deviation from column to column. Then, a profile is drawn based on the learning data, which represents the highest power level at which each frequency has been seen during learning. In FIG. **41**, the profile is represented by line c (green).
(188) Gradient detection is then applied to the profile to identify areas of transition. An algorithm continues to accumulate a gradient value as long as the “step” from the previous cell to this cell is always non-zero and the same direction. When it arrives at a zero or different direction step, it evaluates the accumulated difference to see if it is significant, and if so, considers it a gradient. A transition is identified by a continuous change (from left to right) that exceeds the average range between the high and low boundaries of power levels shown as lines b (white) in FIG. **41**. Positive and negative gradients are matched, and the resulting interval is identified as a signal. FIG. **42** shows the identification of signals, which are represented by the black brackets above the knowledge display. Similar to FIG. **41**, the knowledge map in FIG. **42** color codes (e.g., black, dark blue, baby blue) the values in each column (normal distribution) based on how often the power level of that frequency (column) has been at a particular level. Lines b (white) represent the high and low boundaries of a desirable percentage of power level. Line c (green) represents a profile of the RF environment comprising the highest power level at which each frequency has been seen during learning.
(189) FIG. **43** shows more details of the narrow band signals at the left of the spectrum around 400 MHz in FIG. **42**. Similar to FIG. **41**, the knowledge map in FIG. **43** color codes (e.g., black, dark blue, baby blue) the values in each column (normal distribution) based on how often the power level of that frequency (column) has been at a particular level. Lines b (white) represent the high and low boundaries of a desirable percentage of power level. Line c (green) represents a profile of the RF environment comprising the highest power level at which each frequency has been seen during learning. The red cursor at 410.365 MHz in FIG. **43** points to a narrow band signal. The real-time spectrum sweep on the top window shows the narrow band signal, and the TFE process identifies the narrow band signal as well.
(190) To a prior art receiver, the narrow band signal hidden within a wideband signal is not distinguishable or detectable. The systems and methods and devices of the present invention are operable to scan a wideband with high resolution or high definition to identify channel divisions within a wideband, and identify narrowband signals hidden within the wideband signal, which are not a part of the wideband signal itself, i.e., the narrow band signals are not part of the bundled channels within the wideband signal.
(191) FIG. **44** shows more details of the two wide band signals around 750 MHz and a similar signal starting at 779 MHz. Similar to FIG. **41**, the knowledge map in FIG. **44** color codes (e.g., black, dark blue, baby blue) the values in each column (normal distribution) based on how often the power level of that frequency (column) has been at a particular level. Lines b (white) represent the high and low boundaries of a desirable percentage of power level. Line c (green) represents a profile of the RF environment comprising the highest power level at which each frequency has been seen during learning. The present invention detects the most prominent parts of the signal starting at 779 MHz. The transmitters of these two wide band signals are actually in the distance, and normal signal detectors, which usually have a fixed threshold, are not able to pick up these two wide band signals but only see them as static noises. Because the TFE system in the present invention uses an aggregation of signal data over time, it can identify these signals and fine tune the ASD sensitivity of individual segments. Thus, the system in the present invention is able to detect signals that normal radio gear cannot. ASD in the present invention, is enhanced by the

