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(54) Title: MAPPING SIGNALS FROM A VIRTUAL FREQUENCY BAND TO PHYSICAL FREQUENCY BANDS

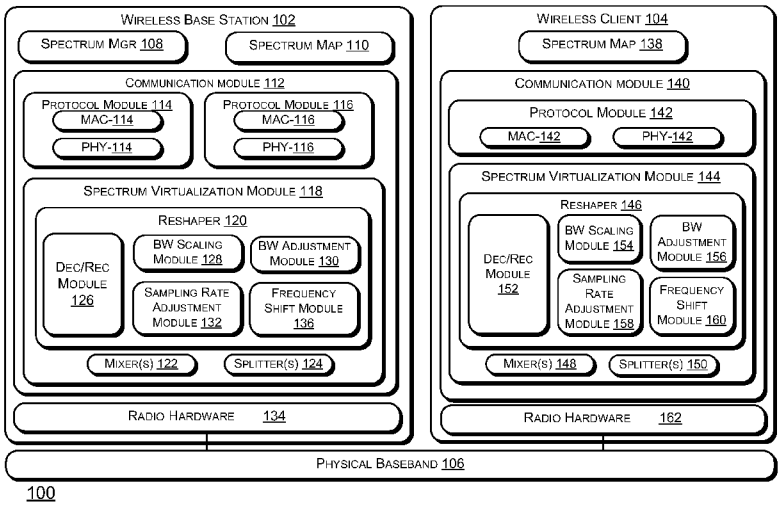

FIG. 1

(57) Abstract: Embodiments include processes, systems, and devices for reshaping virtual baseband signals for transmission on non-contiguous and variable portions of a physical baseband, such as a white space frequency band. In the transmission path, a spectrum virtualization layer maps a plurality of frequency components derived from a transmission symbol produced by a physical layer protocol to sub-carriers of the allocated physical frequency band. The spectrum virtualization layer then outputs a time-domain signal derived from the mapped frequency components. In the receive path, a time-domain signal received on the physical baseband is reshaped by the virtual spectrum layer in order to recompose a time-domain symbol in the virtual baseband.

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MAPPING SIGNALS FROM A VIRTUAL FREQUENCY BAND TO PHYSICAL FREQUENCY BANDS

BACKGROUND

[0001] White space frequency bands are frequency bands allocated to television (TV) broadcasting service and to wireless microphone service, but not used in a local geographic area. Recent Federal Communication Commission (FCC) rules allow unlicensed access to white space frequency bands in the United States as long as such access does not interfere with TV and wireless microphone transmission (i.e., "incumbent" or "primary user" access to the frequency bands). Non-U.S. jurisdictions may also in the future implement similar provisions for access to television frequency bands. Available white space frequency bands may have variable bandwidths, and they may be non-contiguous and location-specific. These aspects make white space transmission networks different from conventional wireless transmission networks.

[0002] Conventional media access control and physical layer protocols may not support variable and non-contiguous frequency transmission as is typically needed in order to transmit over white space frequency bands. Conventional approaches to adapting a signal to an available spectrum include SampleWidth, SWIFT, and Jello. SampleWidth changes the bandwidth of a signal by adjusting the ticking rate of the baseband clock, which is equivalent to changing the signal's sampling rate. SWIFT and Jello split an orthogonal frequency-divisional signal into non-contiguous spectrum bands.

BRIEF SUMMARY

[0003] This Summary is provided in order to introduce simplified concepts of signal mapping and reshaping, which are further described below in the Detailed Description. This summary is not intended to identify essential features of the claimed subject matter, nor is it intended for use in determining the scope of the claimed subject matter.

[0004] In embodiments, a wireless device includes a spectrum virtualization layer that reshapes transmission symbols generated for transmission in a virtual baseband into time-domain signals for transmission on one or more non-contiguous and/or variable allocated portions of a physical baseband, such as a white space frequency band. The reshaping process includes a fast Fourier transform of the signal to produce a plurality of frequency components of the transmission symbol, a mapping of the frequency components to sub-carriers of the allocated portions of a physical baseband, and an inverse fast Fourier transform of the mapped frequency components to produce a time-domain signal in the

physical frequency band. The spectrum virtualization layer also performs bandwidth adjustment, sampling rate adjustment, and frequency shift operations to allow the reshaped transmission signals to be transmitted by a radio front-end on the physical baseband.

[0005] On the receiver side, signals are received by a radio front-end on the physical baseband. A spectrum virtualization layer performs frequency shift, bandwidth adjustment, and sampling rate operations on the received signal. Then, the spectrum virtualization layer reshapes the received signal to produce the symbol in the virtual baseband produced by the PHY layer on the transmitter side. The reshaping includes a fast Fourier transform of the receive signal to produce a plurality of frequency components, a mapping of the frequency components to sub-carriers of the virtual baseband, and an inverse fast Fourier transform of the mapped frequency components to produce the virtual baseband PHY layer symbol in the time domain. Spectrum virtualization layers and the reshapers according to embodiments allow conventional (or non-conventional) physical layer protocols (such as Carrier Division Multiple Access (CDMA) and others) to utilize white space networking without modification to the conventional physical layer protocols. This may speed adoption of white space networking.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The Detailed Description is set forth with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different figures indicates similar or identical items.

[0007] FIG. 1 is a schematic diagram of an example environment usable to reshape and transmit signals from a virtual baseband to a physical frequency band.

[0008] FIG. 2 is a block diagram of an example wireless device having a spectrum virtualization module with a reshaper.

[0009] FIG. 3A illustrates the reshaping of PHY layer time-domain transmission symbols in the virtual baseband into time-domain symbols in the physical baseband.

[0010] FIG. 3B illustrates the reshaping of PHY layer time-domain reception symbols in the physical baseband into time-domain symbols in the virtual baseband.

[0011] FIG. 4 illustrates transmission and reception paths within a spectrum virtualization layer in accordance with embodiments.

[0012] FIG. 5 is a flow diagram showing an example process of reshaping during transmission.

[0013] FIG. 6 is a flow diagram showing an example process of reshaping during reception.

DETAILED DESCRIPTION

Overview

[0014] As discussed above, white space frequency bands may have variable bandwidths, and they may be non-contiguous and location-specific. A wireless device according to embodiments of the present disclosure utilizes conventional media access control (MAC) and physical layer (PHY) protocols (such as in Wi-Fi®, protocols within the 802.11 suite of protocols, code division multiple access (CDMA) based protocols, carrier sense multiple access (CSMA) based protocols, time division multiple access (TDMA) based protocols, others, and combinations thereof) to communicate over white space frequency bands. The ability to use conventional MAC and PHY protocols may speed the adoption of white space frequency networking, especially if those conventional protocols do not need to be changed by a lengthy standards-setting process. But conventional MAC and PHY protocols may not support variable or non-contiguous frequency transmissions as is required in white space networking, and conventional MAC and PHY protocols may set forth requirements for transmissions on specific frequency bands that differ from the white space frequency bands that happen to be available in a particular geographic area. Embodiments of the present disclosure include devices and methods for enabling conventional MAC and PHY layer protocols to utilize non-contiguous and variable frequency bands.

[0015] Embodiments of the present disclosure include a signal reshaper within a spectrum virtualization layer. Conceptually, the spectrum virtualization layer sits beneath the PHY layer (referring to, for example, the Physical (PHY) layer of the seven-layer Open Standards Interface (OSI) model). The spectrum virtualization layer is configured to, among other things, reshape baseband signals that have been generated in accordance with conventional or non-conventional MAC and PHY protocols (i.e., signals that are in a fixed and contiguous baseband or frequency band specified by those protocols") into signals for radio transmission on the variable and/or non-contiguous available physical frequency bands (i.e., signals that are in one or more white space frequency bands). Frequency bands specified by conventional or non-conventional MAC and PHY protocols are hereinafter referred to as a "virtual baseband" or a "virtual frequency band. Reshaping performed by the spectrum virtualization layer is transparent to the MAC and PHY protocols. Transparent reshaping allows signals generated by the MAC and PHY

protocols to be transmitted on variable frequency bands without altering the MAC and PHY protocols, thereby potentially speeding adoption of white space networking. Distortion introduced by the reshaping process is handled by existing mechanisms in the MAC and PHY protocols.

[0016] A spectrum virtualization module according to embodiments includes a reshaper module. The reshaper module performs signal decomposition/recomposition, bandwidth adjustment, sample rate adjustment, and frequency shifting on transmitted and received signals in order to utilize the available white space frequency bands. Decomposition of a transmitted signal includes transforming a transmission symbol generated by a PHY protocol to generate frequency components of the transmission symbol, mapping the transmission symbol's frequency components to subcarriers within the allocated physical frequency bands (such as white space frequency bands), and inverse transforming the mapped frequency components into a time-domain transmission signal for transmission. The transmission signal is passed to a radio front-end for transmission.

