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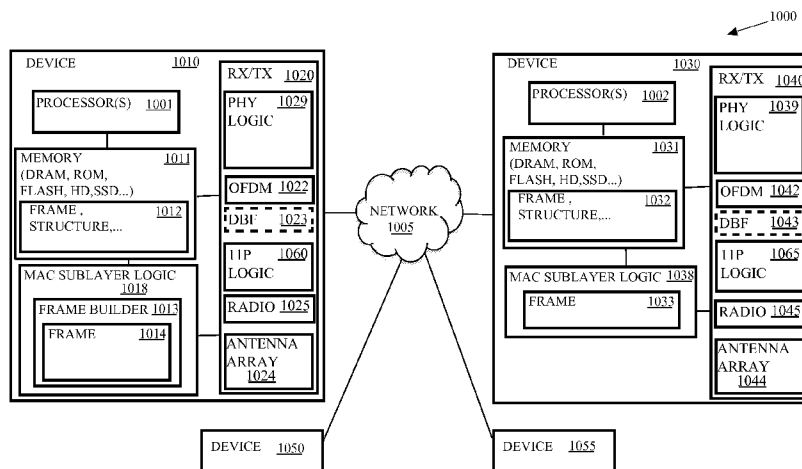


FIG. 1

(57) **Abstract:** Logic may estimate a carrier frequency offset. Logic may determine a type of a signal as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal, an IEEE 802.11ac signal, or an IEEE 802.11n signal. Logic may select a capture window for capturing a short training sequence of the signal based upon the type of the signal. Logic may determine a coarse frequency offset based upon the short training sequence and the capture window. Logic may select a data processing path for the signal based upon the type of the signal. Logic may determine a fine carrier frequency offset correction based upon a long training sequence of the signal. And logic may update a carrier frequency based on the carrier frequency offset correction.

METHODS AND ARRANGEMENTS TO ESTIMATE CARRIER FREQUENCY OFFSET

TECHNICAL FIELD

Embodiments are in the field of wireless communications. More particularly, embodiments are in the field of communications estimating carrier frequency offset.

5 BACKGROUND

A wireless communications system may utilize bi-directional signaling of control information to coordinate operations between geographically disparate communications devices. When a new device is designed to be operable in a frequency band that is currently in use by another technology, it may be important that the device being introduced to the frequency band
10 “play fairly” with the current devices on the band. Playing fairly means that the new device, at a minimum, should not interfere with ongoing communications on the band between devices that currently designed to use the band. For the new device in the band to avoid interference with the communications of devices currently designed to use the band, the new devices must remain off the band if energy is detected or be able to understand at least some of the control information of the
15 communications between devices currently designed to use the band even if current communications on the band follow different standards or protocols. Understanding communications, at least to an extent to decode a portion of a transmission to obtain enough information for updating the Network Allocation Vector can provide more efficient coexistence than offered by just using of energy detection.

20 BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts an embodiment of a wireless network comprising a plurality of communications devices, including Institute of Electrical and Electronic Engineers (IEEE) 802.11ac and IEEE 802.11p communications devices;

FIG. 1A depicts an embodiment of 11P logic to estimate a carrier frequency offset correction
25 for an IEEE 802.11p signal in an IEEE 802.11ac communications device;

FIG. 1B depicts an embodiment of a simulation illustrating a comparison of the coarse frequency offset estimation error for an 8 microsecond (uS) capture window for short training sequences of 10 MegaHertz (MHz) and a 20 MHz bandwidth IEEE 802.11p

signals with zero decibel (dB) signal-to-noise ratio in an Additive White Gaussian Noise (AWGN) channel model via a graph of Cumulative Distribution Function (CDF) versus normalized absolute error;

FIG. 1C depicts an embodiment of a simulation illustrating a comparison of the coarse frequency offset estimation error for an 8 uS capture window for short training sequences of a 10 and 20 MHz bandwidth IEEE 802.11p signals with 27 dB signal-to-noise ratio in an AWGN channel model via a graph of CDF versus normalized absolute error;

FIG. 1D depicts an embodiment of a simulation illustrating a packet error rate (PER) comparison of 10 MHz bandwidth IEEE 802.11p and 20 MHz bandwidth IEEE 802.11ac in an AWGN channel model after final coarse and fine frequency-offset estimation and correction;

FIG. 1E depicts an embodiment of an illustration of (a) proposed channel centers for 20 MHz bandwidth, IEEE 802.11ac signals, (b) Intelligent Transportation System (ITS) 20 MHz centers with partial overlapping channels with IEEE 802.11ac, (c) ITS 10 MHz centers with partial overlapping channels with IEEE 802.11ac, and (d) ITS 5 MHz centers with partial overlapping and non-overlapping channels with IEEE 802.11ac;

FIG. 2 depicts an embodiment of an apparatus to generate, transmit, receive, decode, and interpret communications

FIG. 3 depicts an embodiment of a flowchart to estimate a frequency offset correction; and

FIGs. 4A-B depict embodiments of flowcharts to transmit, receive, decode, and interpret communications with medium access control frames as illustrated in FIGs. 1-2.

DETAILED DESCRIPTION OF EMBODIMENTS

The following is a detailed description of novel embodiments depicted in the accompanying drawings. However, the amount of detail offered is not intended to limit anticipated variations of the described embodiments; on the contrary, the claims and detailed description are to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present teachings as defined by the appended claims. The detailed descriptions below are designed to make such embodiments understandable to a person having ordinary skill in the art.

References to “one embodiment,” “an embodiment,” “example embodiment,” “various embodiments,” etc., indicate that the embodiment(s) so described may include a particular feature,

structure, or characteristic, but not every embodiment necessarily includes the particular feature, structure, or characteristic. Further, repeated use of the phrase “in one embodiment” does not necessarily refer to the same embodiment, although it may.

As used herein, unless otherwise specified the use of the ordinal adjectives “first,” “second,” “third,” etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

The Federal Communications Commission (FCC) recently proposed modifications to the existing rules governing U-NII (Unlicensed-National Information Infrastructure) use of the 5 GigaHertz (GHz) band by which 195 MegaHertz (MHz) of additional spectrum is allocated for U-NII shared access in the 5350-5470 MHz and 5850-5925 MHz bands.

Several federal and non-federal agencies currently use the two mentioned 5 GHz bands. In particular, in the 5850-5925 MHz band; there are Dedicated Short Range Communications Service (DSRCS) systems operating in the Intelligent Transportation System (ITS) radio service for which the Institute of Electrical and Electronic Engineers (IEEE) 802.11p has defined enhancements to IEEE 802.11 to support its applications. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the ITS band of 5.85-5.925 GHz. IEEE "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments", IEEE 802.11p published standard, IEEE, New York, July 15, 2010. IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE published standard IEEE 802.11-2012.

IEEE may amend 802.11n/ac Wi-Fi (Wireless Fidelity) in order to enable such devices to expand their operating bands to take advantage of this 195 MHz additional spectrum. Embodiments herein describe 11P logic to allow IEEE 802.11n/ac devices and variants thereof to coexist with IEEE 802.11p devices and variants thereof thus allowing the IEEE 802.11n/ac devices to operate in this newly allocated band.

Embodiments may modify existing IEEE 802.11n/ac receiver hardware to enable estimation and correction of carrier frequency inaccuracy of IEEE 802.11p signals operating in the licensed ITS band of 5.85-5.925 GHz. Estimating and correcting carrier frequency inaccuracy of IEEE 802.11p signals may enable IEEE 802.11n/ac devices, or variants thereof, to coexist with IEEE

802.11p compliant devices. Further embodiments include new devices capable of receiving and processing IEEE 802.11n/ac and IEEE 802.11p signals.

To operate in this new band, embodiments may comprise 11P logic to detect and coexist with IEEE 802.11p devices and networks since 802.11n/ac devices overlap several of the IEEE 802.11p channels. One problem is that IEEE 802.11p devices operate over 5 MHz, 10 MHz, and 20 MHz bandwidths, whereas IEEE 802.11n operates over 20 MHz and 40 MHz bandwidths and IEEE 802.11ac operates over 20 MHz, 40 MHz, 80 MHz, and 160 MHz bandwidths. If a current IEEE 802.11n/ac device operated in this band it would be unaware of the IEEE 802.11p devices operating with a 5 MHz or 10 MHz bandwidth because the IEEE 802.11p devices have different subcarrier spacing, transmit center frequency tolerance, and symbol clock frequency tolerance. Currently there are no solutions to this problem because the FCC did not allow IEEE 802.11n/ac devices to operate in this frequency band.

Many embodiments implement 11P logic that allows a device to not only detect energy of the IEEE 802.11p signal, but also identify it as an IEEE 802.11p device and decode at least a portion of the transmission. Note that, embodiments are not limited to IEEE 802.11n/ac/p devices, but also other IEEE 802.11 amendments that build upon IEEE 802.11n/ac/p. With the 11P logic, embodiments may detect and process the preamble, estimate carrier frequency offset, and correct carrier frequency offset. Some embodiments may decode the SIGNAL (SIG) field to gain knowledge of the transmitted packet and obtain the required information to update the Network Allocation Vector (NAV) setting.

To decode a portion of the IEEE 802.11p transmission, the 11P logic may be designed based on differences from IEEE 802.11n/ac devices including differences in subcarrier spacing. There are two possible bandwidths that an IEEE 802.11n device can use in the 5 GHz band, namely 20 MHz and 40 MHz. In IEEE 802.11ac, this was expanded to add 80 MHz and 160 MHz, where the 160 MHz can be contiguous or non-contiguous. For brevity and simplicity of discussion, the discussions herein focus on 20 MHz bandwidth operations of IEEE 802.11n/ac devices, but the concepts can easily be extended for the other bandwidths as well.

The IEEE 802.11p devices can operate using 5 MHz, 10 MHz, and 20 MHz bandwidth transmissions. For each bandwidth of the IEEE 802.11p, the FFT size (number of subcarriers) is 64. Since the same FFT size is maintained for lower bandwidths of 5 MHz and 10 MHz, the duration of the packet and, therefore, the STF (short training field) increases to 32 uS and 16 uS, respectively.

Additionally, unlike in IEEE 802.11a/g/n/ac where the subcarrier spacing is maintained for all bandwidths, in 5 MHz and 10 MHz, subcarrier spacing is smaller.

To decode a portion of the IEEE 802.11p transmission, the 11P logic may also be designed based on differences in tolerances from IEEE 802.11n/ac devices. The IEEE 802.11 specification
5 defines the transmitted center frequency tolerance and symbol clock frequency tolerance to be ± 20 parts per million (ppm) maximum for bandwidths greater than or equal to a 10 MHz channel bandwidth and ± 10 ppm maximum for a 5 MHz channel bandwidth. Therefore, an IEEE 802.11n/ac device receiving a 5 MHz bandwidth, IEEE 802.11p signal may experience, for example, $[+20 - (-10)]$ ppm offset that consists of IEEE 802.11n/ac receiver-side carrier inaccuracy of +20 ppm, and
10 IEEE 802.11p transmitter-side carrier inaccuracy of -10 ppm. This generates different inaccuracy, or asymmetrical inaccuracy, in frequency offset estimator at the receiver based on whether the receiver is 11p or 11n/ac. The differences in the tolerances are important with respect to estimating the carrier frequency offset from the short training sequences (STSS). For instance, if carrier frequency offset is larger than what the correlation of STSS can estimate, then an ambiguity may
15 arise in the direction of the phasor. In other words, the phase may rotate beyond the 180-degree point causing an ambiguity in the direction of the frequency offset that may not be resolvable.

For the IEEE 802.11n/ac, 10 STSS are transmitted in the short training field (STF) of the preambles. So the IEEE 802.11n/ac coarse frequency offset estimator may correlate over the last four of STSS that are 0.8 μ S per sequence for the total of 3.2 μ S, which results in generation of a
20 coarse carrier offset estimate. For the IEEE 802.11p, each STS is 1.6 μ S and 3.2 μ S for 10MHz and 5MHz bandwidth, respectively. Based on the tolerances in the center carrier frequencies, correlating STSS of the IEEE 802.11p signals over only 3.2 μ S may result in a less accurate estimate. So the 11P logic may set the capture windows for the IEEE 802.11p signals at more than 3.2 μ S. In some embodiments, the 11P logic may set the capture windows at 6.4 μ S to cover
25 exactly four 10MHz STSS and two 5MHz STSS, respectively or the 11P logic may set the capture windows at 8 μ S to cover more STSS. To study the impact of this asymmetrical inaccuracy and whether IEEE 802.11n/ac device can estimate and correct an offset upon receiving 5 MHz and 10 MHz bandwidth, IEEE 802.11p signals that have 1/4th the subcarrier spacing an IEEE 802.11n/ac
20 MHz signal, several simulation studies were performed. The results of these studies are
30 discussed in conjunction with FIGs. 1B, 1C, and 1D.