knowledge obtained by TFE and is now able to detect and record these signals where gradient detection alone would not have seen them. The threshold bar in the present invention is not fixed, but changeable.
(192) Also, at the red cursor in FIG. **44** is a narrow band signal in the distance that normally would not be detected because of its low power at the point of observation. But the present invention interprets knowledge gained over time and is able to identify that signal.
(193) FIG. **45** illustrates the operation of the ASD in the present invention. Line A (green) shows the spectrum data between 720 MHz and 791 MHz. 1st and 2nd derivatives of the power levels are calculated inside spectrum on a cell by cell basis, displayed as the overlapping line B (blue) and line C (red) at the top. The algorithm then picks the most prominent derivatives and performs a squaring function on them as displayed by line D (red). The software then matches positive and negative gradients, to identify the edges of the signals, which are represented by the brackets on the top. Two wideband signals are identified, which may be CDMA, LTE, or other communication protocol used by mobile phones. Line E (red) at the bottom is a baseline established by averaging the spectrum and removing areas identified by the gradients. At the two wideband signals, line E (red) is flat. By subtracting the baseline from the real spectrum data, groups of cells with average power above baseline are identified, and the averaging algorithm is run against those areas to apply the sensitivity measurement.
(194) The ASD system has the ability to distinguish between large eruptions of energy that increase the baseline noise and the narrow band signals that could normally be swamped by the additional energy because it generates its baseline from the spectrum itself and looks for relative gradients rather than absolute power levels. This baseline is then subtracted from the original spectrum data, revealing the signals, as displayed by the brackets at the top of the screen. Note that the narrow-band signals are still being detected (tiny brackets at the top that look more like dots) even though there is a hump of noise super-imposed on them.
(195) TFE is a learning process that augments the ASD feature in the present invention. The ASD system enhanced with TFE function in the present invention can automatically tune parameters based on a segmented basis, the sensitivity within an area is changeable. The TFE process accumulates small differences over time and signals become more and more apparent. In one embodiment, the TFE takes 40 samples per second over a 5-minute interval. The ASD system in the present invention is capable of distinguishing signals based on gradients from a complex and moving noise floor without a fixed threshold bar when collecting data from an environment.
(196) The ASD system with TFE function in the present invention is unmanned and water resistant. It runs automatically 24/7, even submerged in water.
(197) The TFE is also capable of detecting interferences and intrusions. In the normal environment, the TFE settles, interprets and identifies signals. Because it has a statistical knowledge of the RF landscape, it can tell the difference between a low power, wide band signal that it normally sees and a new higher power narrow band signal that may be an intruder. This is because it “scrubs” each of the FFT bins of each event that the ASD system detects against its knowledge base. When it detects that a particular group of bins in a signal from ASD falls outside the statistical range that those frequencies normally are observed, the system can raise an anomaly report. The TFE is capable of learning new knowledge, which is never seen before, from the signals identified by a normal detector. In one embodiment, a narrow band signal (e.g., a pit crew to car wireless signal) impinges on an LTE wideband signal, the narrow band signal may be right beside the wideband signal, or drift in and out of the wideband signal. On display, it just looks like an LTE wideband signal. For example, a narrow band signal with a bandwidth of 12 kHz or 25-30 kHz in a wideband signal with a bandwidth of 5 MHz over a 6 GHz spectrum just looks like a spike buried in the middle. But, because signals are characterized in real time against learned knowledge, the proposed ASD system with TFE function is able to pick out narrow band intruder immediately.
(198) The present invention is able to detect a narrow band signal with a bandwidth from 1-2 kHz to 60 kHz inside a wideband signal (e.g., with a bandwidth of 5 MHz) across a 6 GHz spectrum. In FIGS. **40-45**, the frequency resolution is 19.5 kHz, and a narrow band signal with a bandwidth of 2-3 kHz can be detected. The frequency resolution is based on the setting of the FFT result bin size.
(199) Statistical learning techniques are used for extracting temporal feature, creating a statistical knowledge map of what each frequency is and determining variations and thresholds and etc. The ASD system with TFE function in the present invention is capable of identifying, demodulating and decoding signals, both wideband and narrowband with high energy.