[0017] Recomposition of a received signal includes transforming a received signal to produce frequency components of the received signal, mapping the frequency components to sub-carriers of the virtual baseband, and inverse transforming the mapped components into a time-domain symbol in the virtual baseband. The recomposed signal is passed to the upper layer PHY and MAC protocols for further processing according to those protocols.

[0018] The spectrum virtualization layer employs bandwidth adjustment if the virtual baseband bandwidth does not equal the aggregate bandwidth of the allocated white space frequency bands. In such cases, the spectrum virtualization layer uses a scaling factor to artificially increase the size of the physical frequency bands so that their aggregate bandwidth is equal to the bandwidth of the virtual baseband. This aspect of bandwidth adjustment is performed in conjunction with the decomposition/recomposition process, and the mapping process maps the frequency components to sub-carriers of the artificially scaled physical frequency bands. Then, after a time-domain signal is produced by the decomposition/recomposition process, the signal bandwidth is reduced by the same factor that was used to artificially increase the size of the physical frequency bands. This reduction includes interpolation, low-pass filtering, and decimation. At the receiver side, the spectrum virtualization layer performs reverse bandwidth scaling and adjustment operations.

[0019] Sampling rate adjustment by the spectrum virtualization layer adjusts the sampling rate of the transmit signal to match the sampling rate of the radio front-end used by a wireless device. Similar to the process of bandwidth adjustment, the spectrum virtualization layer uses interpolation and decimation to adjust the sampling rate. At the receiver side, the spectrum virtualization layer performs reverse operations to adjust the sampling rate of the received signal to match the sampling rate of the virtual baseband.

[0020] Frequency shifting compensates for an artificial frequency shift that occurs during the mapping portion of the decomposition/recomposition process. During frequency shifting, the spectrum virtualization layer shifts the signal frequencies to match the allocated white space frequency ranges so that the transmission signals can be transmitted on the physical baseband. At the receiver side, the spectrum virtualization layer artificially shifts the signal frequencies back before the received signals are recomposed by the reshaper.

[0021] Although various embodiments may be described herein as being related to "white space" transmissions, "white space" networks, "white space" base stations, and "white space" clients, embodiments of the present disclosure are not limited to white space environments. Rather, embodiments include transmissions, networks, base stations, environments, and clients that are usable and/or compatible with any of various Dynamic Spectrum Access (DSA) networks, which include White Space networks. Embodiments refer to "white space" networking for the sake of discussion, and such references should not be taken in a limiting way.

[0022] The processes, systems, and devices described herein may be implemented in a number of ways. Example implementations are provided below with reference to the following figures.

Example Environment for Frequency Allocation

[0023] FIG. 1 is a schematic diagram of an example environment usable to reshape signals from a virtual baseband to a physical frequency band. The environment 100 may include a wireless base station 102 and a wireless client 104. The wireless base station 102 may be implemented on various suitable computing device types that are capable of implementing a wireless base station. Suitable computing device or devices may include, or be part of, one or more personal computers, servers, server farms, datacenters, special purpose computers, combinations of these, or any other computing device(s) capable of storing and executing all or part of a wireless base station.

[0024] In addition, the wireless client 104 may also be implemented on various suitable computing device types that are capable of implementing a wireless client. Suitable computing device or devices may include, or be part of, one or more personal computers, servers, server farms, datacenters, special purpose computers, combinations of these, or any other computing device(s) capable of storing and executing all or part of a wireless client.

[0025] The physical baseband 106 is a wireless frequency range or ranges that the wireless client 104 and the wireless base station 102 may use to communicate with one another. These frequency ranges may include, for example, white space frequency ranges. The wireless base station 102 and the wireless client 104 may be coupled to each other through the physical baseband 106 using various communication connections and protocols.

[0026] In the illustrative example of FIG. 1, the wireless base station 102 includes a spectrum manager 108. The spectrum manager 108 determines an allocation of white space or other physical frequency ranges of the physical baseband 106 that are available for use in a local geographic area of the wireless base station 102 and the wireless client 104. The spectrum manager 108 may be configured, for example, to communicate with a white space finder service (not shown) and to receive from the white space finder service an allocation of physical frequency ranges of the physical baseband 106 for use in the local geographic area. The spectrum manager 108 contains one or more policies such as regulatory policies or transmission requirements, and the spectrum manager 108 may select from the allocated physical frequency ranges based on these policies. Non-limiting examples of regulatory policies include guard bands requirements, power mask requirements, times that white space frequency bands are available, acceptable transmission power level ranges, and so forth. In another example, the spectrum manager 108 may be configured to determine locally available white space frequencies and to select one or more for transmission according to various policies. See PCT Application PCT/CN2011/073647, filed on May 4, 2011, for examples of a spectrum manger and a white space finder service. The spectrum manager 108 builds and maintains a spectrum map 110, based on the availability of physical frequency bands in the local geographic area. The spectrum map 110 includes a mapping of virtual frequency bands to physical frequency bands.

[0027] The wireless base station 102 includes a communication module 112. The communication module 112 includes various protocol modules, such as the protocol

modules 114 and 116. The protocol modules 114 and 116 implement the media access control protocols MAC-114 and MAC-116 and the physical layer protocols PHY-114 and PHY-116. The MAC-114 may be different from or the same as the MAC-116, and the PHY-114 may be different from or the same as the PHY-116. The protocol modules 114 and 116 may implement conventional wireless protocols such as in Wi-Fi®, protocols within the 802.11 suite of protocols, code division multiple access (CDMA) based protocols, carrier sense multiple access (CSMA) based protocols, time division multiple access (TDMA) based protocols, others, and combinations thereof. Such conventional wireless protocols may be designed to transmit and receive on specific frequency ranges set forth by those protocols. These specific frequency ranges are referred to herein as virtual frequency ranges, or virtual basebands. Wireless devices according to embodiments may include more or fewer protocol modules than does the wireless base station 102.

[0028] The communication module 112 includes a spectrum virtualization module 118. The spectrum virtualization module 118 includes a reshaper 120, mixer(s) 122, and splitter(s) 124. The reshaper 120 includes a decomposition/recomposition module 126 configured to, among other things, map received and transmitted time-domain symbols between the virtual baseband and physical baseband 106 according to spectrum map 110. The decomposition/recomposition module 126 is configured to produce frequency components of the time-domain transmission symbol produced by the protocol modules 114 and 116. The decomposition/recomposition module 126 is configured to accept a transmission symbol from one of the protocol module 114 or the protocol module 116. Such a transmission symbol is produced by the upper layer protocols for transmission on the virtual baseband according to the upper layer protocols. The decomposition/recomposition module 126 is configured to perform an *M*-point fast Fourier transform (FFT) on the transmission symbol, map or reassign the resulting frequency components to sub-carriers of the allocated physical frequency bands of the physical baseband 106, and perform an *N*-point inverse fast Fourier transform (iFFT) on the mapped frequency components to produce a time-domain signal for transmission. These processes decompose the time-domain symbols into *M* frequency-domain components, map the *M* frequency-domain components to sub-carriers of the allocated portions of the physical baseband 106, and produce *N* time-domain samples of the mapped *M* components to produce a time-domain signal for transmission.

[0029] Upon receipt of a signal (such as from the wireless client 104 over the physical baseband 106), the decomposition/recomposition module 126 is configured to perform an *N*-point FFT on the received time-domain signal to produce *N* frequency components, to map *M* of the *N* resulting frequency components that correspond to the allocated physical frequency bands of the physical baseband 106 to sub-carriers of the virtual baseband, and to perform an *M*-point iFFT on the *M* mapped components to produce a time-domain symbol in the virtual baseband. These processes recompose the symbol originally produced by the protocol module (such as in wireless client 104). The decomposition/recomposition module 126 is configured to pass the resulting time-domain symbol to the appropriate PHY layer, such as those in the protocol modules 114 and 116. More details on the operation of the components of the decomposition/recomposition module 126 are described elsewhere within this Detailed Description.

[0030] The bandwidth scaling module 128 is configured to determine whether the bandwidth of the virtual baseband differs from the aggregate bandwidth of the allocated physical frequency bands of the physical baseband 106. If a difference in the bandwidths is determined, then the bandwidth scaling module 128 artificially scales the allocated physical frequency bands such that their aggregate bandwidth equals the bandwidth of the virtual baseband. In these situations, the decomposition/recomposition module 126 maps the *M* frequency components to sub-carriers of the scaled allocated physical frequency bands. If the ratio of the aggregate bandwidth of the one or more allocated portions of the physical baseband is 1:1, then no scaling is necessary, and the decomposition/recomposition module 126 maps the *M* frequency components to sub-carriers of the un-scaled frequency bands. Upon receipt of a receive signal, the bandwidth scaling module 128 performs reverse scaling operations upon a determination that the aggregate bandwidth of the allocated physical frequency bands is not equal to the bandwidth of the virtual baseband. More details regarding the operations of the bandwidth scaling module 128 are described elsewhere within this Detailed Description.