In several embodiments, the 11P logic may employ a .11 STS detector to determine a type of a signal such as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal that is a

5 MHz and 10 MHz bandwidth signal, a 20 MHz IEEE 802.11p signal, and a 20 MHz or greater IEEE 802.11n/ac signal. The .11 STS detector may determine the start of packet of the IEEE 802.11n/.11ac or IEEE 802.11p signal. The .11 STS detector may implement auto-correlation of Short Training Sequences (STS) for detection. In some embodiments, the same auto-correlation block may also be used for coarse frequency offset estimation.

In many embodiments, the coarse frequency offset estimator may have a selectable capture window based upon the type of the signal. In several embodiments, the 11P logic may employ the coarse frequency offset estimator to determine a coarse frequency offset estimate with a capture window based upon the STSs received in the signal as well as the type of signal identified by the .11 STS detector. For embodiments in which an IEEE 802.11n/ac signal is detected, the period of time for the capture window may be 3.2 μ S. The STF structure in time domain has 10 repetitions of STSs. By properties of the Fourier transform, every four-repetition in time-domain results in three null subcarriers between non-zero subcarriers in the frequency domain. This allows STSs to be used for coarse estimation of carrier offset as large as twice subcarrier spacing.

For example, if the signal is an IEEE 802.11p signal, the 11P logic may select the capture window as less than 32 μ S and, in some embodiments, at approximately 8 μ S. For embodiments in which the period of time for the capture window may be 3.2 μ S based upon the capture window for IEEE 802.11n/ac, the 11P logic may perform four integrations of the coarse frequency offset within the 3.2 μ S period and average the 3 resulting phase offset estimates to determine the coarse phase offset. The 11P logic may set the capture window for the IEEE 802.11p to 8 μ S to perform four or less than four integration for 10MHz bandwidth or 5MHz bandwidth that have each STS of duration 1.6 μ S and 3.2 μ S, respectively.

After determining the coarse phase offset, the long training fields (LTF) of the preambles of the IEEE 802.11p signals and the IEEE 802.11n/ac signals may be determined. Processing LTFs results in a refined phase offset correction for correcting the carrier frequency offset.

In many embodiments, the 11P logic may select the data processing chain path (or data processing path) based upon the type of the signal determined by the .11 STS detector. Many embodiments employ an ancillary data processing path for IEEE 802.11p, 5 MHz and 10 MHz bandwidth signals to connect to the digital front end, branch off and then reconnect to the normal processing chain because the dedicated short range communication (DSRC) system including the 5 MHz and 10 MHz IEEE 802.11p signals use, as their basic waveform, the IEEE 802.11a/b specification (for the physical layer "PHY", Clause 18, with a Class C transmit mask).

The ancillary processing chain for 5MHz and 10MHz IEEE 802.11p signals may handle change of symbol duration, generally referred to as an Orthogonal frequency-division multiplexing (OFDM) symbol, duration of 5 MHz and 10 MHz signals by, e.g., filtering the signal to the appropriate bandwidth and down-sampling the signal to an appropriate sampling rate for the 20 MHz bandwidth, IEEE 802.11n/ac receiver. The following analyses determine the carrier frequency offsets allowable for the 5 MHz and 10 MHz bandwidth, IEEE 802.11p signals being received by 20 MHz bandwidth, IEEE 802.11n/ac receiver:

(a) For the 5 MHz IEEE 802.11p device operating at 5.8 GHz with -10 ppm offset has 58 KiloHertz (KHz) of offset, an IEEE 802.11n/ac device with +20 ppm has 116 KHz of offset, for total of 174 KHz while subcarrier spacing of the STF of 5 MHz bandwidth IEEE 802.11p signal would correct up to twice 5 MHz subcarrier spacing which is 156.25 KHz. Therefore, if the IEEE 802.11n/ac device has maximum allowed inaccuracy, it may not be able to correct this large of a carrier offset and may fail to decode the IEEE 802.11p signal. For a 20MHz bandwidth, IEEE 802.11n/ac device to meet the maximum level of correctable 5 MHz bandwidth, IEEE 802.11p signal, the IEEE 802.11n/ac device's frequency inaccuracy may be calculated as follows:

Maximum correctable phase offset on the ancillary IEEE 802.11p receiver-side $156.25 - (10 \text{ ppm} * 5.9125 \text{ GHz}) = 97.1 \text{ KHz}$, where 5.9125 GHz is the highest ITS 5 MHz channel center frequency. See FIG. 1E row (d) for a representation of the channels.

According to this calculation, 97.1 KHz may be the largest carrier frequency offset on the 20 MHz receiver-side. Since the highest 20MHz channel is centered at 5.905GHz, then $97.1 \text{ KHz} / 5.905 \text{ GHz} = 16.44 \text{ ppm}$ correctable inaccuracy.

(b) The 10 MHz bandwidth, IEEE 802.11p device operating at 5.8 GHz with -20 ppm offset has 116 KHz of offset, and IEEE 802.11n/ac device with +20 ppm has 116 KHz of offset, for a total of 232 KHz. Subcarrier spacing of the STF of the 10 MHz bandwidth, IEEE 802.11p signal may correct up to twice the offset of a 10 MHz subcarrier spacing which is 312.5 KHz and which is within correctable range of a 20 MHz bandwidth, IEEE 802.11n/ac device. Therefore, future .11n/ac devices has to meet reduced transmit center frequency intolerance and symbol clock frequency intolerance of $\pm 16 \text{ ppm}$ to enable receive of a 5 MHz bandwidth, IEEE 802.11p signal. This accuracy is an achievable limit that in fact most of Wi-Fi devices in market currently meet.

Various embodiments may be designed to address different technical problems associated with determining the carrier frequency phase offset estimates for an IEEE 802.11p signal in an IEEE 802.11n/ac receiver. Other technical problems may determining the type of signal being

received, determining a capture window for estimating a carrier frequency phase offset correction, determining a processing path for digital data for the received signal, determining a coarse carrier frequency offset based upon STSs, determining a refined carrier frequency offset based upon long training sequences (LTSs), and/or the like.

5 Different technical problems such as those discussed above may be addressed by one or more different embodiments. For instance, some embodiments that address determining the carrier frequency phase offset estimates for an IEEE 802.11p signal in an IEEE 802.11n/ac receiver may do so by one or more different technical means such as detecting a start of packet sequence, selecting a data processing path based upon the type of signal, selecting a capture window based upon the type
10 of signal, estimating a coarse carrier frequency offset based upon STSs and the capture window, determining a refined carrier frequency offset based upon LTSs and/or the like.

Some embodiments implement Institute of Electrical and Electronic Engineers (IEEE) 802.11 systems such as IEEE 802.11n/ac systems and other systems that operate in accordance with standards such as the IEEE 802.11-2012, IEEE Standard for Information technology—
15 Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE published standard IEEE 802.11-2012 (<http://standards.ieee.org/getieee802/download/802.11-2012.pdf>).

Some embodiments are particularly directed to improvements for wireless local area
20 network (WLAN), such as a WLAN implementing one or more Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards (sometimes collectively referred to as “Wi-Fi”). In one embodiment, for example, an improved acknowledgement scheme may be implemented for a WLAN such as the IEEE 802.11n wireless communications standard. The embodiments, however, are not limited to this example. IEEE 802.11n-2009—“Amendment 5: Enhancements for Higher
25 Throughput”, IEEE-SA, 29 October 2009.

Several embodiments comprise access points (APs) for and/or client devices of APs or stations (STAs) such as routers, switches, servers, workstations, netbooks, mobile devices (Laptop, Smart Phone, Tablet, and the like), as well as sensors, meters, controls, instruments, monitors, appliances, and the like.

30 Logic, modules, devices, and interfaces herein described may perform functions that may be implemented in hardware and/or code. Hardware and/or code may comprise software, firmware,

microcode, processors, state machines, chipsets, or combinations thereof designed to accomplish the functionality.

Embodiments may facilitate wireless communications. Some embodiments may comprise low power wireless communications like Bluetooth®, wireless local area networks (WLANs),
5 wireless metropolitan area networks (WMANs), wireless personal area networks (WPAN), cellular networks, communications in networks, messaging systems, and smart-devices to facilitate interaction between such devices. Furthermore, some wireless embodiments may incorporate a single antenna while other embodiments may employ multiple antennas. The one or more antennas may couple with a processor and a radio to transmit and/or receive radio waves. For instance,
10 multiple-input and multiple-output (MIMO) is the use of radio channels carrying signals via multiple antennas at both the transmitter and receiver to improve communication performance.

While some of the specific embodiments described below will reference the embodiments with specific configurations, those of skill in the art will realize that embodiments of the present disclosure may advantageously be implemented with other configurations with similar issues or
15 problems.

Turning now to FIG. 1, there is shown an embodiment of a wireless communication system 1000 comprising a plurality of communications devices, including Institute of Electrical and Electronic Engineers (IEEE) 802.11ac and IEEE 802.11p communications devices. In the present embodiment, the wireless communication system 1000 comprises a communications device 1010
20 that may be wire line and wirelessly connected to a network 1005. The communications device 1010 may communicate wirelessly with a plurality of communication devices 1030, 1050, and 1055 via the network 1005. The communications devices 1010 and 1030 may comprise IEEE 802.11ac devices with 11P Logic 1060 and 1065, respectively, to facilitate coexistence with the communications devices 1050 and 1055.

25 The communications devices 1050 and 1055 may comprise IEEE 802.11p devices and may periodically communicate with one another. The communications devices 1010, 1030, 1050, and 1055 may be in such proximity that the transmissions of these communications devices can interfere with one another if two of the devices are transmitting at the same time.

In the present embodiment, the periodic transmissions between the communications devices
30 1050 and 1055 may be allowed to occur periodically without interference by the communications devices 1010 and 1030. In particular, the devices 1010 and 1030 may schedule transmissions during

periods in which the communications devices 1050 and 1055 are not transmitting on the wireless medium. In other embodiments, access to the wireless medium may be contention based such that the devices 1050 and 1055 may not transmit if they detect the energy of an ongoing transmission between the communications devices 1010 and 1030.

5 Upon determining to transmit a data packet to the communications device 1030, the communications device 1010 may determine whether start of packet detection may indicate an 802.11 communication signal transmitted by the communications devices 1050 or 1055. If the start of packet detected by the antenna array 1024 and radio 1025 of the receiver front end of the communications device 1010, indicates that the energy may be an 802.11 transmission, the
10 communications device 1010 may attempt to decode the signal. The 11P logic 1060 of the communications device 1010 may determine the type of signal by, e.g., auto-correlating the signal to determine the start of packet after setting different duration of correlation for STSs of 11p signal. In some embodiments, the 11P logic 1060 may determine that the signal is an IEEE 802.11p, 5
15 MHz bandwidth signal.

15 Based upon the determination that the signal is an IEEE 802.11p, 5 MHz bandwidth signal, the 11P logic may set the capture window for a coarse frequency offset estimator to greater than 3.2uS and less than 32 uS and average the results to estimate a coarse carrier frequency offset. After determining the coarse carrier frequency offset, the 11P logic may refine the coarse carrier frequency offset by integrating the long training sequences (LTSs) of the preamble of the IEEE
20 802.11p, 5 MHz bandwidth signal. In some embodiments, integrating the LTSs may determine the carrier frequency offset that is applied to an oscillation circuit for removal of the carrier frequency from the signal and to a clock.

 The signal may also be directed through a data processing path configured for the IEEE 802.11p, 5 MHz bandwidth signal and decoded via the receiver thereafter to decode the signal (SIG)
25 field of the preamble of the IEEE 802.11p, 5 MHz bandwidth signal, to calculate an updated Network Allocation Vector setting. The NAV setting may indicate the maximum amount of time that the communications devices 1050 and 1055 are expected to transmit on the medium.

 The communications device 1010 may enter a power save mode and awake before, at, or after the expiration of the NAV to initiate the communication with the communications device
30 1030. In many embodiments, the communications device 1030 may also comprise 11P logic 1065 to perform the same functionality in the same manner or by a similar procedure.

FIG. 1A illustrates an embodiment of a receiver 1100 with integrated 11P logic 1101 to estimate a carrier frequency offset correction for an IEEE 802.11p signal in an IEEE 802.11ac communications device such as the 11P logic 1060 and 1065 in FIG. 1. The receiver 1100 may comprise an antenna 1102, a radio frequency (RF) front end 1104, an analog-to-digital (A/D) converter 1106, 11P Logic 1101, a voltage-controlled oscillator 1128, and a clock 1130. The antenna 1102 may be one or more antennas and, in some embodiments, the one or more antennas may be an antenna array comprising one or more antenna elements. The RF front end 1104 may generally comprise the circuitry between the antenna and the first intermediate frequency stage that comprises the components in the receiver 1100 that process the signal at the original incoming radio frequency (RF), before it is down-converted to a lower intermediate frequency. In many embodiments, the RF front end 1104 may comprise circuitry to remove the carrier frequency from the incoming signal based upon a carrier frequency generated by the voltage-controlled oscillator (VCO) 1128.