(200) If a narrowband signal is close to the end of wideband LTE signal, the wideband LTE signal is distorted at the edge. If multiple narrowband signals are within a wideband signal, the top edge of the wideband signal is ragged as the narrow band signal is hidden within the wide band signal. If one narrow band signal is in the middle of a wideband signal, the narrow band signal is usually interpreted as a cell within the wideband signal. However, the ASD system with TFE function in the present invention learns power levels in a spectrum section over time, and is able to recognize the narrow band signal immediately.
(201) The present invention is operable to log the result, display on a channel screen, notify operator and send alarms, etc. The present invention auto records spectrum, but does not record all the time. When a problem is identified, relevant information is auto recorded in high definition.
(202) The ASD system with TFE in the present invention is used for spectrum management. The system in the present invention is set up in a normal environment and starts learning and stores at least one learning map in it. The learning function of the ASD system in the present invention can be enabled and disabled. When the ASD system is exposed to a stable environment and has learned what is normal in the environment, it will stop its learning process. The environment is periodically reevaluated. The learning map is updated at a predetermined timeframe. After a problem is detected, the learning map will also be updated.
(203) The ASD system in the present invention can be deployed in stadiums, ports, airports, or on borders. In one embodiment, the ASD system learns and stores the knowledge in that environment. In another embodiment, the ASD system downloads prior knowledge and immediately displays it. In another embodiment, an ASD device can learn from other ASD devices globally.
(204) In operation, the ASD system then collects real time data and compares to the learning map stored for signal identification. Signals identified by the ASD system with TFE function may be determined to be an error by an operator. In that situation, an operator can manually edit or erase the error, essentially “coaching” the learning system.
(205) The systems and devices in the present invention create a channel plan based on user input, or external databases, and look for signals that are not there. Temporal Feature Extraction not only can define a channel plan based on what it learns from the environment, but it also “scrubs” each spectrum pass against the knowledge it has learned. This allows it to not only identify signals that violate a prescribed channel plan, but it can also discern the difference between a current signal, and the signal that it has previously seen in that frequency location. If there is a narrow band interference signal where there typically is a wide band signal, the system will identify it as an anomaly because it does not match the pattern of what is usually in that space.
(206) The device in the present invention is designed to be autonomous. It learns from the environment, and, without operator intervention, can detect anomalous signals that either were not there before, or have changed in power or bandwidth. Once detected, the device can send alerts by text or email and begin high resolution spectrum capture, or IQ capture of the signal of interest.
(207) FIG. **40** illustrates an environment in which the device is learning. There are some obvious signals, but there is also a very low level wide band signal between 746 MHz and 755 MHz. Typical threshold-oriented systems would not catch this. But, the TFE system takes a broader view over time. The signal does not have to be there all the time or be pronounced to be detected by the system. Each time it appears in the spectrum serves to reinforce the impression on the learning fabric. These impressions are then interpreted and characterized as signals.
(208) FIG. **43** shows the knowledge map that the device has acquired during its learning system, and shows brackets above what it has determined are signals. Note that the device has determined these signals on its own without any user intervention, or any input from any databases. It is a simple thing to then further categorize the signals by matching against databases, but what sets the device in the present invention apart is that, like its human counterpart, it has the ability to draw its own conclusions based on what it has seen.
(209) FIG. **44** shows a signal identified by the device in the present invention between 746 MHz and 755 MHz with low power levels. It is clear to see that, although the signal is barely distinguishable from the background noise, TFE clearly has identified its edges. Over to the far right is a similar signal that is further away so that it only presents traces of itself. But again, because the device in the present invention is trained to distinguish random and coherent energy patterns over time, it can clearly pick out the pattern of a signal. Just to the left of that faint signal was a transient narrow band signal at 777.653 MHz. This

signal is only present for a brief period of time during the training, typically 0.5-0.7 seconds each instance, separated by minutes of silence, yet the device does not miss it, remembers those instances and categorizes them as a narrow band signal.
(210) The identification and classification algorithms that the system uses to identify Temporal Features are optimized to be used in real time. Notice that, even though only fragments of the low level wide band signal are detected on each sweep, the system still matches them with the signal that it had identified during its learning phase.
(211) In one embodiment, a method for automatic signal detection in an RF environment includes learning the RF environment in a learning period based on statistical learning techniques, thereby creating learning data. A knowledge map is formed based on the learning data and a profile of the RF environment is created based on the knowledge map. The profile includes a highest power level for each frequency detected during the learning period. Areas of transition in the profile are identified based on gradient detection, and a real-time spectral sweep is scrubbed against the profile. Positive and negative gradients are matched in the profile to detect at least one signal in the RF environment.
(212) In another embodiment, a system for automatic signal detection in an RF environment includes at least one apparatus for detecting signals in the RF environment. The at least one apparatus is operable to sweep and learn the RF environment in a learning period based on statistical learning techniques, thereby creating learning data. The at least one apparatus is also operable to form a knowledge map based on the learning data. A profile of the RF environment based on the knowledge map is created by the at least one apparatus. The profile includes a highest power level for each frequency detected during the learning period. The at least one apparatus is operable to identify areas of transition in the profile based on gradient detection. A real-time spectral sweep is scrubbed against the profile by the at least one apparatus. Positive and negative gradients of the profile are matched to detect at least one signal in the RF environment.
(213) Also as the system is running, it is scrubbing each spectral sweep against its knowledge map and/or profile. When it finds coherent bundles of energy that are either in places that are usually quiet, or have higher power or bandwidth than it has seen before, it can automatically send up a red flag. Since the system is doing this in real time, it has critical relevance to those in harm's way—the first responder, or the war fighter who absolutely must have clear channels of communication or instant situational awareness of imminent threats. It's one thing to geolocate a signal that the user has identified. It's an entirely different dimension when the system can identify the signal on its own before the user even realizes it's there. Because the device in the present invention can pick out these signals with a sensitivity that is far superior to a simple threshold system, the threat does not have to be obvious to be detected and alert an operator.
(214) Devices in prior art merely make it easy for a person to analyze spectral data, both in real time and historically, locally or remotely. But the device in the present invention operates as an extension of the person, performing the learning and analysis on its own, and even finding things that a human typically may miss.
(215) The device in the present invention can easily capture signal identifications, match them to databases, store and upload historical data. Moreover, the device has intelligence and the ability to be more than a simple data storage and retrieval device. The device is a watchful eye in an RF environment, and a partner to an operator who is trying to manage, analyze, understand and operate in the RF environment.
(216) Geolocation
(217) The prior art is dependent upon a synchronized receiver for power, phase, frequency, angle, and time of arrival, and an accurate clock for timing, and significantly, requires three devices to be used, wherein all are synchronized and include directional antennae to identify a signal with the highest power. Advantageously, the present invention does not require synchronization of receivers in a multiplicity of devices to provide geolocation of at least one apparatus unit or device, thereby reducing cost and improving functionality of each of the at least one apparatus in the systems described hereinabove for the present invention. Also, the present invention provides for larger frequency range analysis, and provides database(s) for capturing events, patterns, times, power, phase, frequency, angle, and combinations for the at least one signal of interest in the RF spectrum. The present invention provides for better measurements and data of signal(s) with respect to time, frequency with respect to time, power with respect to time, and combinations thereof. In preferred embodiments of the at least one apparatus unit of the present invention, geolocation is provided automatically by the apparatus unit using at least one anchor point embedded within the system, by power measurements and transmission that provide for “known” environments of