[0031] Because the scaled allocated portions of the physical baseband 106 do not match the actual allocated portions of the physical baseband 106, the bandwidth adjustment module 130 is configured to compensate for the bandwidth adjustment performed by the bandwidth scaling module 128 by adjusting the bandwidth of the transmission signal produced by the decomposition/recomposition module 126 to match the actual physical frequency ranges of the physical baseband 106. Thus, the bandwidth adjustment module 130 does not perform bandwidth adjustment unless the aggregate

bandwidth of the allocated physical frequency bands of the physical baseband 106 is not equal to the bandwidth of the virtual baseband.

[0032] As will be described in more detail elsewhere within this Detailed Description, the bandwidth adjustment module 130 utilizes interpolation, low-pass filtering, and decimation to perform bandwidth adjustment. Upon receiving a signal, the bandwidth adjustment module 130 performs reverse operations to reconstruct the transmission signal produced by the decomposition/recomposition module of the transmitter (such as the wireless client 104, which is described in more detail below).

[0033] The sampling rate adjustment module 132 is configured to adjust the sampling rate of the transmission signal produced by the reshaper 120 to match the sampling rate of the radio hardware 134. As will be described in more detail elsewhere within this Detailed Description, the sampling rate adjustment module 132 utilizes interpolation and decimation to re-sample the bandwidth-adjusted time-domain transmission signal. Upon receipt of a signal, the sampling rate adjustment module 132 performs reverse operations to adjust the sampling rate of the received signal to match the sampling rate of the virtual baseband.

[0034] The frequency shift module 136 is configured to compensate for a frequency shift that occurs during the mapping operation in the decomposition/recomposition module 126. As will be described in more detail elsewhere within this Detailed Description, the frequency shift module 136 shifts the frequency of the transmission signal by an amount equal to the center frequency of the span of allocated physical bands. Upon receipt of a receive signal from another wireless device, the frequency shift module 136 shifts the frequencies of the receive signal by amount equal to the central frequency spectrum of the span. More details on the operations of the frequency shift module 136 are included elsewhere within this Detailed Description.

[0035] The communication module 112 may include multiple reshapers. These reshapers may be configured to accept transmission signals from various ones of the protocol modules 114 and 116, and to map them to physical frequency ranges allocated to those protocol modules according to the spectrum map 110. Where multiple reshapers are utilized, the mixer(s) 122 mix the various reshaped signals from those multiple reshapers prior to passing them to the radio hardware 134. Also, the splitter(s) 124 split and pass multiple reception signals from the incoming signal stream to the appropriate reshapers for signal recomposition during signal reception.

[0036] The wireless client 104 includes a spectrum map 138, which mirrors at least a portion of the spectrum map 110 in the wireless base station 102. The wireless base station 102 may communicate with multiple wireless clients on various portions of the physical baseband 106, and spectrum map 138 may only define mapping for those physical frequency bands allocated for transmission to and from the wireless client 104.

[0037] The wireless client 104 includes a communication module 140, which includes a protocol module 142. The protocol module 142 includes MAC-142 and PHY-142 protocols. The protocol module 142 may include a conventional or non-conventional protocol stack, configured to transmit on a virtual baseband. The spectrum virtualization module 144 includes a reshaper 146, mixer(s) 148, and splitter(s) 150. The reshaper 146 includes a decomposition/recomposition module 152, a bandwidth scaling module 154, a bandwidth adjustment module 156, a sampling rate adjustment module 158, and a frequency shift module 160. These aspects of the spectrum virtualization module 144 are the same or similar to various aspects of the spectrum virtualization module 118 of the wireless base station 102. The radio hardware 162 is operatively coupled to the mixer(s) 148 and the splitter(s) 150, and is configured to transmit and receive signals via the physical baseband 106.

[0038] The spectrum virtualization modules 118 and 144 operate together to allow conventional wireless protocols to communicate over allocated physical bands within the physical baseband 106 without modification to the conventional wireless protocols. The transparent reshaping of wireless signals may spur adoption of white space frequency transmission by enabling conventional (or non-conventional) protocols to utilize white space networking without the need to make changes to those conventional (or non-conventional) protocols, or the need to adopt new wireless protocols that are capable of utilizing non-contiguous and variable frequency bands.

Example Wireless Device

[0039] FIG. 2 is a block diagram of an example wireless device including a spectrum virtualization module having a reshaper. The wireless device 200 may be configured as any suitable computing device capable of implementing a wireless device. According to various non-limiting examples, suitable computing devices may include personal computers (PCs), servers, server farms, datacenters, special purpose computers, combinations of these, or any other computing device(s) capable of storing and executing all or part of a wireless device service.

[0040] In one example configuration, the wireless device 200 comprises one or more processors 202 and a memory 204. The wireless device 200 may also contain communication connection(s) 206 that allow communications with various devices such as, for example, a white space finder service. The wireless device 200 may also include one or more input devices 208, such as a keyboard, mouse, pen, voice input device, touch input device, etc., and one or more output devices 210, such as a display, speakers, printer, etc. coupled communicatively to the processor(s) 202 and memory 204.

[0041] The wireless device 200 includes radio hardware 212. The radio hardware 212 may be implemented as a white-space radio front-end board, or other radio hardware. The radio hardware 212 includes one or more radio transceivers 214, which include radio frequency (RF) front-ends 216 and antenna(e) 218. The radio hardware 212 may be communicatively coupled to the processor(s) 202 and to the memory 204.

[0042] The memory 204 may store program instructions, such as software instructions, that are loadable and executable on the processor(s) 202, as well as data generated during execution of, and/or usable in conjunction with, these programs. In the illustrated example, the memory 204 stores an operating system 220, a communication module 222, and a spectrum manager 224. The operating system 220 provides basic system functionality of the wireless device 200 and, among other things, provides for operation of the other programs and modules of the wireless device 200.

[0043] The communication module 222 includes a spectrum virtualization module 226 configured to interface with the radio hardware 212 to transmit radio signals to one or more other wireless devices over a physical baseband. The spectrum virtualization module 226 may be the same as one or more of the spectrum virtualization module 118 and the spectrum virtualization module 144 of Fig. 1. The spectrum virtualization module 226 is configured to interface with the wireless transmission protocol module 228. The protocol module 228 may be the same as one or more of protocol modules 114, 116, and 142 of FIG. 1. The spectrum virtualization module 226 is configured to present a virtual baseband to protocol module 228, to reshape outgoing virtual baseband signals to physical baseband signals for transmission on the radio hardware 212, and to reshape incoming physical baseband signals. This allows conventional (or non-conventional) PHY protocols to be used for white space transmission without modification.

[0044] The spectrum virtualization module 226 includes a reshaper module 230, which may be the same as one or more of the reshaper 120 and the reshaper 146 of FIG. 1. . The spectrum virtualization module 226 also includes mixer(s) 232 and splitter(s) 234.

[0045] The spectrum manager 224 may be configured to request and receive information regarding available white space physical transmission frequency bands. The spectrum manager 224 may be the same as the spectrum manager 108 in FIG. 1.

[0046] FIG. 3A illustrates the reshaping of PHY layer time-domain transmission symbols in the virtual baseband (i.e., virtual transmission band) into time-domain symbols in the physical baseband. The transmission path Tx begins with the PHY layer generating time-domain symbols 300 in the virtual baseband which are then received by a spectrum virtualization layer. In a reshaper of the spectrum virtualization layer, an M-point FFT 302 is performed on individual ones of the time-domain symbols 300 to produce M frequency components 304 of the time-domain symbols 300. The value M determines the resolution of frequency decomposition. If the PHY layer is a multi-carrier modulated PHY with C sub-carriers in the virtual baseband, then M is set to be equal to or greater than C. If M were less than C, then reshaping operations would potentially introduce inter-carrier interference. If M were very large, on the other hand, then the FFT and iFFT operations of the reshaper would create unnecessary overhead as the computation complex of the FFT operation increases. Therefore, in embodiments, M may be selected according to the following formula:

$$M = \max(C, M_{min})$$

[0047] M_{min} specifies a minimal resolution. For example, M_{min} equals 64 in various embodiments.

[0048] A mapping module 306 maps the M frequency components 304 to sub-carriers of scaled or unscaled allocated portions of the physical frequency band 308 (the allocated portions are shown shaded in FIG. 3A). An N-point iFFT 310 is performed on the M mapped frequency components to produce a time-domain signal 312 of mixed sub-streams for transmission in the physical frequency band. N is chosen such that the resulting number of N sub-carriers is large enough to cover all of the physical frequency bands. If b_v is the width of the virtual baseband, b_s is the aggregated bandwidth of the allocated portions of the physical frequency band 308, and b_{span} is the width of the span of the physical frequency band 308, then where $b_s = b_v$, N satisfies the equation:

$$N \geq M \frac{b_{span}}{b_v}$$

[0049] In various embodiments, N is chosen to be the smallest power of 2 that satisfies this equation. Selecting N this way eases computation.