The A/D converter 1106 may convert the subcarriers from an analog signal to a digital signal based upon a sampling clock signal from the clock 1130 to process the remainder of the signal as a digital signal. The clock 1130 may output a clock signal to the VCO 1128 to generate the carrier frequency and a controller 1124 of the 11P logic 1101 may output the carrier frequency offset correction 1126 to the VCO 1128 to adjust the phase of the carrier frequency generated by the VCO 1128. In addition to this functionality, the clock signal output by the clock 1130 to the receiver 1116 may allow a potentially separate clock (slower) to be sent to the receiver 1116

The 11P logic 1100 may be integrated with the IEEE 802.11ac communications device. The 11P logic 1101 may comprise two data processing paths, path A 1112 and path B 1110. The path A 1112 may be a standard 20 MHz bandwidth, IEEE 802.11n/ac signal path that may also be the data processing path for 20 MHz bandwidth and greater IEEE 802.11p signals and the path B 1110 may be the data processing path for the 5 MHz and 10 MHz bandwidth, IEEE 802.11p signals. In many embodiments, the path B 1110 may address the extended symbol duration associated with the 5 MHz and 10 MHz bandwidth, IEEE 802.11p signals. In some embodiments, the 11P digital Frontend 1108 may implement a low pass filter to limit the bandwidth of the 5 MHz and 10 MHz bandwidth, IEEE 802.11p signals and down-sample the signals to reduce the sampling rates.

The 11P logic 1101 may comprise an .11p STS detector 1122, a coarse frequency offset estimator 1118, a carrier offset correction module 1120, a controller 1124, a switch 1114, and a

receiver 1116. The .11p STS detector 1122 may be an energy detection block and a start of the packet detector block to detect the presence of either an IEEE 802.11n/.11ac or .11p signal. In many embodiments, the .11p STS detector 1122 may also distinguish the 5 MHz and 10 MHz bandwidth, IEEE 802.11p signals from the 20 MHz and greater bandwidth, IEEE 802.11p signals. In several
5 embodiments, the .11p STS detector 1122 may monitor for the start of packet for the signals and may include, e.g., auto-correlation circuitry to auto-correlate the STSs of the incoming signal to determine the type of the signal as a 5 MHz or 10 MHz bandwidth, IEEE 802.11p signal, a 20 MHz and greater bandwidth, IEEE 802.11p signal, or an IEEE 802.11n/ac signal.

In the present embodiment, the .11 STS detector 1122 may output a determination of the
10 type of the incoming signal to the controller 1124. In response to receiving the output of the type of the signal, the controller 1124 may output the an indication of the same of other associated output to the coarse frequency offset estimator 1118, to the switch 1114, and to the receiver 1116. More specifically, the controller 1124 may output a selection signal to the coarse frequency offset estimator 1118 to select a capture window based upon the identification of the incoming signal by
15 the .11p STS detector 1122. If the incoming signal is an IEEE 802.11n/ac signal, the .11p STS detector 1122 may transmit a signal to the coarse frequency offset estimator 1118 to select a capture window of 3.2 uS. On the other hand, if the incoming signal is an IEEE 802.11p signal, the .11p STS detector 1122 may transmit a signal to the coarse frequency offset estimator 1118 to select a capture window of less than 32 uS such as 8 uS. In other embodiments, the .11 STS detector 1122
20 may output an indication of the type of signal or a selection signal directly to the coarse frequency offset detector 1118 to select a capture window based upon the type of the incoming signal.

The controller 1124 may output an indication of the type of incoming signal to the switch 1114 to switch between the path A 1112 and the path B 1110. For instance, if the type of the signal as a 5 MHz or 10 MHz bandwidth, IEEE 802.11p signal then the output of the controller 1124 may
25 cause the switch 1114 to select the path B 1110. Otherwise, the output of the controller 1124 may cause the switch 1114 to select the path A 1112.

The controller 1124 may output an indication of the type of incoming signal to the receiver 1116 to switch between an IEEE 802.11n/ac signal mode and an IEEE 802.11p signal mode. For instance, if the type of the signal as an IEEE 802.11p signal then the output of the controller 1124
30 may cause the receiver 1116 to select the IEEE 802.11p signal mode for demodulating the signal. Otherwise, the output of the controller 1124 may cause the receiver 1116 to select the IEEE 802.11n/ac signal mode to demodulate the signal. In many embodiments, the output of the control

signal from the controller 1124 to the receiver 1116 may inform the receiver 1116 when the DSRC signal is present, allowing the receiver 1116 to configure for the new sampling rate and to adjust algorithms based on the different subcarrier spacing.

After the capture window is set for the coarse frequency offset estimator 1118, the coarse
5 frequency offset estimator 1118 may determine one or more phasor for incoming STSs in the STF field(s) of the preamble of the incoming signal and average the phasors to determine an estimate for the frequency offset of the carrier frequency. The coarse frequency offset estimator 1118 may output the carrier frequency offset estimation to the carrier offset correction module 1120 to determine a refined carrier frequency offset correction. In many embodiments, the carrier offset
10 correction module 1120 may determine the refined or fine carrier frequency offset correction by integrating the long training sequences (LTSs) from the long training fields in the preamble of the incoming signal over a period of time.

After determining the refined carrier frequency offset correction, the carrier offset correction module 1120 may output the fine carrier frequency offset correction to the controller 1124 and the
15 controller 1124 may output indications of the same to the clock 1130 and the VCO 1128.

FIG. 1B illustrates an embodiment of a simulation 1200 illustrating a comparison of the coarse frequency offset estimation error for an 8 microsecond (uS) capture window for short training sequences of 10 MegaHertz (MHz) and 20 MHz bandwidth, IEEE 802.11p signals. In this simulation, the IEEE 802.11p signals have a zero decibel (dB) signal-to-noise ratio (SNR) in an
20 Additive White Gaussian Noise (AWGN) channel model and the results are represented in a graph of Cumulative Distribution Function (CDF) versus normalized absolute error.

FIG. 1C illustrates an embodiment of a simulation 1300 illustrating a comparison of the coarse frequency offset estimation error for an 8 uS capture window for short training sequences of 10 MHz and 20 MHz bandwidth, IEEE 802.11p signals. The simulation includes a 27 dB SNR in
25 an AWGN channel model and the results are represented by a graph of CDF versus normalized absolute error.

The results of simulation studies 1200 and 1300 shown in FIGs. 1B and 1C confirms that using smaller number of STSs for the 10 MHz bandwidth, IEEE 802.11p signal does generate larger errors vs. 20 MHz bandwidth signal. However, the combination of the offset correction from the
30 controller to the voltage-controlled oscillator (VCO), or other hardware controlling the radio frequency (RF) carrier frequency, providing the appropriate correction, and the output of the .11 STS detector to select the data processing path for the 10 MHz bandwidth, IEEE 802.11p signals

allows correct reception of IEEE 802.11p signals. After the incoming signal goes through a correct duration of LTF processing for 5 MHz and 10 MHz bandwidth, IEEE 802.11p signals, the final fine carrier frequency offset estimation using the LTF allows correct reception and demodulation of IEEE 802.11p signals. FIG. 1D illustrates this in final Packet Error Rate (PER) vs. SNR curves.

FIGs. 1B, 1C, and 1D show results of the simulation studies for different cases of the coarse frequency offset estimation in an AWGN channel model. It is observed that the IEEE 802.11n/ac receiver faces higher estimation error when receiving a 10 MHz bandwidth IEEE 802.11p signal vs. receiving a 20 MHz bandwidth signal. This is due to the longer symbol duration of the 10 MHz signal. During the observation/estimation interval of 8 μ s, a complete short training field (STF) structure (10 STSs) of the 20 MHz bandwidth signal is processed while if the received signal is 10 MHz, then only half of STF is received and processed. Despite this excess error, final packet error rate (PER) performance vs. signal-to-noise ratio (SNR) of two signals are the same because in both scenarios fine frequency estimation is done using complete LTF structure.

FIG. 1E illustrates an embodiment of depicts an embodiment of an illustration of (a) proposed channel centers for 20 MHz bandwidth, IEEE 802.11ac signals every 5 MHz between 5860 MHz and 5915 MHz, (b) Intelligent Transportation System (ITS) 20 MHz centers with partial overlapping channels with IEEE 802.11ac every 5 MHz between 5860 MHz and 5915 MHz, (c) ITS 10 MHz centers with partial overlapping channels with IEEE 802.11ac every 5 MHz between 5852.5 MHz and 5917.5 MHz, and (d) ITS 5 MHz centers with partial overlapping and non-overlapping channels with IEEE 802.11ac.

Referring again to FIG. 1, the network 1005 may represent an interconnection of a number of networks. For instance, the network 1005 may couple with a wide area network such as the Internet or an intranet and may interconnect local devices wired or wirelessly interconnected via one or more hubs, routers, or switches. In the present embodiment, the network 1005 communicatively couples communications devices 1010 and 1030.

The communication devices 1010 and 1030 comprise processor(s) 1001 and 1002, memory 1011 and 1031, and MAC sublayer logic 1018 and 1038, respectively. The processor(s) 1001 and 1002 may comprise any data processing device such as a microprocessor, a microcontroller, a state machine, and/or the like. The memory 1011 and 1031 may comprise a storage medium such as Dynamic Random Access Memory (DRAM), read only memory (ROM), buffers, registers, cache, flash memory, hard disk drives, solid-state drives, or the like. The memory 1012 and 1032 may store the frames such as the frames and/or the frame structures, and may store frame headers such as

short MAC headers or portions thereof. In many embodiments, the frames may comprise fields based upon the structure of the standard frame structures identified in IEEE 802.11.

Referring again to FIG. 1, the MAC sublayer logic 1018, 1038 may comprise logic to implement functionality of the MAC sublayer of the data link layer of the communications device 1010, 1030. The MAC sublayer logic 1018, 1038 may generate the frames 1014, 1033 such as management frames, data frames, and control frames, and may communicate with the physical layer (PHY) logic 1029, 1039 to transmit these frames. The PHY logic 1029, 1039 may generate physical layer protocol data units (PPDUs) based upon the frames 1014, 1033. More specifically, the frame builders 1013 may generate frames 1014, 1033 and the data unit builders of the PHY logic 1029, 1039 may prepend the frames 1014, 1033 with preambles to generate PPDUs for transmission via a physical layer device such as the transceivers (RX/TX) 1020 and 1040.

The frame 1014, also referred to as MAC layer Service Data Units (MSDUs), may comprise, e.g., a management frame. For example, frame builder 1013 may generate a management frame such as a beacon frame to identify the communications device 1010 as having capabilities such as supported data rates, power saving features, cross-support, and a service set identification (SSID) of the network to identify the network to the communications device 1030.

The communications devices 1010, 1030, 1050, and 1055 may each comprise a transceiver such as transceivers (RX/TX) 1020 and 1040. In many embodiments, transceivers 1020 and 1040 implement orthogonal frequency-division multiplexing (OFDM) 1022, 1042. OFDM 1022, 1042 implements a method of encoding digital data on multiple carrier frequencies. OFDM 1022, 1042 comprises a frequency-division multiplexing scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal subcarrier signals are used to carry data. The data is divided into several parallel data streams or channels, one for each subcarrier. Each subcarrier is modulated with a modulation scheme at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

An OFDM system uses several carriers, or "tones," for functions including data, pilot, guard, and nulling. Data tones are used to transfer information between the transmitter and receiver via one of the channels. Pilot tones are used to maintain the channels, and may provide information about time/frequency and channel tracking. And guard tones may help the signal conform to a spectral mask. The nulling of the direct component (DC) may be used to simplify direct conversion receiver designs. And guard intervals may be inserted between symbols such as between every OFDM

symbol as well as between the short training field (STF) and long training field (LTF) symbols in the front end of the transmitter during transmission to avoid inter-symbol interference (ISI), which might result from multi-path distortion.

Each transceiver 1020, 1040 comprises a radio 1025, 1045 comprising an RF transmitter and
5 an RF receiver. The RF transmitter comprises an OFDM 1022, which impresses digital data, OFDM symbols encoded with tones, onto RF frequencies, also referred to as subcarriers, for transmission of the data by electromagnetic radiation. In the present embodiment, the OFDM 1022 may impress the digital data as OFDM symbols encoded with tones onto the subcarriers for transmission. The OFDM 1022 may transform information signals into signals to be applied via the
10 radio 1025, 1045 to elements of an antenna array 1024. An RF receiver receives electromagnetic energy at an RF frequency and extracts the digital data from the OFDM symbols.