data. The known environments of data include measurements from the at least one anchorpoint that characterize the RF receiver of the apparatus unit or device. The known environments of data include a database including information from the FCC database and/or user-defined database, wherein the information from the FCC database includes at least maximum power based upon frequency, protocol, device type, and combinations thereof. With the geolocation function of the present invention, there is no requirement to synchronize receivers as with the prior art; the at least one anchorpoint and location of an apparatus unit provide the required information to automatically adjust to a first anchorpoint or to a second anchorpoint in the case of at least two anchorpoints, if the second anchorpoint is easier to adopt. The known environment data provide for expected spectrum and signal behavior as the reference point for the geolocation. Each apparatus unit or device includes at least one receiver for receiving RF spectrum and location information as described hereinabove. In the case of one receiver, it is operable with and switchable between antennae for receiving RF spectrum data and location data; in the case of two receivers, preferably each of the two receivers are housed within the apparatus unit or device. A frequency lock loop is used to determine if a signal is moving, by determining if there is a Doppler change for signals detected.

(218) Location determination for geolocation is provided by determining a point (x, y) or Lat Lon from the at least three anchor locations (x1, y1); (x2, y2); (x3, y3) and signal measurements at either of the node or anchors. Signal measurements provide a system of non-linear equations that must be solved for (x, y) mathematically; and the measurements provide a set of geometric shapes which intersect at the node location for providing determination of the node.

(219) For trilateration methods for providing observations to distances the following methods are used:

(220) RSS $= d = d_0 10^{(\frac{P_0 - P_r}{10n})}$ wherein do is the reference distance derived from the reference transmitter and signal characteristics (e.g., frequency, power, duration, bandwidth, etc.); Po is the power received at the reference distance; Pr is the observed received power; and n is the path loss exponent; and Distance from observations is related to the positions by the following equations:

(221) $d_1 = (\sqrt{(x - x_1)^2 + (y - y_1)^2}) d_2 = (\sqrt{(x - x_2)^2 + (y - y_2)^2}) d_3 = (\sqrt{(x - x_3)^2 + (y - y_3)^2})$

(222) Also, in another embodiment of the present invention, a geolocation application software operable on a computer device or on a mobile communications device, such as by way of example and not limitation, a smartphone, is provided. Method steps are illustrated in the flow diagram shown in FIG. **46**, including starting a geolocation app; calling active devices via a connection broker; opening spectrum display application; selecting at least one signal to geolocate; selecting at least three devices (or apparatus unit of the present invention) within a location or region, verifying that the devices or apparatus units are synchronized to a receiver to be geolocated; perform signal detection (as described hereinabove) and include center frequency, bandwidth, peak power, channel power, and duration; identify modulation of protocol type, obtain maximum, median, minimum and expected power; calculating distance based on selected propagation model; calculating distance based on one (1) meter path loss; calculating distance based on one (1) meter path loss model; calculating distance based on one (1) meter path loss model; perform circle transformations for each location; checking if RF propagation distances form circles that are fully enclosed; checking if RF propagation form circles that do not intersect; performing trilateration of devices; deriving z component to convert back to known GPS Lat Lon (latitude and longitude) coordinate; and making coordinates and set point as emitter location on mapping software to indicate the geolocation.