[0050] In order to map the N sub-carriers to allocated portions of the physical frequency band 308, each allocated portion will be shifted by $-f_{span}$, where f_{span} is the central frequency of the span B_{span} of the physical frequency band 308. Thus, each physical band $B_{p,i}(f_i, b_i) \in \ominus$, is shifted by $(-f_{span})$ to be $\hat{B}_{p,i}(f_i - f_{span}, b_i)$. A sub-carrier is available if it is covered by any $\hat{B}_{p,i}$. An available sub-carrier can be mapped to a frequency component of a baseband signal. There are at least M available sub-carriers in the allocated portions of the physical frequency band 308.

[0051] In various embodiments, the number of samples K in a PHY symbol may be different from M. For a single-carrier PHY, K is usually smaller than M. In a multi-carrier PHY, K is usually greater than M due to the use of a cyclic-prefix in the PHY layer. Performing a decomposition of the time-domain symbol, including the M-point FFT and an N-point iFFT, enlarges the signal bandwidth by a factor of $\beta = \frac{N}{M}$. At the same time, the decomposition converts K samples of a symbol to βK samples.

[0052] If K is less than or equal to M, then the reshaper pads zeros to the K sample before performing M-point FFT. According to digital signal processing theory, zero padding in the time-domain does not change the frequency response of a signal. After the mapping and N-point iFFT operations, the first βK samples are output and the reshaper truncates the remaining samples. The remaining samples are truncated because they are not significant.

[0053] If K is greater than M, then the reshaper performs M-point FFT for every M samples. The number of remaining samples is $L = K - M$. An additional M-point FFT (not shown) is performed on the $(K - M)$th sample to the Kth sample. This artificial shift in the FFT window by $(M - L)$ samples causes a phase rotation in the frequency domain. The reshaper compensates for this prior to performing the N-point iFFT 310. Compensation is performed by rotations of the phase of values on corresponding sub-carriers. For example, if a frequency component i has been assigned to sub-carrier j, the sample at sub-carrier j is multiplied by a factor of $e^{j2\pi\frac{M-L}{M}(j-i)}$. After performing the N-point iFFT 310, the last group of samples will overlap with its previous group by $\beta(M - L)$ samples. An average for the $\beta(M - L)$ samples is taken as output.

[0054] FIG. 3B illustrates the reshaping of PHY layer time-domain reception symbols in the physical baseband into time-domain symbols in the virtual baseband (i.e., virtual reception band). The reception path Rx begins with the spectrum virtualization layer receiving time-domain signal 312 of the receive signal in a mixed sub-stream. An N-point

FFT 314 is performed on the time-domain signal 312 to produce N frequency components 316 of the receive signal. A mapping module 318 maps M of the N frequency components from sub-carriers in allocated portions of the physical frequency band 308 to sub-carriers in the virtual spectrum band 320. Thus, some of the N frequency components (such as the shaded frequency component in FIG. 3B) may not be mapped to the virtual spectrum band 320; these unmapped frequency components correspond to signals from the unallocated portions of the physical frequency band 308. An M-point iFFT 322 is performed on the M mapped frequency components in the virtual baseband to recompose time-domain symbols 300 in the virtual baseband, which are then passed by the spectrum virtualization layer to the PHY layer protocol.

[0055] In the case where the number of samples K in the virtual baseband time-domain symbol is greater than M, the reshaper will reduce the signal bandwidth by β. Accordingly, in the receive path Rx the reshaper takes K samples from the physical bands and regenerates $\frac{K}{\beta}$ virtual baseband samples.

[0056] As noted elsewhere within this Detailed Description, the reshaper scales the physical frequency bands whenever b_s (the aggregated bandwidth of the physical frequency bands) is less than b_v (the virtual bandwidth). The transmitting reshaper scales the physical frequency bandwidths by a factor of $\alpha = b_v/b_s$. Thus, the aggregated bandwidth of the scaled physical frequency bands $\widehat{b_s}$ is equal to b_v. Whenever scaling is performed, the decomposition/recomposition operations described above are performed using these scaled bandwidths. As is described elsewhere within this Detailed Description, bandwidth adjustment will compensate for this scaling prior to transmission.

[0057] FIG. 4 illustrates transmission and reception paths within a spectrum virtualization layer in accordance with embodiments. In the transmission path Tx, the PHY layer 400 passes transmission symbols to a decomposition/recomposition module 402. An M-point FFT 404 is performed on the transmission symbols to generate M frequency components. A sub-carrier mapping 406 is performed to map the M frequency components to sub-carriers of scaled or unscaled allocated portions of the physical frequency band. In certain instances, such as where b_s (the aggregated bandwidth of the physical frequency bands) is less than b_v (the virtual bandwidth), a bandwidth scaling 408 scales the allocated portions of the physical frequency band by a factor of $\alpha = b_v/b_s$. Once the frequency components have been mapped, an N-point iFFT 410 is performed on the

mapped frequency components to produce time domain transmission signals in the (scaled or unscaled) physical frequency bands.

[0058] A bandwidth adjustment module 412 receives the transmission signals from the decomposition/recomposition module 402 and performs a bandwidth adjustment 414 to compensate for bandwidth scaling performed by the bandwidth scaling 408. Where the bandwidth scaling 408 scales the physical frequency bands by a factor α, the bandwidth adjustment 414 reduces the bandwidth of the signal by α. To reduce the bandwidth of the signal, zero pad samples are added to the signal. In particular, α times more samples are added to the signal to reduce the bandwidth by α. This is achieved by interpolation and decimation. In particular, where $\alpha = k/l$, and where k and l are integers, the following steps are taken:

[0059] 1. Zero padding is performed. For each sample, $k - 1$ zeros are padded.

[0060] 2. Low-pass filtering is performed. A low-pass filter is applied to the zero-padded samples to remove the high-frequency signal image.

[0061] 3. Decimation is performed. Every lth sample is picked up to obtain the final signal.

[0062] A sampling rate adjustment module 416 receives the bandwidth-adjusted transmission signals and performs a sampling rate adjustment 418 to adjust the sampling rate of the bandwidth-adjusted time-domain transmission symbols to match the sampling rate of the RF front-end 420. The sampling rate adjustment 418 re-samples the transmission symbol using the real sampling rate of the RF front-end 420. The sampling rate adjustment 418 includes interpolation and decimation. For example, where f_s is the sampling rate after the bandwidth adjustment 414, f_r is the real sampling rate of the RF front-end 420, and f_{LCM} is the least common multiple of both f_s *and* f_r, interpolation is accomplished by padding the signal by $m = (f_{LCM} / f_s - 1)$ zero samples, and by passing the signal through a low-pass filter to remove imaging. Then, the padded signal is decimated by $n = f_{LCM} / f_r$ to get the final signal with a desired sampling rate of f_r. Because the bandwidth adjustment 414 and the sampling rate adjustment 418 utilize the same digital signal processing operations of interpolation and decimation, they are combined in embodiments to save computation.

[0063] The frequency shift module 422 receives the sampling rate-adjusted, bandwidth-adjusted time-domain transmission signals and performs a frequency shift 424 to compensate for the frequency shift caused by sub-carrier mapping 406. The signal generated by the N-point iFFT 410 is centered at zero. Thus, the sub-carrier mapping 406

shifts the physical bands artificially by $-f_{\text{span}}$, where f_{span} is the central frequency of the span B_{span} of the allocated physical bands. The frequency shift 424 compensates for this in order to allow the signals to be transmitted on the actual allocated portions of the physical baseband. The frequency shifting includes multiplying a digital sample $\{ x_i \}$ by a factor of $e^{j2\pi f_h i}$., where j is the imaginary unit, $f_h$is the amount of frequency (in Hz) to be shifted, and i is the index of samples.

[0064] The sampling rate-adjusted, bandwidth-adjusted, frequency-shifted time-domain transmission signals are mixed by the mixer 426 with other transmission signals from other reshapers (not shown) of the spectrum virtualization layer, as needed (e.g., where other reshapers are utilized to reshape transmission symbols from other PHY layers besides the PHY layer 400). The RF front-end 420 receives the mixed transmission signals and transmits them on the physical baseband via the antenna 428.

[0065] In the receive path Rx, a receive signal is picked up by the antenna 430 (which may be the same antenna as the antenna 428) on the physical baseband and is passed to the RF front-end 432 (which may be the same RF front-end as the RF front-end 420). The receive signal is passed to the splitter 434 which splits multiple receive signals and passes them to various reshapers. One of the split signals is passed to the frequency shift module 422 which performs a frequency shift 436. The frequency shift 436 is the reverse of the shift operation that occurs in frequency shift 424. The signal is shifted by $-f_{\text{span}}$.

[0066] The sampling rate adjustment module 416 receives the frequency-shifted signal and performs a sampling rate adjustment 438 to adjust the sampling rate of the signal to be equal to the sampling rate of the virtual baseband. The inverse of the operations performed by the sampling rate adjustment 418 are performed here. The sampling-rate adjusted signal is passed to the bandwidth adjustment module 412, which performs a bandwidth adjustment 440 to adjust the bandwidth in order to compensate for the fact that the bandwidth scaling 408 will artificially scale the physical frequency bands during the recomposition process. The inverse of the operations performed by the sampling rate adjustment 414 are performed here. The bandwidth adjustment 440 occurs only where b_s (the aggregated bandwidth of the physical frequency bands) is less than b_v (the virtual bandwidth).