In some embodiments, the communications device 1010 optionally comprises a Digital Beam Former (DBF) 1023, as indicated by the dashed lines. The DBF 1023 transforms information signals into signals to be applied to elements of an antenna array 1024. The antenna array 1024 is
15 an array of individual, separately excitable antenna elements. The signals applied to the elements of the antenna array 1024 cause the antenna array 1024 to radiate spatial channels. Each spatial channel so formed may carry information to one or more of the communications devices 1030, 1050, and 1055. Similarly, the communications device 1030 comprises the transceiver (RX/TX) 1040 to receive and transmit signals from and to the communications device 1010. The transceiver
20 (RX/TX) 1040 may comprise an antenna array 1044 and, optionally, a DBF 1042.

FIG. 1 may depict a number of different embodiments including a Multiple-Input, Multiple-Output (MIMO) system with, e.g., four spatial streams, and may depict degenerate systems in which one or more of the communications devices 1010, 1030, 1050, and 1055 comprise a receiver and/or a transmitter with a single antenna including a Single-Input, Single Output (SISO) system, a Single-
25 Input, Multiple Output (SIMO) system, and a Multiple-Input, Single Output (MISO) system. In the alternative, FIG. 1 may depict transceivers that include multiple antennas and that may be capable of multiple-user MIMO (MU-MIMO) operation.

FIG. 2 depicts an embodiment of an apparatus to generate, transmit, receive, and interpret or decode frames including frames. The apparatus comprises a transceiver 200 coupled with Medium
30 Access Control (MAC) sublayer logic 201 and a physical layer (PHY) logic 202. The MAC sublayer logic 201 may determine a frame and the physical layer (PHY) logic 202 may determine

the PPDU by prepending the frame or multiple frames, also called MAC protocol data units (MPDUs), with a preamble to transmit via transceiver 200. For example, a frame builder may generate a frame including a type field that specifies the type of the frame such as a management, control, or data frame and an ACK policy field to the ACK policy associated with the frame. A control frame may include a Ready-To-Send or Clear-To-Send frame. A management frame may comprise a Beacon, Probe Request/Response, Association Request/Response, and Reassociation Request/Response frame type. And the data type frame is designed to transmit data.

In many embodiments, the MAC sublayer logic 201 may comprise a frame builder 202 to generate frames (MPDU). For example, in some embodiments, a frame builder 202 may generate a frame with a short MAC header defined in memory of the communications device and the MAC sublayer logic 201 may transmit the short frame to the PHY logic 202.

The PHY logic 202 may comprise a data unit builder 203. The data unit builder 203 may determine a preamble and the PHY logic 202 may prepend the MPDU with the preamble to generate a PPDU. In many embodiments, the data unit builder 203 may create the preamble based upon communications parameters chosen through interaction with a destination communications device.

The transceiver 200 comprises a receiver 204 and a transmitter 206. The transmitter 206 may comprise one or more of an encoder 208, a modulator 210, an OFDM 212, and a DBF 214. The encoder 208 of transmitter 206 receives and encodes data destined for transmission from the MAC sublayer logic 202 with, e.g., a binary convolutional coding (BCC), a low density parity check coding (LDPC), and/or the like. The modulator 210 may receive data from encoder 208 and may impress the received data blocks onto a sinusoid of a selected frequency via, e.g., mapping the data blocks into a corresponding set of discrete amplitudes of the sinusoid, or a set of discrete phases of the sinusoid, or a set of discrete frequency shifts relative to the frequency of the sinusoid.

The output of modulator 209 is fed to an orthogonal frequency division multiplexing (OFDM) module 212. The OFDM module 212 may comprise a space-time block coding (STBC) module 211, a digital beamforming (DBF) module 214, and an inverse, fast Fourier transform (IFFT) module 215. The STBC module 211 may receive constellation points from the modulator 209 corresponding to one or more spatial streams and may spread the spatial streams to a greater number of space-time streams (also generally referred to as data streams). Further embodiments may omit the STBC.

The OFDM module 212 impresses or maps the modulated data formed as OFDM symbols onto a plurality of orthogonal subcarriers so the OFDM symbols are encoded with the subcarriers or tones. In some embodiments, the OFDM symbols are fed to the Digital Beam Forming (DBF) module 214. Generally, digital beam forming uses digital signal processing algorithms that operate
5 on the signals received by, and transmitted from, an array of antenna elements.

The Inverse Fast Fourier Transform (IFFT) module 215 may perform an inverse discrete Fourier transform (IDFT) on the OFDM symbols. The output of the IFFT module 215 may enter the transmitter front end 240. The transmitter front end 240 may comprise a radio 242 with a power amplifier (PA) 244 to amplify the signal and prepare the signal for transmission via the antenna
10 array 218.

In one embodiment, the radio 242, 252 may include a component or combination of components adapted for transmitting and/or receiving single carrier or multi-carrier modulated signals (e.g., including complementary code keying (CCK) and/or orthogonal frequency division multiplexing (OFDM) symbols) although the embodiments are not limited to any specific over-the-
15 air interface or modulation scheme. The radio 242, 252 may include, for example, a receiver, a transmitter and/or a frequency synthesizer. The radio 242, 252 may include, for instance, bias controls, and a crystal oscillator, and may couple with one or more antennas 218. In another embodiment, the radio 242 may use external voltage-controlled oscillators (VCOs), surface acoustic wave filters, intermediate frequency (IF) filters and/or RF filters, as desired. Due to the variety of
20 potential RF interface designs an expansive description thereof is omitted.

The signal may be up-converted to a higher carrying frequency or may be performed integrally with up-conversion. Shifting the signal to a much higher frequency before transmission enables use of an antenna array of practical dimensions. That is, the higher the transmission frequency, the smaller the antenna can be. Thus, an up-converter multiplies the modulated
25 waveform by a sinusoid to obtain a signal with a carrier frequency that is the sum of the central frequency of the waveform and the frequency of the sinusoid.

The transceiver 200 may also comprise duplexers 216 connected to antenna array 218. Thus, in this embodiment, a single antenna array is used for both transmission and reception. When transmitting, the signal passes through duplexers 216 and drives the antenna with the up-converted
30 information-bearing signal. During transmission, the duplexers 216 prevent the signals to be transmitted from entering receiver 204. When receiving, information bearing signals received by

the antenna array pass through duplexers 216 to deliver the signal from the antenna array to receiver 204. The duplexers 216 then prevent the received signals from entering transmitter 206. Thus, duplexers 216 operate as switches to alternately connect the antenna array elements to the receiver 204 and the transmitter 206.

5 The antenna array 218 radiates the information bearing signals into a time-varying, spatial distribution of electromagnetic energy that can be received by an antenna of a receiver. The receiver can then extract the information of the received signal. In other embodiments, the transceiver 200 may comprise one or more antennas rather than antenna arrays and, in several embodiments, the receiver 204 and the transmitter 206 may comprise their own antennas or antenna
10 arrays.

 The transceiver 200 may comprise a receiver 204 for receiving, demodulating, and decoding information bearing communication signals. The receiver 204 may comprise a receiver front-end 250 coupled with 11P logic 260 to detect the signal, detect the start of the packet to determine the type of the signal, determine a carrier frequency offset correction estimate, remove the carrier
15 frequency, and amplify the subcarriers via a radio 252 with a low noise amplifier (LNA) 254. In several embodiments, the 11P logic 260 may set a capture window in a coarse frequency offset determination based upon the type of the signal such as an IEEE 802.11p or .11ac signal and may select a separate data processing path for 5 MHz and 10 MHz bandwidth IEEE 802.11p signals to filter and down-sampling the signals for demodulation by the receiver 204.

20 The communication signals may comprise, e.g., 64 tones on a 5.8 GHz carrier frequency with subcarrier spacing that depends upon the type of the signal. For instance, the subcarrier spacing may be smaller in the 5 MHz and 10 MHz bandwidth IEEE 802.11p signals than the 20 MHz bandwidth IEEE 802.11n/ac/p signals. The receiver 204 may comprise, e.g., a 64-point, fast Fourier transform (FFT) module 219. The FFT module 219 may transform the communication
25 signals from the time domain to the frequency domain. Note that operational bandwidth of 802.11n/ac device may be greater than 20MHz. But the idea explained here can be extended to higher bandwidth. For simplicity, only the 20MHz case is explained.

 The receiver 204 may also comprise an OFDM module 222, a demodulator 224, a deinterleaver 225, and a decoder 226, and the equalizer 258 may output the weighted data signals
30 for the OFDM packet to the OFDM module 222. The OFDM 222 extracts signal information as

OFDM symbols from the plurality of subcarriers onto which information-bearing communication signals are modulated.

The OFDM module 222 may comprise a DBF module 220, and an STBC module 221. The received signals are fed from the equalizer to the DBF module 220 transforms N antenna signals into L information signals. And the STBC module 221 may transform the data streams from the space-time streams to spatial streams.

The demodulator 224 demodulates the spatial streams. Demodulation is the process of extracting data from the spatial streams to produce demodulated spatial streams. The method of demodulation depends on the method by which the information is modulated onto the received carrier signal and such information is included in the transmission vector (TXVECTOR) included in the communication signal. Thus, for example, if the modulation is BPSK, demodulation involves phase detection to convert phase information to a binary sequence. Demodulation provides to the deinterleaver 225 a sequence of bits of information.

The deinterleaver 225 may deinterleave the sequence of bits of information. For instance, the deinterleaver 225 may store the sequence of bits in columns in memory and remove or output the bits from the memory in rows to deinterleave the bits of information. The decoder 226 decodes the deinterleaved data from the demodulator 224 and transmits the decoded information, the MPDU, to the MAC sublayer logic 202.

Persons of skill in the art will recognize that a transceiver may comprise numerous additional functions not shown in FIG. 2 and that the receiver 204 and transmitter 206 can be distinct devices rather than being packaged as one transceiver. For instance, embodiments of a transceiver may comprise a Dynamic Random Access Memory (DRAM), a reference oscillator, filtering circuitry, synchronization circuitry, an interleaver and a deinterleaver, possibly multiple frequency conversion stages and multiple amplification stages, etc. Further, some of the functions shown in FIG. 2 may be integrated. For example, digital beam forming may be integrated with orthogonal frequency division multiplexing.

The MAC sublayer logic 201 may parse the MPDU based upon a format defined in the communications device for a frame to determine the particular type of frame by determining the type value and the subtype value. The MAC sublayer logic 201 may then parse and interpret the remainder of MPDU based upon the definition for the frame of the particular type and subtype indicated in the MAC header.

FIG. 3 depicts an embodiment of a flowchart 300 to estimate a frequency offset correction. The flowchart 300 begins with receipt of an incoming signal at 11P logic of a receiver such as the receiver 204 and 11P logic 260 described in conjunction with FIG. 2. The 11P logic may determine a type of the signal that is being received (element 305). For example, the 11P logic may search for a start of packet for the incoming signal by comparing the expected short training sequences (STSs) in the short training field (STF) of the preamble of the incoming signal. In some embodiments, the incoming signal may comprise at least an STF, an LTF, and a signal (SIG) field. The STF may comprise up to ten STSs so the 11P logic may auto-correlate the STSs to determine the whether the incoming signal is a 5 MHz bandwidth, IEEE 802.11p signal; a 10 MHz bandwidth, IEEE 802.11p signal; a 20 MHz bandwidth, IEEE 802.11p signal; a 20 MHz bandwidth, IEEE 802.11n signal; a 40 MHz bandwidth, IEEE 802.11n signal, a 20 MHz bandwidth, IEEE 802.11ac signal; a 40 MHz bandwidth, IEEE 802.11ac signal; an 80 MHz bandwidth, IEEE 802.11ac signal; or a 160 MHz bandwidth, IEEE 802.11ac signal. In other embodiments, such as embodiments with other IEEE 802.11 signals are received that are variations of the IEEE 802.11n/ac signals, the circuitry may be modified in a similar manner to the changes discussed herein.

After determining the type of the incoming signal by energy detection and the start of the packet detection, the 11P logic may set a capture window for coarse carrier frequency estimation (element 310). For example, the capture window for the 5MHz and 10MHz IEEE 802.11p signals may be set to a window of greater than 3.2 uS, for example at least 6.4uS to cover two 5MHz STSs each 3.2uS and/or to cover four STSs of 10 MHz STSs each 1.6 uS and the capture window for the IEEE 802.11n/ac signals or 20MHz IEEE 11p signal may be set to a window of 3.2 uS to capture four 20MHz STSs.