(223) The equations referenced in FIG. **46** are provided hereinbelow: Equation 1 for calculating distance based on selected propagation model:

(224) PLossExponent = (Parameter$C$ - 6.55 * log10(BS_AntHeight)) / 10
MS_AntGainFunc = 3.2 * (log10(11.75 * MS_AntHeight))^2 - 4.97
Constant(C) = ParameterA + ParameterB * log10(Frequency) - 13.82 * log10(BS_AntHeight) - MS_AntGainFunc
DistanceRange = 10$^{((\mathrm{PLoss - PLossConstant}) / 10 * \mathrm{PLossExponent}))}$ Equation 2 for calculating distance based on 1 meter Path Loss Model (first device):

(225) $d0 = 1$; k = PLossExponent; PL_d = Pt + Gt - RSSI - TotalMargin
PL_0 = 32.44 + 10 * k * log10(d0) + 10 * k * log10(Frequency)$D = d_0 * (10^{((\mathrm{PL\_}d - \mathrm{PL\_0}) / (10k))})$ Equation 3: (same as equation 2) for second device Equation 4: (same as equation 2) for third device Equation 5: Perform circle transformations for each location (x, y, z) Distance d; Verify ATA=0; where A={matrix of locations 1-N} in relation to distance; if not, then perform circle transformation check Equation 6: Perform

trilateration of devices if more than three (3) devices aggregation and trilaterate by device; set circles to zero origin and solve from y=Ax where y=[x, y] locations

(226) Equation7 $$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2(x_a - x_c) & 2(y_a - y_c) \\ 2(x_b - x_c) & 2(y_b - y_c) \end{bmatrix}^{-1} \begin{bmatrix} x_a^2 - x_c^2 + y_a^2 - y_c^2 + d_c^2 - d_a^2 \\ x_b^2 - x_c^2 + y_b^2 - y_c^2 + d_c^2 - d_b^2 \end{bmatrix}$$

(227) Note that check if RF propagation distances form circles where one or more circles are Fully Enclosed if it is based upon Mod Type and Power Measured, then Set Distance **1** of enclosed circle to Distance **2** minus the distance between the two points. Also, next, check to see if some of the RF Propagation Distances Form Circles, if they do not intersect, then if so based on Mod type and Max RF power Set Distance to each circle to Distance of Circle+(Distance between circle points-Sum of the Distances)/2 is used. Note that deriving z component to convert back to known GPS lat lon coordinate is provided by: z=sqrt (Dist.sup.2−x.sup.2−y.sup.2).

(228) Accounting for unknowns using Differential Received Signal Strength (DRSS) is provided by the following equation when reference or transmit power is unknown:

(229) $$\frac{d_i}{d_j} = 10^{\left(\frac{P_{r_j} - P_{r_i}}{10n}\right)}$$

(230) And where signal strength measurements in dBm are provided by the following:

(231) $$P_{r_2}\,(\text{dBm}) - P_{r_1}\,(\text{dBm}) = 10n\log_{10}\left(\sqrt{(x - x_1)^2 + (y - y_1)^2}\right) - 10n\log_{10}\left(\sqrt{(x - x_2)^2 + (y - y_2)^2}\right)$$

$$P_{r_3}\,(\text{dBm}) - P_{r_1}\,(\text{dBm}) = 10n\log_{10}\left(\sqrt{(x - x_1)^2 + (y - y_1)^2}\right) - 10n\log_{10}\left(\sqrt{(x - x_3)^2 + (y - y_3)^2}\right)$$

$$P_{r_2}\,(\text{dBm}) - P_{r_3}\,(\text{dBm}) = 10n\log_{10}\left(\sqrt{(x - x_3)^2 + (y - y_3)^2}\right) - 10n\log_{10}\left(\sqrt{(x - x_2)^2 + (y - y_2)^2}\right)$$

(232) For geolocation systems and methods of the present invention, preferably two or more devices or units are used to provide nodes. More preferably, three devices or units are used together or “joined” to achieve the geolocation results. Also preferably, at least three devices or units are provided. Software is provided and operable to enable a network-based method for transferring data between or among the at least two device or units, or more preferably at least three nodes, a database is provided having a database structure to receive input from the nodes (transferred data), and at least one processor coupled with memory to act on the database for performing calculations, transforming measured data and storing the measured data and statistical data associated with it; the database structure is further designed, constructed and configured to derive the geolocation of nodes from saved data and/or from real-time data that is measured by the units; also, the database and application of systems and methods of the present invention provide for geolocation of more than one node at a time. Additionally, software is operable to generate a visual representation of the geolocation of the nodes as a point on a map location.