[0067] The decomposition/recomposition module 402 receives the frequency-shifted, sampling rate-adjusted, bandwidth-adjusted signal and performs N-point FFT 442 to produce N frequency domain components. A subcarrier mapping 444 maps M of the N

frequency components that correspond to (scaled or unscaled) allocated portions of the physical baseband to subcarriers of the virtual baseband. The mapped M frequency components are passed to an M-point iFFT 446 to produce time-domain symbols in the virtual baseband. The virtual baseband time-domain symbols are then passed to the PHY 448, which may be the same as the PHY layer 400.

Example Reshaping Process during Transmission

[0068] FIG. 5 is a flow diagram showing an example process 500 of reshaping during transmission. A PHY layer generates a transmission symbol in a virtual baseband, block 502. In embodiments, such as where the PHY layer is part of a conventional wireless protocol, the virtual frequency band may be contiguous and non-variable.

[0069] A spectrum virtualization layer receives the transmission symbol and performs a transformation of the symbol to derive a plurality of frequency components, block 504. The transformation may be an M-point FFT that produces M frequency components. M is the resolution of the FFT process, and is the greater of either a predetermined value – such as 64 – or the number of sub-carriers of the virtual frequency band.

[0070] Where b_s (the aggregated bandwidth of the physical frequency bands) is less than b_v (the virtual bandwidth), block 506, the spectrum virtualization layer artificially scales the bandwidth of the allocated physical frequency bands, block 508. The spectrum virtualization layer scales the one or more allocated physical frequency bands by a factor α determined at least in part by a ratio of an aggregate bandwidth of the one or more allocated physical frequency bands and a virtual bandwidth of the virtual frequency band.

[0071] The spectrum virtualization layer maps the frequency components of the transmission symbol to sub-carriers of the scaled or un-scaled ones of the one or more allocated physical frequency bands, block 510. The mapping process includes a frequency shift of the one or more allocated physical frequency bands by an amount equal to $-f_{span}$, where f_{span} is the central frequency of the span B_{span} of the allocated physical bands.

[0072] The spectrum virtualization layer performs an inverse transformation on the plurality of frequency components to generate a time-domain signal for transmission, block 512. In embodiments, the spectrum virtualization layer performs an N-point iFFT on the mapped M frequency components. As noted elsewhere within this Detailed Description, N is at least as large as M multiplied by a ratio that is a function of the virtual bandwidth and the associated aggregate physical bandwidth.

[0073] If the physical frequency bands have been scaled by a factor α to account for the fact that b_s (the aggregated bandwidth of the physical frequency bands) is less than b_v

(the virtual bandwidth), block 514, then the spectrum virtualization layer adjusts the bandwidth of the time-domain signal by the same factor α, block 516. This adjustment includes the digital signal processing steps of interpolation (zero padding of the signal samples), low-pass filtering, and decimation.

[0074] The spectrum virtualization layer adjusts the sampling rate of the transmission signal to match the sampling rate of the radio front-end, block 518. The sampling rate adjustment includes interpolation and decimation. Because bandwidth adjustment and sampling rate adjustment use similar digital signal processing operations, embodiments may combine the two processes to decrease computational overhead.

[0075] The spectrum virtualization layer shifts the frequencies of the sampling rate-adjusted signal to compensate for a frequency shift that occurs during the mapping process, block 520. Shifting the frequency includes multiplying digital samples of the signal $\{ x_i \}$ by a factor of $e^{j2\pi f_h i}$.

[0076] The radio front-end transmits the transmission signal on the physical baseband, block 522. Thus, a PHY layer transmission symbol, generated on a contiguous, fixed virtual baseband is transmitted on non-contiguous and variable allocated portions of the physical baseband.

Example Reshaping Process during Reception

[0077] FIG. 6 is a flow diagram showing an example process 600 of reshaping during reception. A radio front-end receives a signal on a physical baseband, block 602. The physical baseband may include one or more non-contiguous portions allocated for transmission by one or more wireless devices. The wireless devices may employ a conventional PHY layer protocol that expects to receive symbols in a fixed, contiguous virtual frequency band that differs from the physical baseband. The wireless device may also employ a spectrum virtualization layer to map the incoming signals from the physical spectrum band to the virtual frequency band.

[0078] A frequency shift module of the spectrum virtualization layer shifts the frequency of the allocated physical frequency band, block 604. This frequency shift compensates for a frequency shift that occurs during a remapping operation later in the reception path. The frequency is shifted by the frequency shift module by an amount equal to a negative of a central frequency of a span of the one or more allocated physical frequency bands.

[0079] A sampling rate adjustment module adjusts the sampling rate of the received signal to match the sampling rate of the virtual baseband, block 606. Operations here are the inverse of operations performed with respect to block 518 of FIG. 5.

[0080] Where b_s (the aggregated bandwidth of the physical frequency bands) is less than b_v (the virtual bandwidth), block 608, a bandwidth adjustment module scales the frequency of the signal by a factor α so as to make b_s equal to b_v, block 610. Operations here are the inverse of operations performed with respect to block 516 of FIG. 5.

[0081] A reshaper obtains the frequency-shifted, sampling rate-adjusted, bandwidth-adjusted signal and performs a transformation on time-domain samples of the signal to produce a plurality of frequency components of the signal, block 612. The reshaper may perform an N-point FFT on the signal to produce N frequency components.

[0082] If the bandwidth of the signal was adjusted by a bandwidth adjustment module by a factor α, block 614, the reshaper will artificially scale the physical frequency bands by the same factor α, block 616. The bandwidth scaling enables the frequency components of the reception signal to be mapped to sub-carriers of the virtual frequency band.

[0083] The spectrum virtualization layer maps the frequency components to sub-carriers of the virtual frequency band, block 618. M of the N frequency components produced by the N-point FFT that correspond to allocated portions of the physical baseband are mapped to sub-carriers of the virtual frequency band. The mapping process includes a frequency shift of the one or more allocated physical frequency bands by an amount equal to $-f_{\text{span}}$, where f_{span} is the central frequency of the span B_{span} of the allocated physical bands.

[0084] The spectrum virtualization layer performs an inverse transform on the mapped frequency components to produce time-domain symbols in the virtual frequency band, block 620. The spectrum virtualization layer performs an M-point iFFT on the M mapped frequency components to produce the time-domain symbol. Because M is the same at both the transmitter and the receiver, the reshaper at the receiver can maintain the frame size of the transmitted PHY symbol, and therefore reproduce the symbol that was produced by the PHY layer at the transmitter.

[0085] The spectrum virtualization layer passes the recomposed time-domain symbol to the PHY layer in the virtual frequency band, block 622. Any distortion caused by the reshaping process is handled using mechanisms available in the conventional PHY protocol.

Computer-Readable Media

[0086] Depending on the configuration and type of computing device used, memory 204 of wireless device 200 in FIG. 2 may include volatile memory (such as random access memory (RAM)) and/or non-volatile memory (such as read-only memory (ROM), flash memory, etc.). Memory 204 may also include additional removable storage and/or non-removable storage including, but not limited to, flash memory, magnetic storage, optical storage, and/or tape storage that may provide non-volatile storage of computer-readable instructions, data structures, program modules, and other data for wireless device 200.

[0087] Memory 204 is an example of computer-readable media. Computer-readable media includes at least two types of computer-readable media, namely computer storage media and communications media.

[0088] Computer storage media includes volatile and non-volatile, removable and non-removable media implemented in any process or technology for storage of information such as computer-readable instructions, software, data structures, program modules, or other data. Computer storage media includes, but is not limited to, phase change memory (PRAM), static random-access memory (SRAM), dynamic random-access memory (DRAM), other types of random-access memory (RAM), read-only memory (ROM), electrically erasable programmable read-only memory (EEPROM), flash memory or other memory technology, compact disk read-only memory (CD-ROM), digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other non-transmission medium that can be used to store information for access by a computing device.

[0089] In contrast, communication media may embody computer-readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave, or other transmission mechanism. As defined herein, computer storage media does not include communication media.

Conclusion

[0090] Although the disclosure uses language that is specific to structural features and/or methodological acts, the invention is not limited to the specific features or acts described. Rather, the specific features and acts are disclosed as illustrative forms of implementing the invention.

WHAT IS CLAIMED IS:

1. A method, comprising:

mapping, by a spectrum virtualization module of a wireless device, a plurality of frequency components that are derived from a transmission symbol produced by a wireless protocol module of the wireless device for transmission on a virtual frequency band, to sub-carriers associated with one or more allocated physical frequency bands; and

outputting, by the spectrum virtualization layer, a transmission signal that includes time-domain samples derived from the mapped plurality of frequency components.