After setting the capture window, the 11P logic may estimate the carrier frequency offset by correlation of the short training sequences (STSs) during the capture window (element 320). In several embodiments, the 11P logic may correlate the STSs to determine a coarse carrier frequency offset within the capture window. For embodiments based upon the 5MHz IEEE 802.11p signals, the period for receipt of the STSs is 10 STSs times 3.2 uS per STS or 32 uS. Thus, the 11P logic may correlate the STSs for the IEEE 802.11p STSs for up to 32 uS. In one embodiment, the capture window is set to 8 uS, which can capture more than four times of the 3.2 uS duration of one STS.

Based upon the determination of the type of the incoming signal, the 11P logic may also select a data processing path for the incoming signal (element 325). In many embodiments, an alternative data processing path may be established as necessary to conform the incoming digital

signal to signal requirements or approximate signal requirements for processing by the receiver. For example, the IEEE 802.11p signals with 5 MHz and 10 MHz bandwidths may comprise different symbol durations so the alternate data processing path may filter the bandwidth and down-sample the digital signal.

5 Upon receipt of the LTF, the 11P logic may refine the estimate of the carrier frequency offset to determine a finer carrier frequency offset correction (element 335). Thereafter, the fine carrier frequency offset correction may be applied to an RF oscillation circuit such as a voltage-controlled oscillator to generate the accurate carrier frequency and remove the carrier frequency offset from the incoming signal (element 340).

10 FIGs. 4A-B depict embodiments of flowcharts 400 and 450 to transmit, receive, decode, and interpret communications with medium access control frames as illustrated in FIGs. 1-2. Referring to FIG. 4A, the flowchart 400 may begin with receiving a frame from the frame builder. The MAC sublayer logic of the communications device may generate the frame as a management frame to transmit to an access point and may pass the frame as an MAC protocol data unit (MPDU) to a data
15 unit builder that transforms the data into a packet that can be transmitted to the access point. The data unit builder may generate a preamble with at least an STF, an LTF and a SIG field to prepend the PHY service data unit (PSDU) (the MPDU from the frame builder) to form a PHY protocol data unit (PPDU) for transmission (element 405). In some embodiments, more than one MPDU may be prepended in a PPDU.

20 The PPDU may then be transmitted to the physical layer device such as the transmitter 206 in FIG. 2 or the transceiver 1020, 1040 in FIG. 1 so the PPDU may be converted to a communication signal (element 410). The transmitter may then transmit the communication signal via the antenna (element 415).

25 Referring to FIG. 4B, the flowchart 450 begins with a receiver of an access point such as the receiver 204 in FIG. 2 receiving a communication signal via one or more antenna(s) such as an antenna element of antenna array 218 (element 455). The receiver may convert the communication signal into an MPDU in accordance with the process described in the preamble (element 460). More specifically, the received signal is fed from the one or more antennas to a DBF such as the DBF 220. The DBF transforms the antenna signals into information signals. The output of the
30 DBF is fed to OFDM such as the OFDM 222. The OFDM extracts signal information from the plurality of subcarriers onto which information-bearing signals are modulated. Then, the demodulator such as the demodulator 224 demodulates the signal information via, e.g., BPSK, 16-

QAM, 64-QAM, 256-QAM, QPSK, or SQPSK. And the decoder such as the decoder 226 decodes the signal information from the demodulator via, e.g., BCC or LDPC, to extract the MPDU (element 460) and transmits the MPDU to MAC sublayer logic such as MAC sublayer logic 202 (element 465).

5 The MAC sublayer logic may determine frame field values from the MPDU (element 470) such as the frame control fields and subfields. For instance, the MAC sublayer logic may determine frame field values such as the ACK policy field value of the frame.

 The following examples pertain to further embodiments. One example comprises an apparatus to estimate a carrier frequency offset. The apparatus may comprise a detector to
10 determine a type of a signal as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal; a coarse frequency offset estimator to select a capture window for capturing a short training sequence of the signal based upon the type of the signal; and to determine a coarse frequency offset based upon the short training sequence and the capture window; a controller to select a data processing path for the signal based upon the type of the signal; and a carrier offset correction
15 module to determine a fine carrier frequency offset correction based upon a long training sequence of the signal.

 In some embodiments, the apparatus may further comprise a radio and an antenna array to receive the signal. In some embodiments, the controller is coupled with the carrier offset correction module to update a carrier frequency based on the carrier frequency offset correction. In some
20 embodiments, the detector comprises logic to determine a type of a signal as an IEEE 802.11ac signal. In some embodiments, the detector comprises logic to determine a type of a signal by determining a start of packet associated with an IEEE 802.11p signal by auto-correlation of the short training sequence. In some embodiments, the coarse frequency offset estimator comprises logic to select a capture window appropriate for the duration of the STS based upon the determined
25 type of the signal.

 Another embodiment comprises a method to estimate a carrier frequency offset. The method may comprise determining a type of a signal as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal; selecting a capture window for capturing a short training sequence of the signal based upon the type of the signal; determining a coarse frequency offset
30 based upon the short training sequence and the capture window; selecting a data processing path for

the signal based upon the type of the signal; and determining a fine carrier frequency offset correction based upon a long training sequence of the signal.

In some embodiments, the method may further comprise updating a carrier frequency based on the carrier frequency offset correction. In some embodiments, the method may further comprise
5 determining a type of a signal as an IEEE 802.11ac signal. In some embodiments, determining a type of a signal as an IEEE 802.11p signal comprises determining a start of packet associated with an IEEE 802.11p signal by auto-correlation of the short training sequence. In some embodiments, selecting a capture window for capturing a short training sequence based upon the type of the signal comprises selecting a capture window appropriate for the duration of the STS based upon the
10 determined type of the signal.

Another embodiment comprises a system to interpret a packet. The system may comprise a processor; a memory coupled with the processor; a detector to determine a type of a signal as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal; a coarse frequency offset estimator to select a capture window for capturing a short training sequence of the signal based
15 upon the type of the signal; and to determine a coarse frequency offset based upon the short training sequence and the capture window; a controller to select a data processing path for the signal based upon the type of the signal; a fine carrier frequency offset correction module to determine a fine carrier frequency offset correction based upon a long training sequence of the signal; an oscillation circuit to adjust a carrier frequency based upon the carrier frequency offset correction; a radio
20 coupled with the oscillation circuit; and one or more antennas coupled with the radio to receive the signal.

In some embodiments, the detector comprises logic to determine a type of a signal as an IEEE 802.11ac signal. In some embodiments, the detector comprises logic to determine a type of a signal by determining a start of packet associated with an IEEE 802.11p signal by auto-correlation
25 of the short training sequence. In some embodiments, the coarse frequency offset estimator comprises logic to select a capture window appropriate for the duration of the STS based upon the determined type of the signal.

Another embodiment comprises an apparatus to estimate a carrier frequency offset. The apparatus may comprise a means for determining a type of a signal as an Institute of Electrical and
30 Electronic Engineers (IEEE) 802.11p signal; a means for selecting a capture window for capturing a short training sequence of the signal based upon the type of the signal; a means for determining a

coarse frequency offset based upon the short training sequence and the capture window; a means for selecting a data processing path for the signal based upon the type of the signal; and a means for determining a fine carrier frequency offset correction based upon a long training sequence of the signal.

5 In some embodiments, the apparatus may further comprise the means for determining the type of the signal comprises a means for updating a carrier frequency based on the carrier frequency offset correction. In some embodiments, the means for determining the type of the signal comprises a means for determining a start of packet associated with an IEEE 802.11p signal by auto-correlation of the short training sequence. In some embodiments, the means for wherein selecting
10 the capture window comprises a means for selecting a capture window appropriate for the duration of the STS based upon the determined type of the signal.

In some embodiments, some or all of the features described above and in the claims may be implemented in one embodiment. For instance, alternative features may be implemented as alternatives in an embodiment along with logic or selectable preference to determine which
15 alternative to implement. Some embodiments with features that are not mutually exclusive may also include logic or a selectable preference to activate or deactivate one or more of the features. For instance, some features may be selected at the time of manufacture by including or removing a circuit pathway or transistor. Further features may be selected at the time of deployment or after deployment via logic or a selectable preference such as a dipswitch or the like. A user after via a
20 selectable preference such as a software preference, an e-fuse, or the like may select still further features.

Another embodiment is implemented as a program product for implementing systems and methods described with reference to FIGs. 1-4. Some embodiments can take the form of an entirely hardware embodiment, an entirely software embodiment, or an embodiment containing both
25 hardware and software elements. One embodiment is implemented in software, which includes but is not limited to firmware, resident software, microcode, etc.

Furthermore, embodiments can take the form of a computer program product (or machine-accessible product) accessible from a computer-usable or computer-readable medium providing program code for use by or in connection with a computer or any instruction execution system. For
30 the purposes of this description, a computer-usable or computer readable medium can be any

apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device). Examples of a computer-readable medium include a semiconductor or solid-state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk, and an optical disk. Current examples of optical disks include compact disk – read only memory (CD-ROM), compact disk – read/write (CD-R/W), and DVD.

A data processing system suitable for storing and/or executing program code will include at least one processor coupled directly or indirectly to memory elements through a system bus. The memory elements can include local memory employed during actual execution of the program code, bulk storage, and cache memories which provide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution.

The logic as described above may be part of the design for an integrated circuit chip. The chip design is created in a graphical computer programming language, and stored in a computer storage medium (such as a disk, tape, physical hard drive, or virtual hard drive such as in a storage access network). If the designer does not fabricate chips or the photolithographic masks used to fabricate chips, the designer transmits the resulting design by physical means (e.g., by providing a copy of the storage medium storing the design) or electronically (e.g., through the Internet) to such entities, directly or indirectly. The stored design is then converted into the appropriate format (e.g., GDSII) for the fabrication.

The resulting integrated circuit chips can be distributed by the fabricator in raw wafer form (that is, as a single wafer that has multiple unpackaged chips), as a bare die, or in a packaged form. In the latter case, the chip is mounted in a single chip package (such as a plastic carrier, with leads that are affixed to a motherboard or other higher level carrier) or in a multichip package (such as a ceramic carrier that has either or both surface interconnections or buried interconnections). In any case, the chip is then integrated with other chips, discrete circuit elements, and/or other signal processing devices as part of either (a) an intermediate product, such as a motherboard, or (b) an end product.

WHAT IS CLAIMED IS:

1. An apparatus to estimate a carrier frequency offset, the apparatus comprising:
5 a detector to determine a type of a signal as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal;
a coarse frequency offset estimator to select a capture window for capturing a short training sequence of the signal based upon the type of the signal; and to determine a coarse frequency offset based upon the short training sequence and the capture window;
10 a controller to select a data processing path for the signal based upon the type of the signal; and
a fine carrier offset correction module to determine a fine carrier frequency offset correction based upon a long training sequence of the signal.
2. The apparatus of claim 1, further comprising a radio and an antenna array to receive the
15 signal.
3. The apparatus of claim 1, wherein the controller is coupled with the carrier offset correction module to update a carrier frequency based on the carrier frequency offset correction.
4. The apparatus of claim 1, wherein the detector comprises logic to determine a type of a signal as an IEEE 802.11ac signal.
- 20 5. The apparatus of claim 1, wherein the detector comprises logic to determine a type of a signal by determining a start of packet associated with an IEEE 802.11p signal by auto-correlation of the short training sequence.
6. The apparatus of claim 1, wherein the coarse frequency offset estimator comprises logic to select a capture window appropriate for the duration of the STS based upon the determined
25 type of the signal.
7. A method to estimate a carrier frequency offset, the method comprising:

determining a type of a signal as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal;
selecting a capture window for capturing a short training sequence of the signal based upon the type of the signal;
5 determining a coarse frequency offset based upon the short training sequence and the capture window;
selecting a data processing path for the signal based upon the type of the signal; and
determining a fine carrier frequency offset correction based upon a long training sequence of the signal.

- 10 8. The method of claim 7, further comprising updating a carrier frequency based on the carrier frequency offset correction.
9. The method of claim 7, further comprising determining a type of a signal as an IEEE 802.11ac signal.
- 15 10. The method of claim 7, wherein selecting a capture window for capturing a short training sequence based upon the type of the signal comprises selecting a capture window appropriate for the duration of the short training sequence (STS) based upon the determined type of the signal.
- 20 11. The method of claim 7, wherein determining a type of a signal as an IEEE 802.11p signal comprises determining a start of packet associated with an IEEE 802.11p signal by auto-correlation of the short training sequence.
- 25 12. A system to interpret a packet comprising:
a processor;
a memory coupled with the processor;
a detector to determine a type of a signal as an Institute of Electrical and Electronic Engineers (IEEE) 802.11p signal;
a coarse frequency offset estimator to select a capture window for capturing a short training sequence of the signal based upon the type of the signal; and to determine a coarse
30 frequency offset based upon the short training sequence and the capture window;

a controller to select a data processing path for the signal based upon the type of the signal;
 a carrier offset correction module to determine a fine carrier frequency offset correction
 based upon a long training sequence of the signal;
 an oscillation circuit to adjust a carrier frequency based upon the carrier frequency offset
 5 correction;
 a radio coupled with the oscillation circuit; and
 one or more antennas coupled with the radio to receive the signal.