(233) Errors in measurements due to imperfect knowledge of the transmit power or antenna gain, measurement error due to signal fading (multipath), interference, thermal noise, no line of sight (NLOS) propagation error (shadowing effect), and/or unknown propagation model, are overcome using differential RSS measurements, which eliminate the need for transmit power knowledge, and can incorporate TDOA and FDOA techniques to help improve measurements. The systems and methods of the present invention are further operable to use statistical approximations to remove error causes from noise, timing and power measurements, multipath, and NLOS measurements. By way of example, the following methods are used for geolocation statistical approximations and variances: maximum likelihood (nearest neighbor or Kalman filter); least squares approximation; Bayesian filter if prior knowledge data is included; and the like. Also, TDOA and FDOA equations are derived to help solve inconsistencies in distance calculations. Several methods or combinations of these methods may be used with the present invention, since geolocation will be performed in different environments, including but not limited to indoor environments, outdoor environments, hybrid (stadium) environments, inner city environments, etc.

(234) Geolocation Using Deployable Large Scale Arrays

(235) Typically, prior art arrays are more localized and deployed in a symmetrical fashion to reduce the complexity of mathematics and the equipment. The problem with localized fixed arrays are twofold: they require a large footprint for assembly and operation to gain accuracy in directional measurements. Conversely, smaller footprint arrays of geometric antenna systems can lose significant accuracy of the directional measurements. To avoid these limitations, a large variable array is used with fixed or mobile sites to allow greater accuracy.

(236) In one embodiment of the present invention, geolocation using angle of arrival is provided by a fixed

position antenna system constructed and configured with a four-pole array in a close proximity to each other. The antenna system is a unique combination of a half (½) Adcock antenna array positioned at each unit. The antenna system is fixed and is operable to be deployed with a switching device to a low-cost full Adcock system. The use of a phase difference on the dual receiver input allows the local unit to determine a hemisphere of influence in a full Adcock configuration or a group of the deployed units as a full space diversity Adcock antenna system. This embodiment advantageously functions to eliminate directions in the vector-based math calculation, thereby eliminating a large group of false positives.

(237) The antenna system used with the geolocation systems and methods of the present invention includes three or more deployed units where none of the units is a full-time master nor slave. Each unit can be set to scan independently for target profiles. Once acquisition is obtained from one unit, the information is automatically disseminated to the other units within the cluster, i.e., the information is communicated wirelessly through a network. Preferably, the unit array is deployed in an asymmetrical configuration.

(238) The antenna system in the present invention utilizes Normalized Earth Centered Earth Fixed vectors. Two additional vector attributes of the monitoring station are selected from the following: pitch, yaw, velocity, altitude (positive and negative) and acceleration.

(239) Once a target acquisition from a single unit is acquired, a formatted message is broadcast to the deployed monitoring array stations. The formatted message includes but is not limited to the following: center frequency, bandwidth, modulation schema, average power and phase lock loop time adjustment from the local antenna system.

(240) The monitoring units include a GPS receiver to aid in high resolution clocks for timing of signal processing and exact location of the monitoring unit. This is key to determine an exact location of the monitoring units, either fixed or mobile, to simulate mathematically the variable large scale antenna array. The phased-locked inputs determine the orientation of the incoming target signal into hemispheres of influence.

(241) For this example, FIG. **47** is a North-South/East-West orientation of a local small diversity array. If the time difference between antenna 1 and antenna 2 is positive, the direction of travel is from North to South. If they are near equal, we are in the East-West plane. Another station with the local antenna on an east-west plane for the monitoring unit is operable to measure and determine if the incoming target is in the eastern hemisphere of the array. Since no site is a master to acquisition and measurement, the processing of any or all measurements can be done on a single monitoring unit. Preferably, the unit that originally captured the unknown target or an external processor processes the measurements.

(242) The next step in the process is to determine for each target measurement the delays of arrival at each location. This will further reveal the direction of travel to the target or additionally if the target is within the large-scale variable array's own footprint.

(243) Once the unit processing the data has received information from the other units in the array, processing of the information begins. First, the unit automatically sorts the array time of arrival at each location of the at least three units to construct mathematically a synthesis of the array. This is crucial to the efficiency and accuracy of the very large scale array, since no single monitoring unit is the point of reference. The point of reference is established by mathematical precedence involving time of arrival and the physical location of each monitoring unit at that point in time.

(244) An aperture is synthesized between any two points on the array using the difference in the arrival time. Establishing a midpoint between two monitoring units establishes a locus for the bearing measurement along the synthesized aperture.