2. The method of claim 1, further comprising:

performing, by the spectrum virtualization module, an *M*-point fast Fourier transform on the transmission symbol to derive the plurality of frequency components; and

performing, by the spectrum virtualization module, an *N*-point inverse fast Fourier transform on the mapped plurality of frequency components to derive the time-domain samples of the transmission signal.

3. The method of claim 2, wherein the virtual frequency band has a virtual bandwidth, wherein the one or more allocated physical frequency bands are part of a physical baseband, and wherein the method further comprises selecting *N* to be at least as large as *M* multiplied by a ratio that is a function of the virtual bandwidth and a span of the physical baseband.

4. The method of claim 2, further comprising selecting *M* to be at least as large as a number of virtual sub-carriers of the virtual frequency band.

5. A wireless device, comprising:

a processor;

a radio front-end configured to wirelessly transmit and receive on a physical baseband;

a protocol module executable by the processor and configured to generate a transmission symbol for transmission on a virtual transmission band; and

a decomposition/recomposition module executable by the processor and configured to perform an *M*-point fast Fourier transform on the transmission symbol to produce *M* transmission frequency domain components, to map the *M* transmission frequency domain components to transmission sub-carriers associated with one or more portions of the physical baseband that are allocated for transmission, and to perform an *N*-point inverse fast Fourier transform on the mapped *M* transmission frequency domain

components to produce time domain samples of a transmission signal in the physical baseband.

6. The wireless device of claim 5, wherein the one or more portions of the physical baseband that are allocated for transmission include an aggregate transmission bandwidth, and wherein the decomposition/recomposition module is configured to select N to be at least as large as M multiplied by a ratio that is a function of a virtual bandwidth of the virtual transmission band and a span of the physical baseband.

7. The wireless device of claim 5, further comprising:

a bandwidth scaling module configured to scale the one or more portions of the physical frequency band allocated for transmission by a factor that is determined at least in part by a ratio of the aggregated physical bandwidth of the one or more portions of the physical baseband allocated for transmission and a virtual bandwidth of the virtual transmission band, wherein the decomposition/recomposition module is further configured to map the M transmission frequency domain components to the transmission sub-carriers based on scaled ones of the one or more portions of the physical frequency band; and

a bandwidth adjustment module configured to reduce a transmission bandwidth of the transmission signal by the factor.

8. The wireless device of claim 7, wherein the bandwidth adjustment module is further configured to:

reduce the transmission bandwidth by addition of zero-pad samples to time domain samples to the transmission signal;

low-pass filter of the zero-padded samples; and

decimate the transmission signal.

9. The wireless device of claim 5, further comprising a sampling rate adjustment module configured to add zero-pad samples to the transmission signal, to low-pass filter the transmission signal, and to decimate the transmission signal by a factor that is a function of a ratio of a least common multiple of a transmission bandwidth of the transmission signal and a sampling rate of the radio front-end.

10. The wireless device of claim 5, wherein the decomposition/recomposition module is further configured to perform N-point fast Fourier transform on a receive signal to produce N receive frequency components, to reverse map M of the N receive frequency components corresponding to allocated portions of one or more portions of the physical frequency band allocated for reception, and to perform M-point inverse fast Fourier

transform on the M receive frequency components to produce time domain samples of a received signal in a virtual reception band.

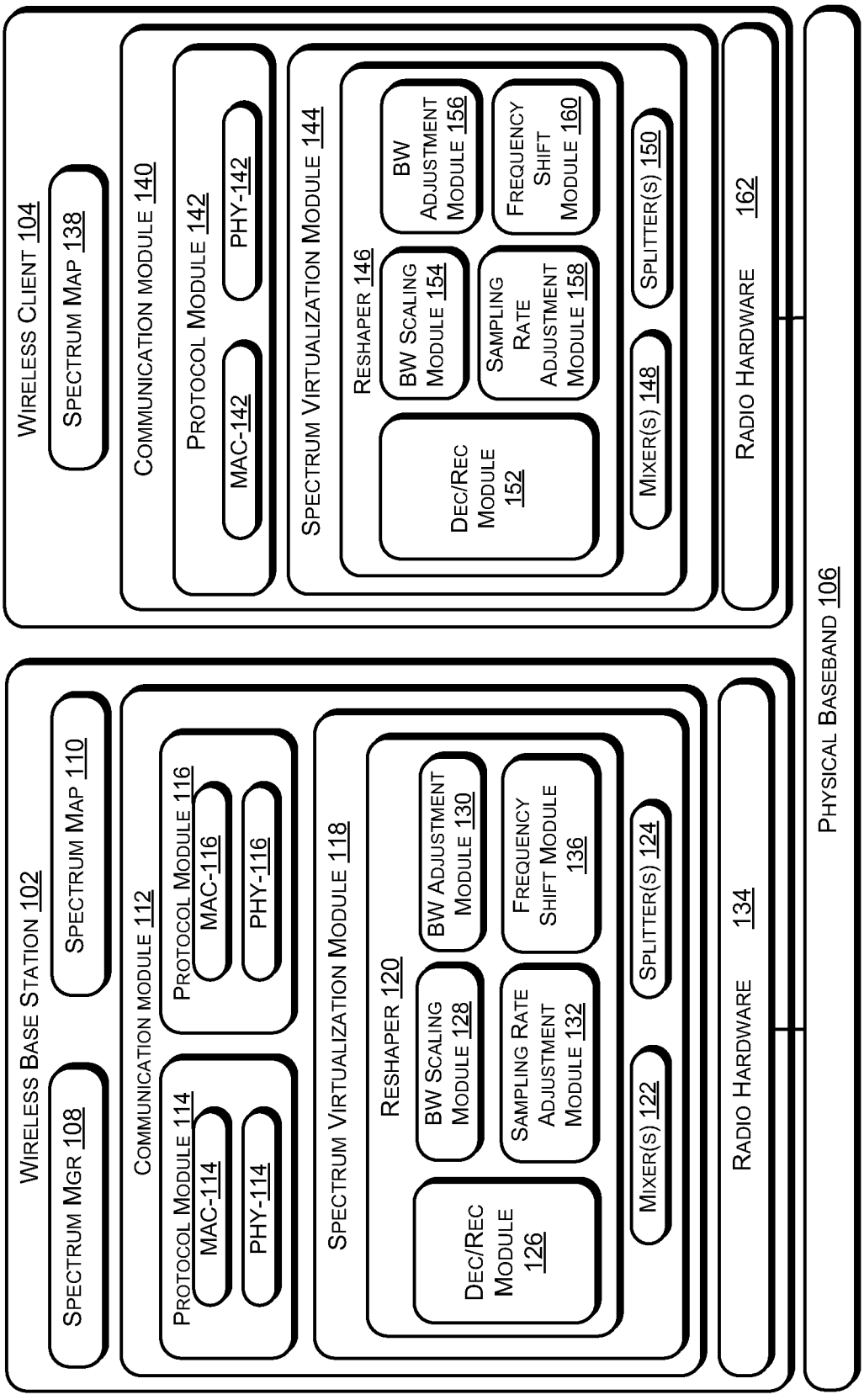
WIRELESS BASE STATION 102
SPECTRUM MGR 108
SPECTRUM MAP 110
COMMUNICATION MODULE 112
PROTOCOL MODULE 114
MAC-114
PHY-114
PROTOCOL MODULE 116
MAC-116
PHY-116
SPECTRUM VIRTUALIZATION MODULE 118
RESHAPER 120
DEC/REC MODULE 126
BW SCALING MODULE 128
BW ADJUSTMENT MODULE 130
SAMPLING RATE ADJUSTMENT MODULE 132
FREQUENCY SHIFT MODULE 136
MIXER(S) 122
SPLITTER(S) 124
RADIO HARDWARE 134
WIRELESS CLIENT 104
SPECTRUM MAP 138
COMMUNICATION MODULE 140
PROTOCOL MODULE 142
MAC-142
PHY-142
SPECTRUM VIRTUALIZATION MODULE 144
RESHAPER 146
DEC/REC MODULE 152
BW SCALING MODULE 154
SAMPLING RATE ADJUSTMENT MODULE 158
BW ADJUSTMENT MODULE 156
FREQUENCY SHIFT MODULE 160
MIXER(S) 148
SPLITTER(S) 150
RADIO HARDWARE 162
PHYSICAL BASEBAND 106
100