13. The system of claim 12, wherein the detector comprises logic to determine a type of a signal
 as an IEEE 802.11ac signal.

10 14. The system of claim 12, wherein the detector comprises logic to determine a type of a signal
 by determining a start of packet associated with an IEEE 802.11p signal by auto-correlation
 of the short training sequence.

15 15. The system of claim 12, wherein the coarse frequency offset estimator comprises logic to
 select a capture window appropriate for the duration of the short training sequence (STS)
 based upon the determined type of the signal.

16. An apparatus to estimate a carrier frequency offset, the apparatus comprising:
 a means for determining a type of a signal as an Institute of Electrical and Electronic
 Engineers (IEEE) 802.11p signal;
 20 a means for selecting a capture window for capturing a short training sequence of the signal
 based upon the type of the signal;
 a means for determining a coarse frequency offset based upon the short training sequence
 and the capture window;
 a means for selecting a data processing path for the signal based upon the type of the signal;
 25 and
 a means for determining a fine carrier frequency offset correction based upon a long training
 sequence of the signal.

17. The apparatus of claim 16, further comprising the means for determining the type of the signal comprises a means for updating a carrier frequency based on the carrier frequency offset correction.
18. The apparatus of claim 16, wherein the means for wherein selecting the capture window
5 comprises a means for selecting a capture window appropriate for the duration of the short training sequence (STS) based upon the determined type of the signal.
19. The apparatus of claim 16, wherein the means for determining the type of the signal comprises a means for determining a start of packet associated with an IEEE 802.11p signal by auto-correlation of the short training sequence.

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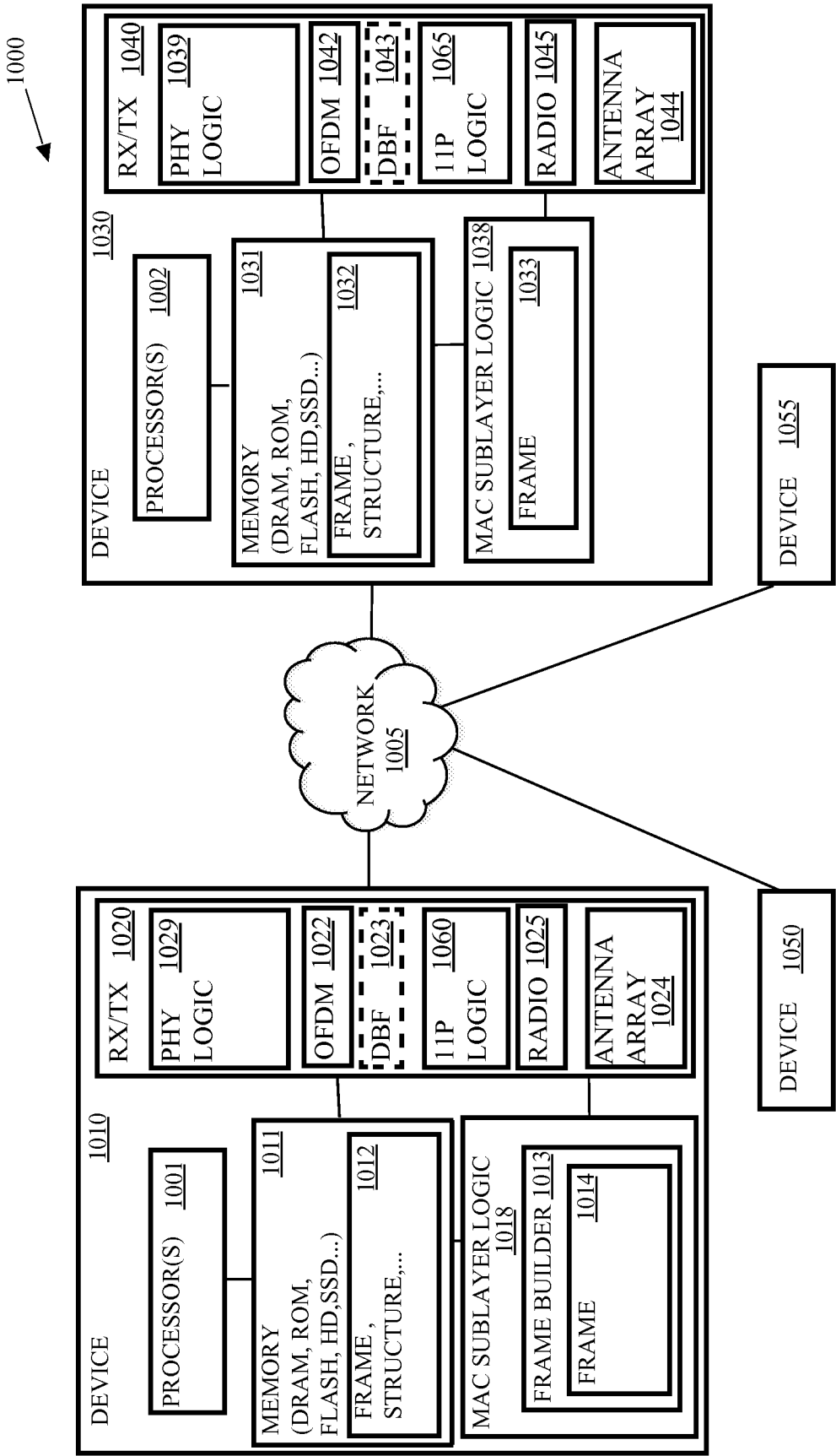