(245) The aperture is given in radians by the following equation, where A is the wavelength in meters, and Distance is the arc length in meters.

(246) AperatureLength = 2 .Math. .Math. $\frac{\text{Distance}}{}$

(247) Distance is calculated by the following equations, where R is the radius of the earth in kilometers, and Lat and Lon refer to the points on installation for latitude and longitude in radians.

(248) $\text{Lat} = \text{Lat}_2 - \text{Lat}_1 \quad \text{Lon} = \text{Lon}_2 - \text{Lon}_1$

$a_1 = \sin(\frac{\text{Lat}}{2})^2 + \cos(\text{Lat}_1)$ .Math. $\cos(\text{Lat}_2)$ .Math. $\sin(\frac{\text{Lon}}{2})^2$ $k_1 = 2$ .Math. $a\tan 2(\sqrt{a_1}, \sqrt{(1 - a_1)})$

Distance = 1000 .Math. R .Math. k_1

(249) The radial distance directly related to the angle of arrival across the aperture is given by the equation representing the radial time between monitor unit 1 and monitor unit 2 divided by Aperture Length:

(250) $0\text{RadialDistance} = \frac{TOA_1 - TOA_2}{\text{AperatureLength}}$

(251) Using fundamental logic, two possible angles of arrival between the units defining the synthetic aperture for a bearing from the midpoint as illustrated in FIG. **48**.

(252) The use of a second component to establish a synthetic aperture yields another bearing as illustrated in FIG. **49**. Thus, as illustrated by the present invention, providing a point and additional elements to the array increases accuracy.

(253) The foregoing method descriptions and the process flow diagrams are provided merely as illustrative examples and are not intended to require or imply that the steps of the various embodiments must be performed in the order presented. As will be appreciated by one of skill in the art the order of steps in the foregoing embodiments may be performed in any order. Words such as "thereafter," "then," "next," etc. are not intended to limit the order of the steps; these words are simply used to guide the reader through the description of the methods. Further, any reference to claim elements in the singular, for example, using the articles "a," "an" or "the" is not to be construed as limiting the element to the singular.

(254) The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

(255) The hardware used to implement the various illustrative logics, logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, 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 conventional 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. Alternatively, some steps or methods may be performed by circuitry that is specific to a given function.

(256) In one or more exemplary aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions or code on a non-transitory computer-readable medium or non-transitory processor-readable medium. The steps of a method or algorithm disclosed herein may be embodied in a processor-executable software module which may reside on a non-transitory computer-readable or processor-readable storage medium. Non-transitory computer-readable or processor-readable storage media may be any storage media that may be accessed by a computer or a processor. By way of example but not limitation, such non-transitory computer-readable or processor-readable media may include RAM, ROM, EEPROM, FLASH memory, CD-ROM or other optical disc storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Disk and disc, as used herein, includes compact disc (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. Combinations of the above are also included within the scope of non-transitory computer-readable and processor-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and/or instructions on a non-transitory processor-readable medium and/or computer-readable medium, which may be incorporated into a computer program product.

(257) Certain modifications and improvements will occur to those skilled in the art upon a reading of the foregoing description. The above-mentioned examples are provided to serve the purpose of clarifying the aspects of the invention and it will be apparent to one skilled in the art that they do not serve to limit the

scope of the invention. All modifications and improvements have been deleted herein for the sake of conciseness and readability but are properly within the scope of the present invention.