FIG. 1

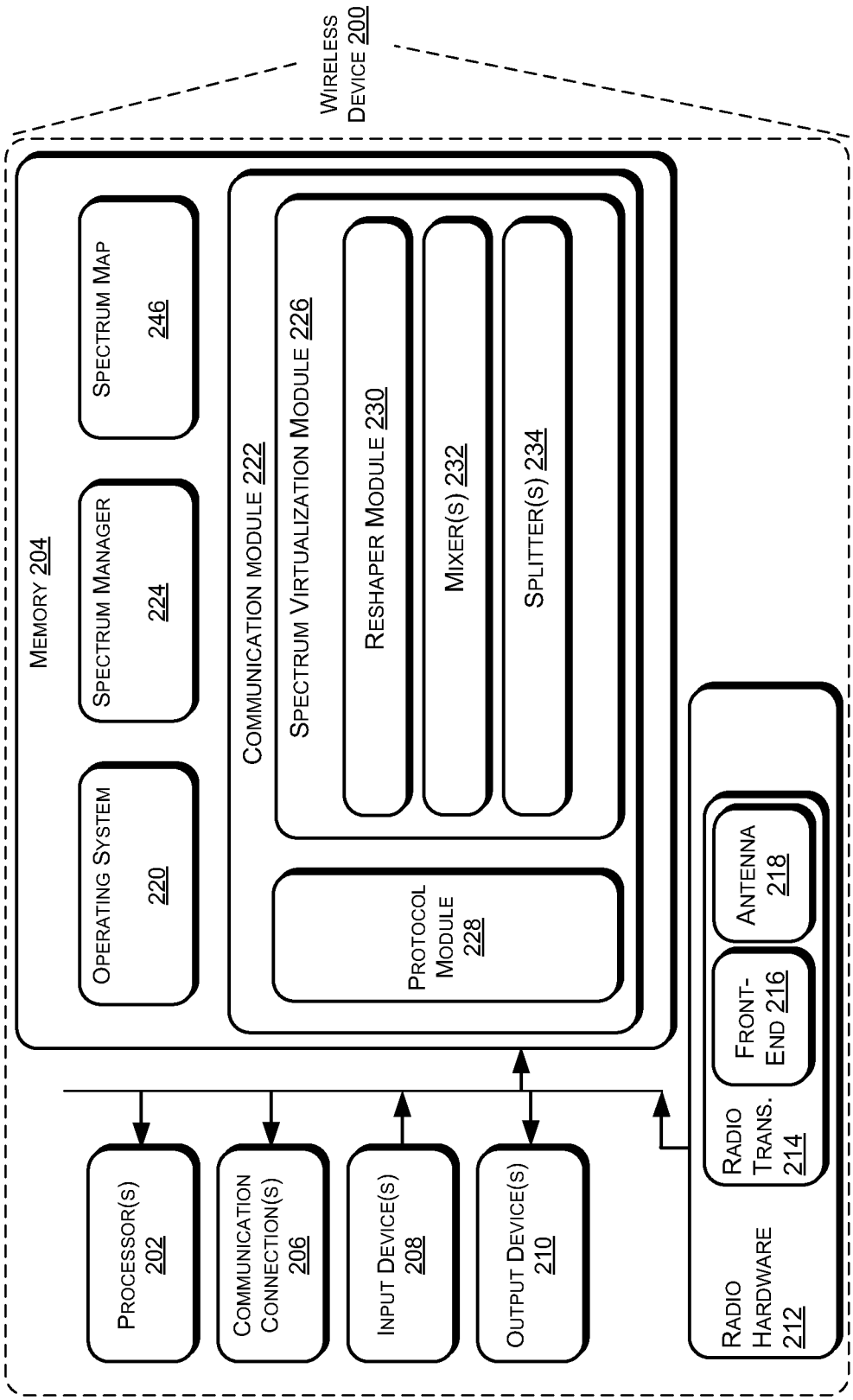
WIRELESS DEVICE 200
MEMORY 204
OPERATING SYSTEM 220
SPECTRUM MANAGER 224
SPECTRUM MAP 246
COMMUNICATION MODULE 222
SPECTRUM VIRTUALIZATION MODULE 226
RESHAPER MODULE 230
MIXER(S) 232
SPLITTER(S) 234
PROTOCOL MODULE 228
PROCESSOR(S) 202
COMMUNICATION CONNECTION(S) 206
INPUT DEVICE(S) 208
OUTPUT DEVICE(S) 210
RADIO HARDWARE 212
RADIO TRANS. 214
FRONT-END 216
ANTENNA 218

FIG. 2

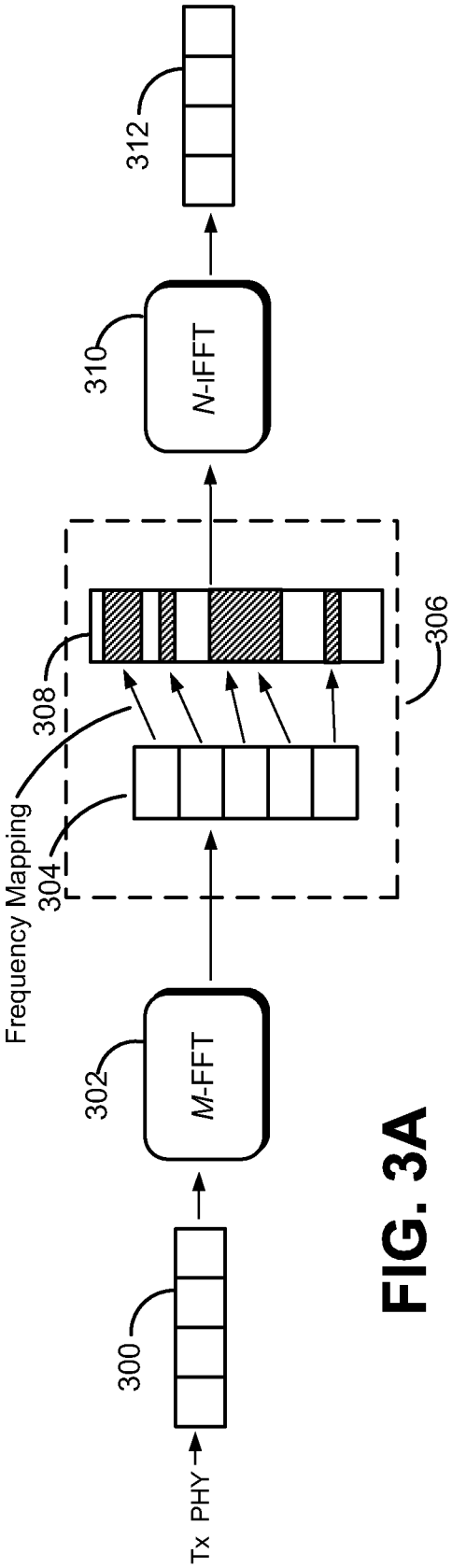
Tx PHY
300
M-FFT
302
Frequency Mapping
304
308
306
N-IFFT
310
312

FIG. 3A

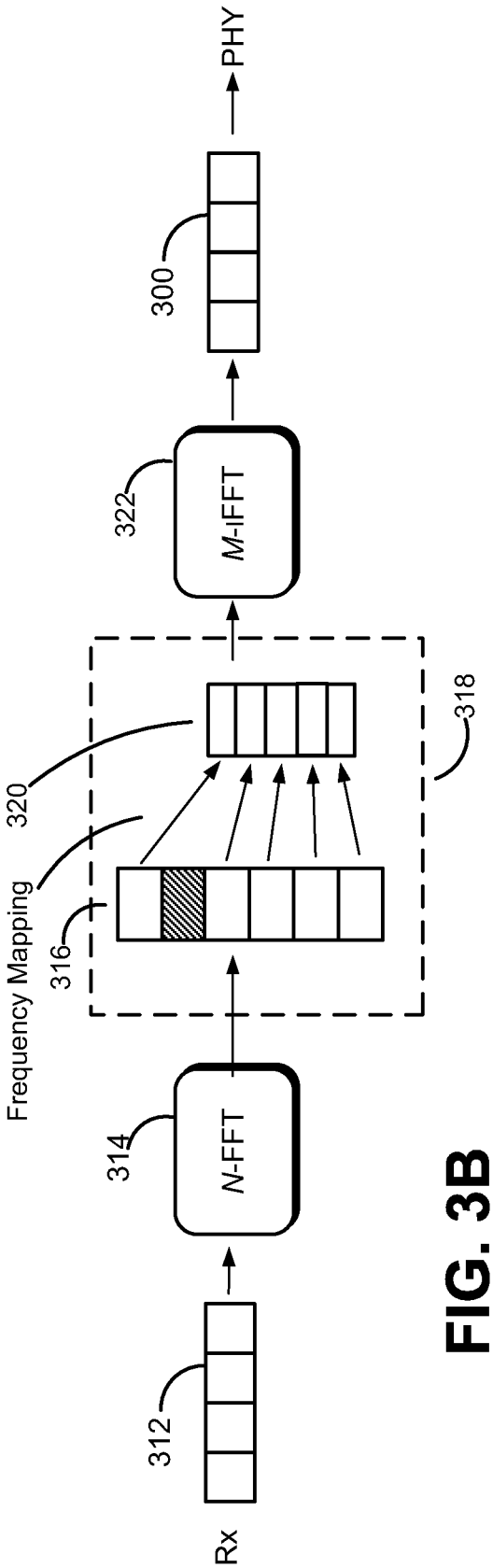
Rx
312
N-FFT
314
Frequency Mapping
316
320
318
M-IFFT
322
300
PHY