FIG. 1

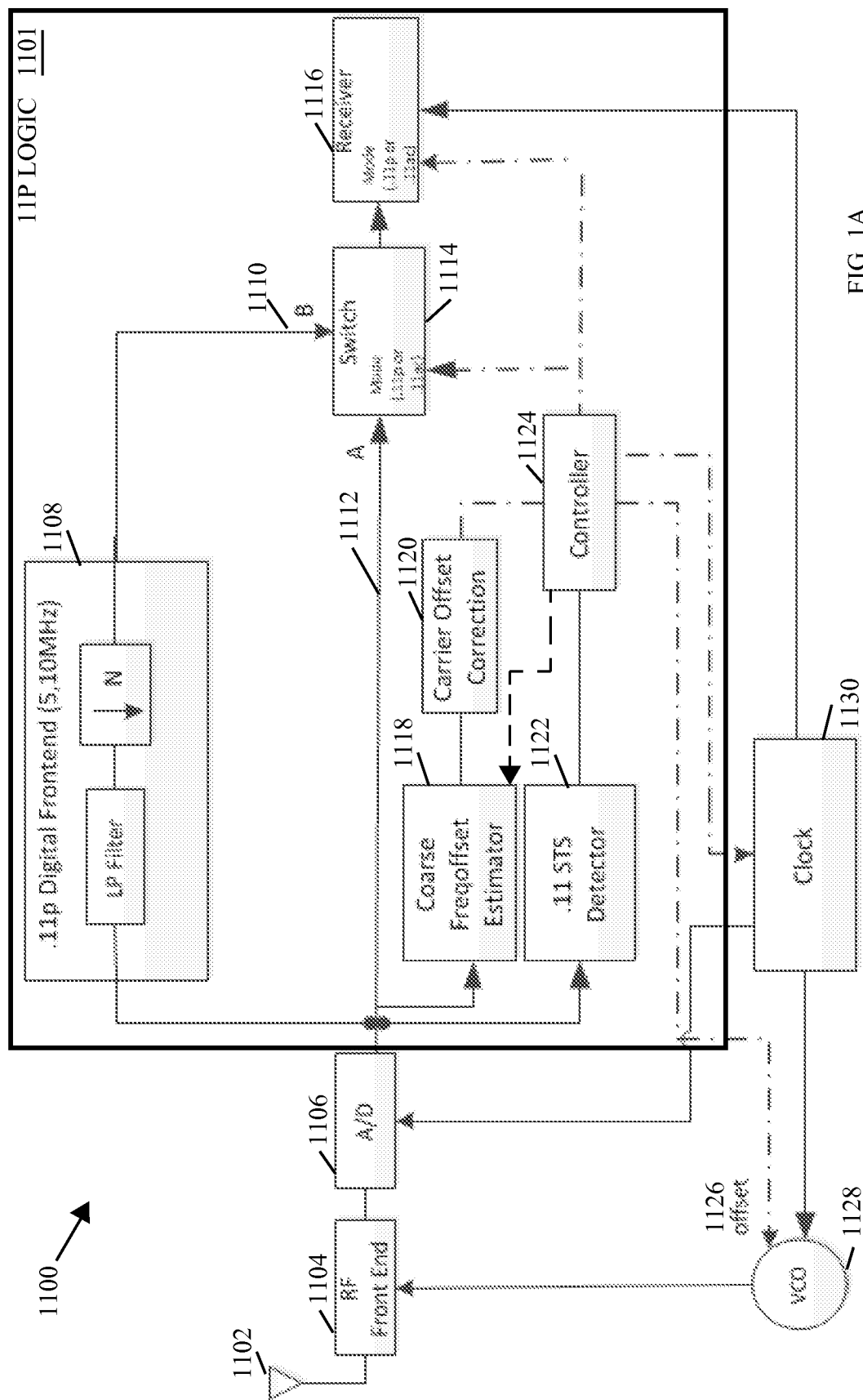


FIG. 1A

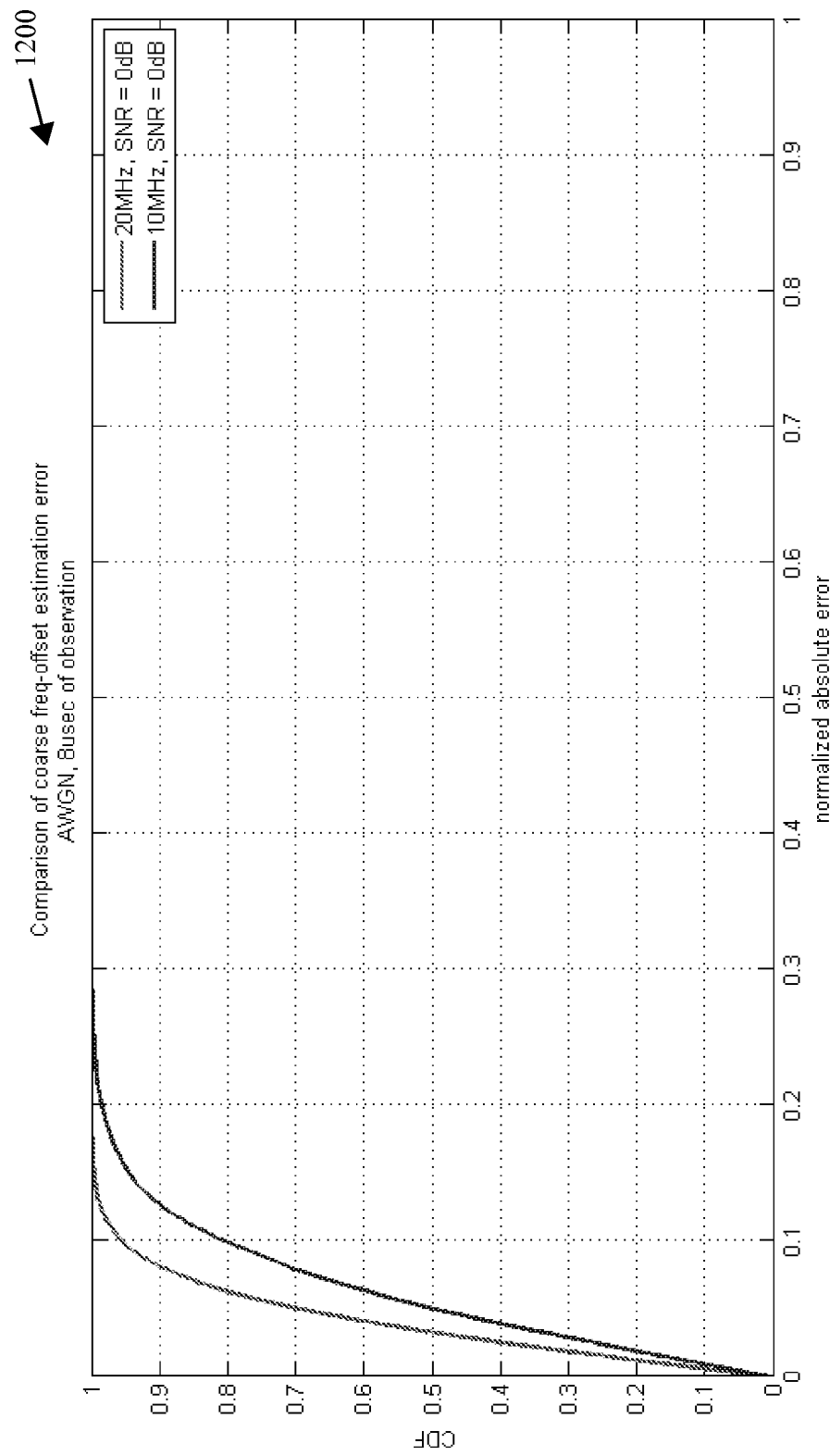
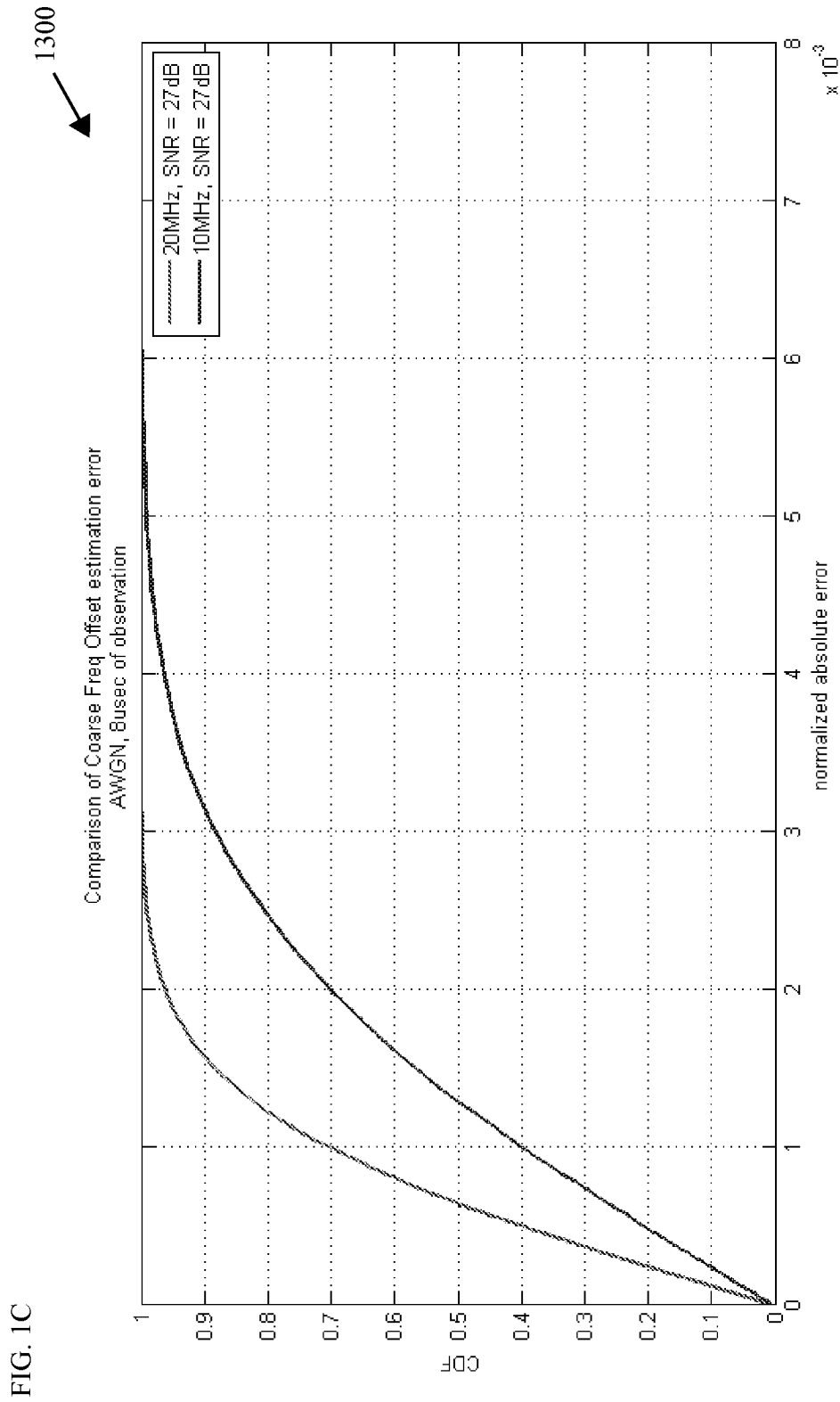
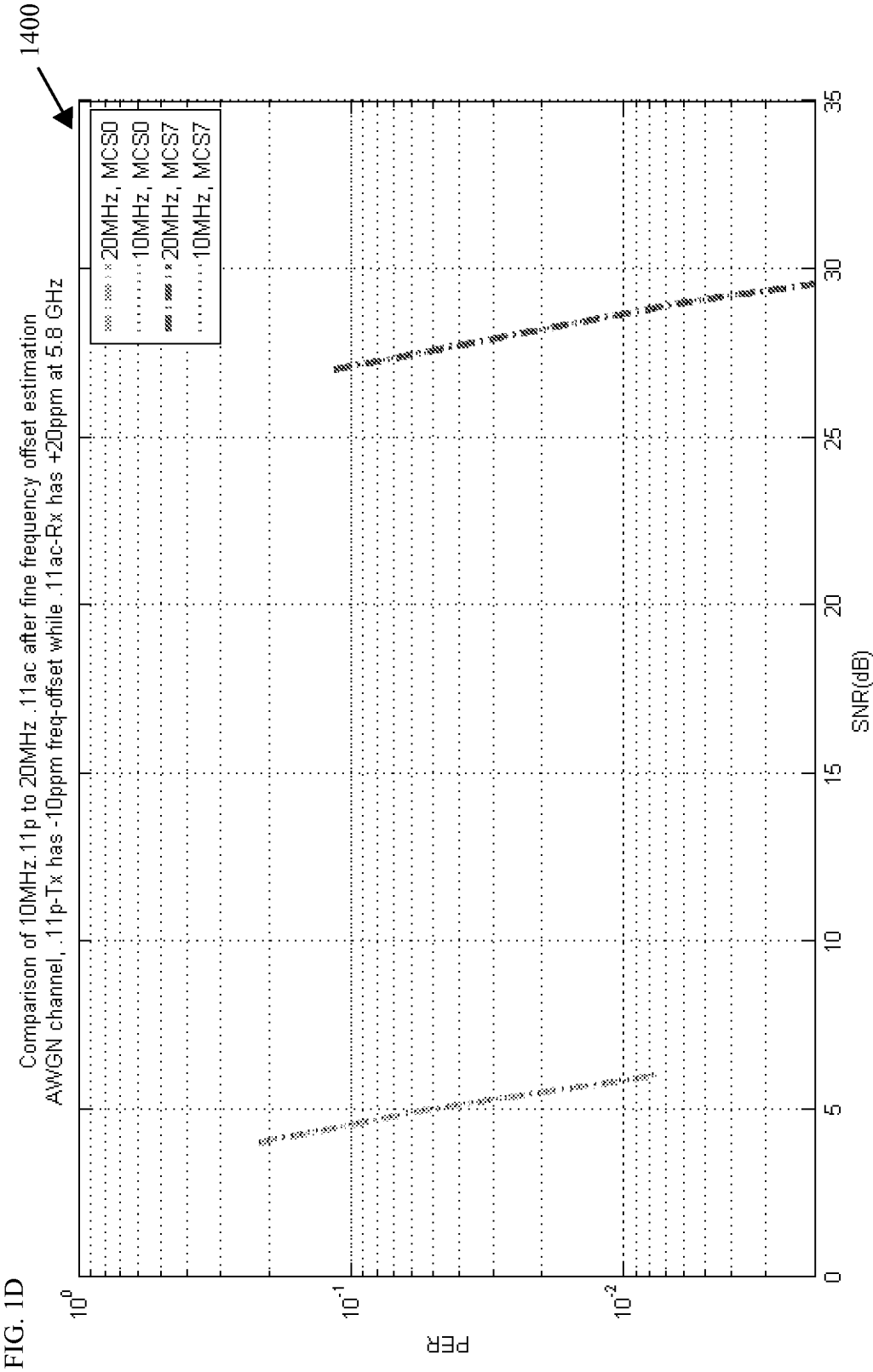