Claims

1. A method for automatic signal detection in an environment, comprising: learning the environment using power level measurements within the environment; calculating a first derivative of the power level measurements and a second derivative of the power level measurements; smoothing a spectral sweep with a correction vector and a first smoothing filter; detecting at least one signal in the environment; locating a transmitter for the at least one signal using at least one angle-of-arrival (AoA) measurement of the at least one signal; adjusting a sensitivity parameter using Quality of Service (QoS) feedback to determine if the at least one signal is a signal of interest; locating the transmitter for the at least one signal using a global positioning system (GPS) receiver and a direction finding location (DF) system; performing a second smoothing filter only on frequencies outside a frequency range of the at least one signal and updating a calibration vector based on an output of the second smoothing filter; averaging the spectral sweep, removing areas identified by matched positive and negative gradients, and connecting points between removed areas to determine a baseline; and creating a reconstructed signal using compressed data for deltas and the baseline; wherein the deltas are differentials from the baseline; and wherein creating the reconstructed signal includes filling gaps where data is absent.
2. The method of claim 1, further comprising indexing the power level measurements in a spectrum section using a learning routine.
3. The method of claim 1, further comprising determining a frequency of the at least one signal.
4. The method of claim 1, wherein detecting the at least one signal in the environment comprises fine-tuning a threshold of power level on a segmented basis.
5. The method of claim 1, wherein smoothing the spectral sweep is based on the first smoothing filter that takes an average of the power level measurements over time.
6. The method of claim 1, wherein the first derivative and/or the second derivative are used to identify the matched positive and negative gradients.
7. The method of claim 1, further comprising sending a notification and/or an alarm to at least one remote device after detecting the at least one signal.
8. The method of claim 1, wherein the deltas provide for signal identification, interference identification, neighboring band identification, device identification, and/or signal optimization.
9. A system for automatic signal detection in an environment, comprising: at least one sensing device for detecting signals in the environment; wherein the at least one sensing device is operable to learn the environment using power level measurements; wherein the at least one sensing device is operable to calculate a first derivative of the power level measurements and a second derivative of the power level measurements; wherein the at least one sensing device is operable to smooth a spectral sweep of the power level measurements with a correction vector and a first smoothing filter; wherein the at least one sensing device is operable to detect at least one signal in the environment based on a machine learning (ML) algorithm; wherein the at least one sensing device is operable to locate a transmitter for the at least one signal using at least one angle-of-arrival (AoA) measurement of the at least one signal; wherein the at least one sensing device is operable to adjust a sensitivity parameter to determine if the at least one signal is a signal of interest using Quality of Service (QOS) feedback; wherein one or more of the at least one sensing device includes a global positioning system (GPS) receiver and a direction finding location (DF) system operable to locate the transmitter for the at least one signal; wherein a second smoothing filter is performed only on frequencies outside a frequency range of the at least one signal; wherein a calibration vector is updated based on an output of the second smoothing filter; wherein the at least one sensing device is operable to remove areas identified by matched positive and negative gradients and connect points between removed areas to determine a baseline; wherein the at least one sensing device is operable to create a reconstructed signal using compressed data for deltas and the baseline; and wherein the deltas are differentials from the baseline.
10. The system of claim 9, wherein the at least one sensing device is operable to index the power level measurements based on a learning routine.

11. The system of claim 9, further comprising a remote device in network-based communication with the at least one sensing device, wherein detecting results are displayed on a remote device in real time.
12. The system of claim 9, wherein the at least one sensing device is operable to fine-tune a threshold of power level on a segmented basis.
13. The system of claim 9, wherein smoothing the spectral sweep is based on the first smoothing filter that takes an average of the power level measurements over time.
14. The system of claim 9, wherein the first derivative and/or the second derivative are used to identify the matched positive and negative gradients.
15. The system of claim 9, wherein the at least one sensing device is operable to fill gaps during creation of the reconstructed signal where data of the at least one signal is absent.
16. The system of claim 9, wherein the at least one sensing device is operable to obtain a knowledge map from another sensing device.
17. An apparatus for automatic signal detection and/or interference detection in an environment, comprising: at least one sensing device for detecting signals in the environment; wherein the at least one sensing device is operable to learn the environment, to create learning data including power level measurements; wherein the at least one sensing device is operable to form a knowledge map based on the power level measurements; wherein the at least one sensing device is operable to scrub a spectral sweep against the knowledge map; wherein the at least one sensing device is operable to calculate derivatives of the power level measurements; wherein the at least one sensing device is operable to smooth the spectral sweep with a correction vector and a first smoothing filter; wherein the at least one sensing device is operable to detect at least one signal in the environment; wherein the at least one sensing device is operable to locate a transmitter for the at least one signal using at least one angle-of-arrival (AoA) measurement of the at least one signal; wherein the at least one sensing device is operable to adjust a sensitivity parameter to determine if the at least one signal is a signal of interest using Quality of Service (QOS) feedback; wherein one or more of the at least one sensing device includes a global positioning system (GPS) receiver and a direction finding location (DF) system operable to locate the transmitter for the at least one signal; wherein a second smoothing filter is performed only on frequencies outside a frequency range of the at least one signal; wherein a calibration vector is updated based on an output of the second smoothing filter; wherein the at least one sensing device is operable to average the spectral sweep, remove areas identified by matched positive and negative gradients, and connect points between removed areas to determine a baseline; wherein the at least one sensing device is operable to create a reconstructed signal using compressed data for deltas and the baseline.
18. The apparatus of claim 17, wherein the at least one sensing device is operable to fine-tune a threshold of power level on a segmented basis.
19. The apparatus of claim 17, wherein smoothing the spectral sweep is based on the first smoothing filter that takes an average of the power level measurements over time.