FIG. 1B





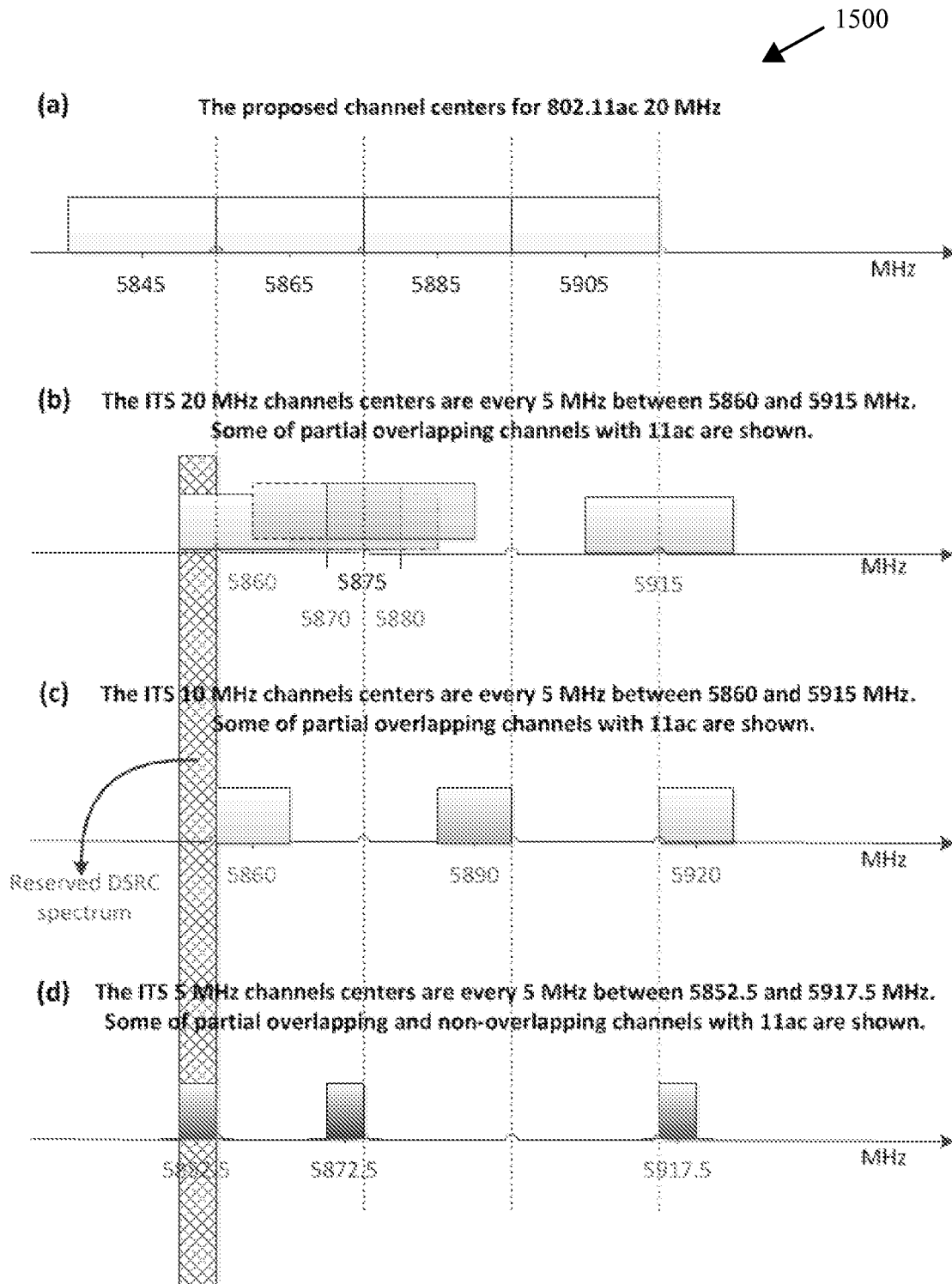


FIG. 1E

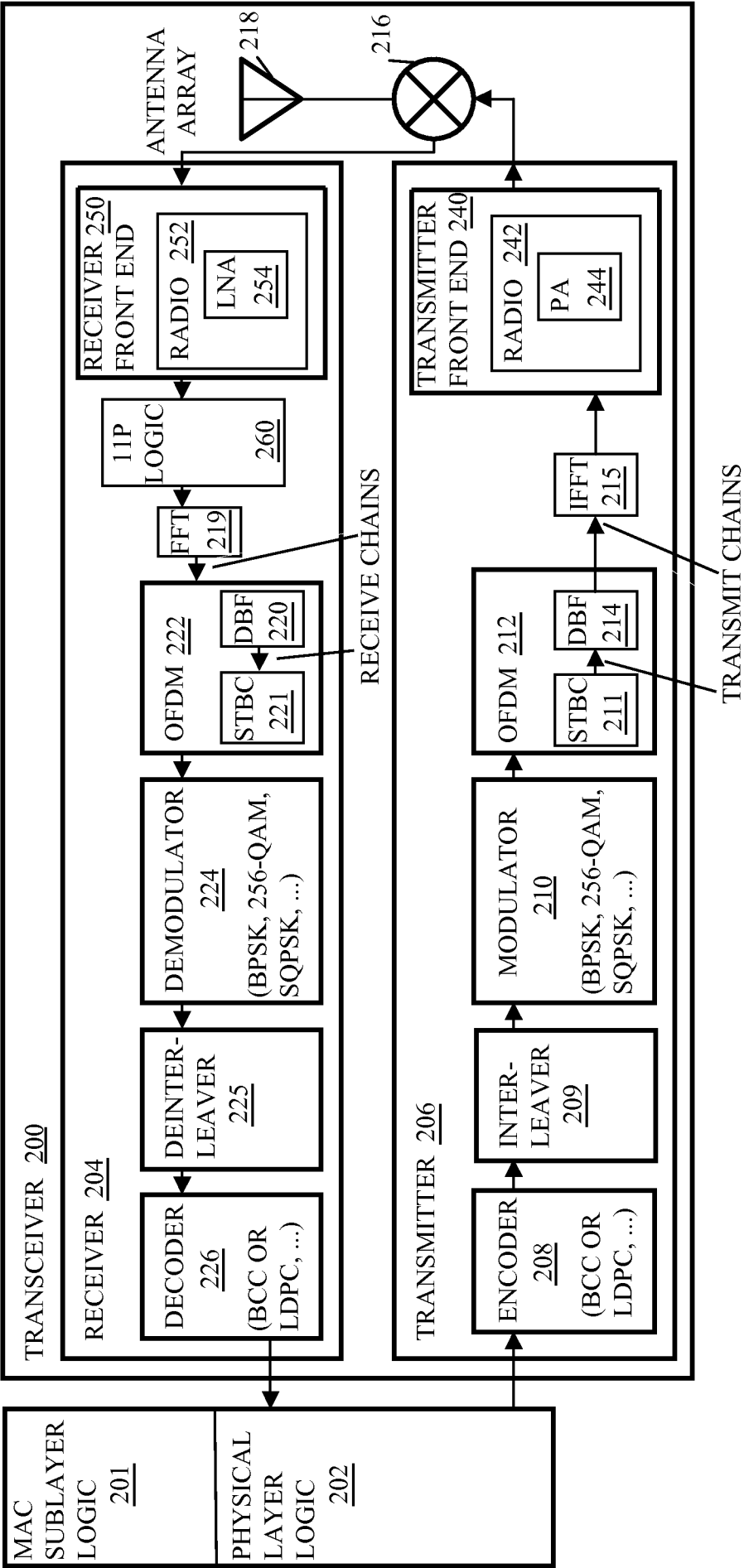


FIG. 2

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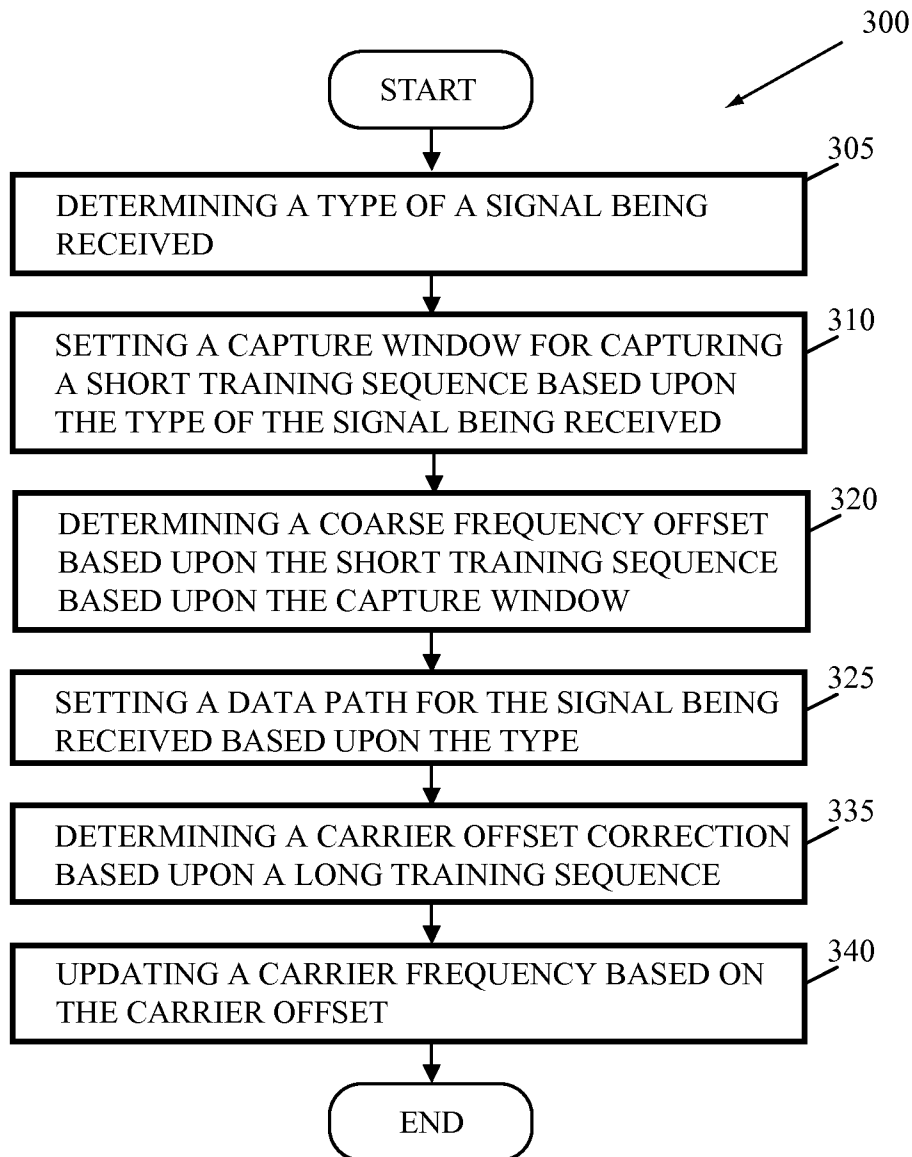


FIG. 3

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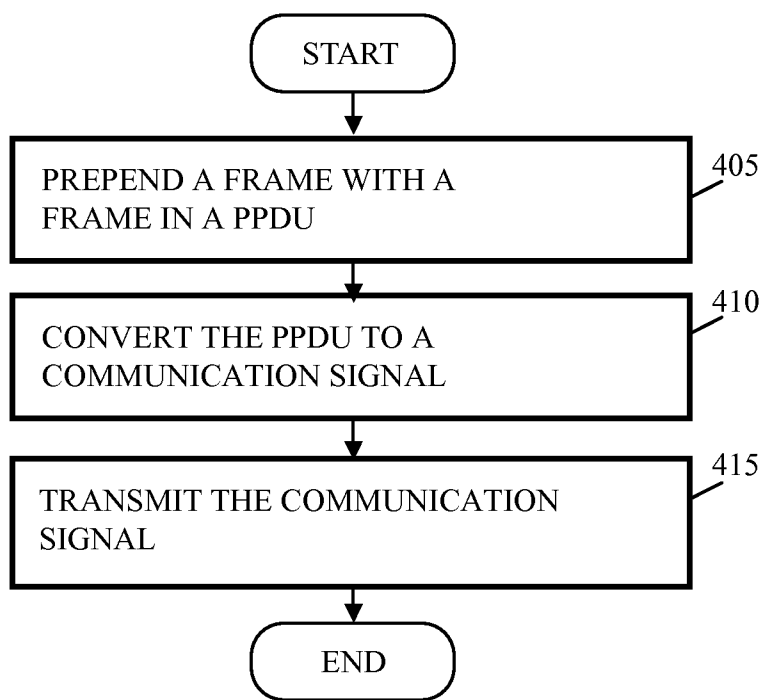


FIG. 4A

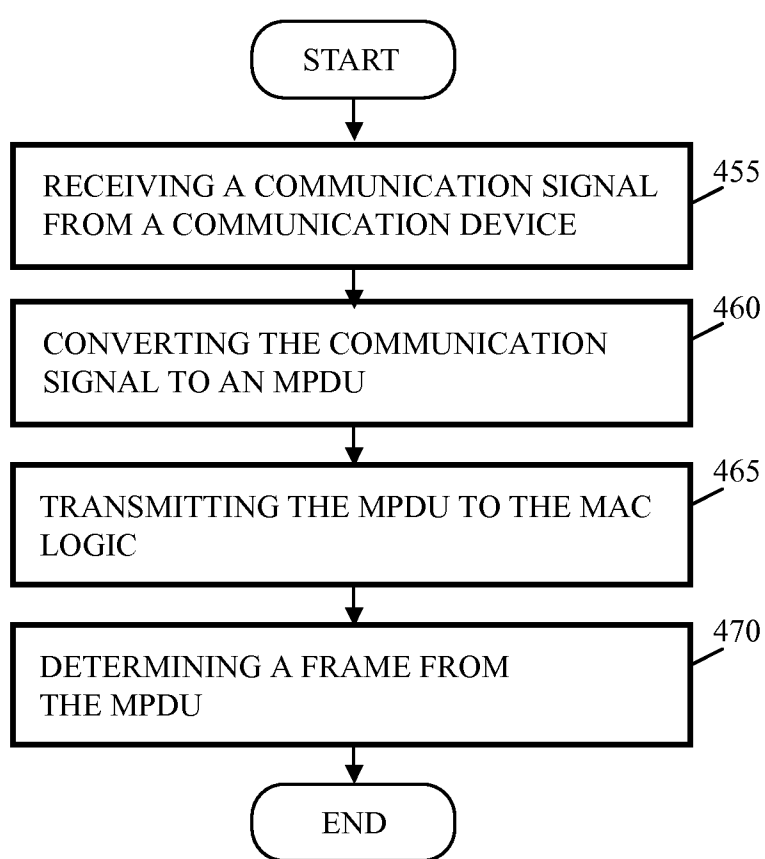


FIG. 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/078161**A. CLASSIFICATION OF SUBJECT MATTER****H04J 11/00(2006.01)i, H04B 7/26(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04J 11/00; H04L 7/00; H04W 24/00; H04L 27/06; H04L 27/28; H04B 7/26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: frequency offset, estimation, correction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2009-0080576 A1 (WEIDONG XIANG) 26 March 2009 See paragraphs [0023]-[0028], [0042]; and figures 1, 2.	1-4, 7-9, 12, 13, 16 , 17 5, 6, 10, 11, 14, 15, 18 , 19
Y A	US 2013-0003568 A1 (HONGYU XIE et al.) 03 January 2013 See paragraphs [0035]-[0058]; and figures 3-6.	1-4, 7-9, 12, 13, 16 , 17
A	US 2011-0280325 A1 (JOSEPH FERNANDEZ et al.) 17 November 2011 See paragraphs [0028]-[0055]; and figures 1-4.	1-19
A	US 2004-0190438 A1 (ALEXANDER A. MALTSEV et al.) 30 September 2004 See paragraphs [0013]-[0043]; and figures 1-4.	1-19
A	US 2006-0233288 A1 (PAULUS WILHELMUS FRANCISCUS GRUIJTERS et al.) 19 October 2006 See paragraphs [0036]-[0053]; and figures 1-4.	1-19



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

26 September 2014 (26.09.2014)

Date of mailing of the international search report

26 September 2014 (26.09.2014)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/078161

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009-0080576 A1	26/03/2009	US 8045657 B2 WO 2009-042226 A2 WO 2009-042226 A3	25/10/2011 02/04/2009 18/06/2009
US 2013-0003568 A1	03/01/2013	US 8493907 B2	23/07/2013
US 2011-0280325 A1	17/11/2011	CN 102244633 A CN 102244633 B DE 102011100930 A1 US 8559537 B2	16/11/2011 05/03/2014 08/12/2011 15/10/2013
US 2004-0190438 A1	30/09/2004	AU 2003-269742 A1 CN 1846415 A CN 1846415 B EP 1611722 A1 US 7336597 B2 WO 2004-086710 A1	18/10/2004 11/10/2006 04/08/2010 04/01/2006 26/02/2008 07/10/2004
US 2006-0233288 A1	19/10/2006	CN 100566316 C CN 1823512 A EP 1647120 A1 JP 2007-519290 A KR 10-2006-0036086 A US 7826567 B2 WO 2005-006697 A1	02/12/2009 23/08/2006 19/04/2006 12/07/2007 27/04/2006 02/11/2010 20/01/2005