FIG. 3B

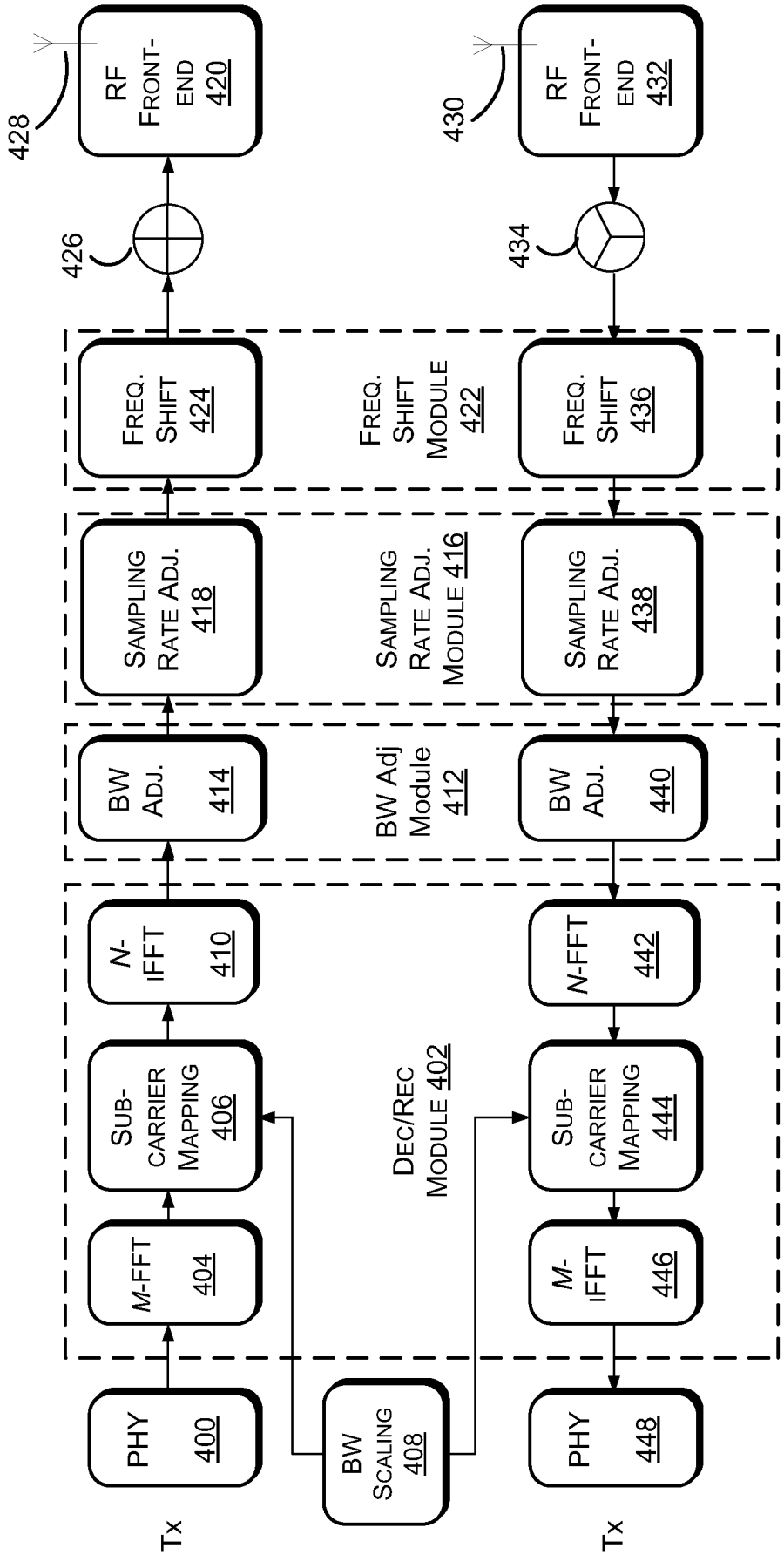
PHY 400
M-FFT 404
SUB-CARRIER MAPPING 406
N-IFFT 410
BW ADJ. 414
SAMPLING RATE ADJ. 418
FREQ. SHIFT 424
RF FRONT-END 420
428
426
Tx
BW SCALING 408
DEC/REC MODULE 402
BW Adj Module 412
SAMPLING RATE ADJ. MODULE 416
FREQ. SHIFT MODULE 422
PHY 448
M-IFFT 446
SUB-CARRIER MAPPING 444
N-FFT 442
BW ADJ. 440
SAMPLING RATE ADJ. 438
FREQ. SHIFT 436
RF FRONT-END 432
430
434
Tx

FIG. 4

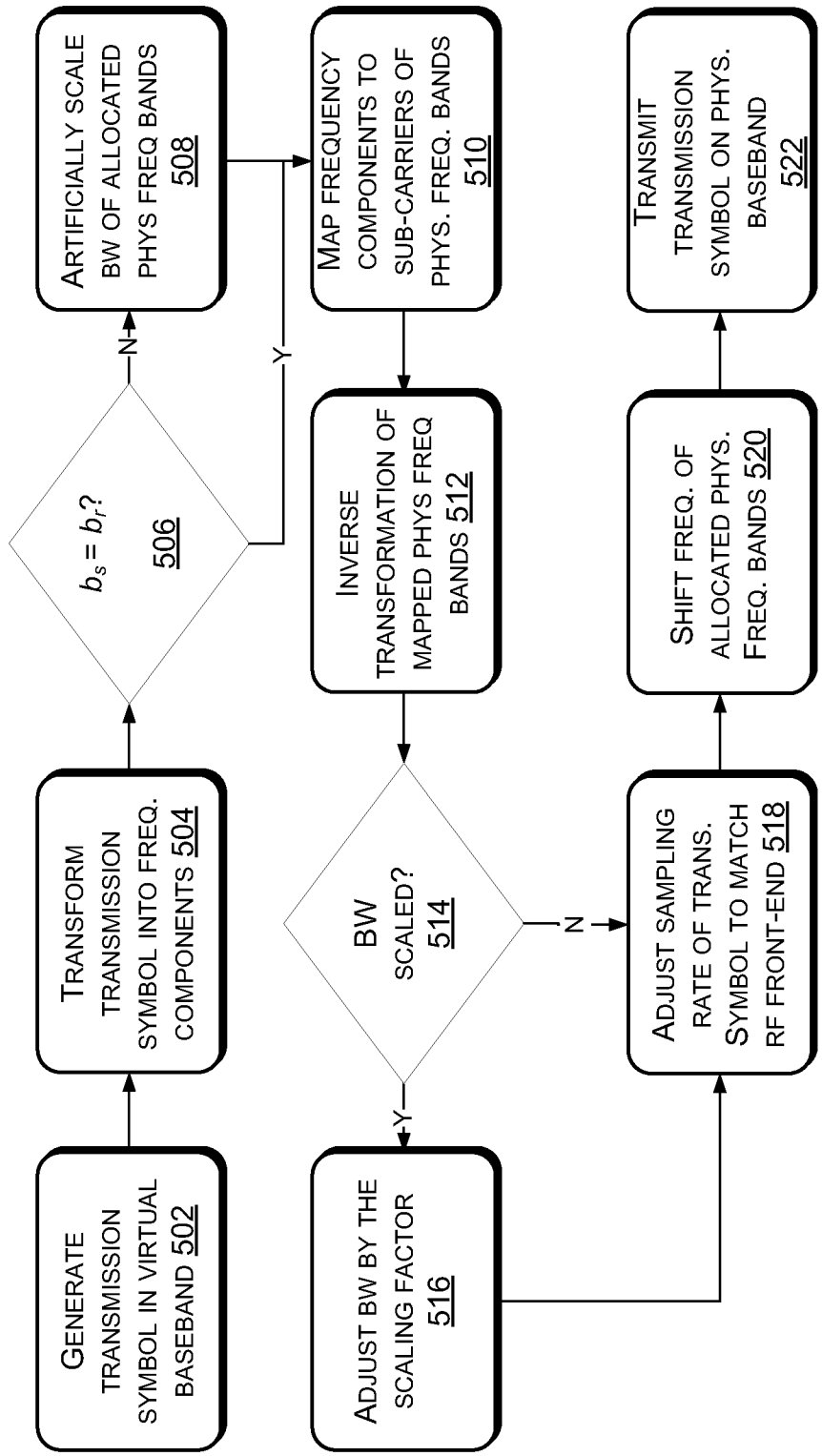
500
GENERATE TRANSMISSION SYMBOL IN VIRTUAL BASEBAND 502
TRANSFORM TRANSMISSION SYMBOL INTO FREQ. COMPONENTS 504
$b_s = b_r$? 506
N
Y
ARTIFICIALLY SCALE BW OF ALLOCATED PHYS FREQ BANDS 508
MAP FREQUENCY COMPONENTS TO SUB-CARRIERS OF PHYS. FREQ. BANDS 510
INVERSE TRANSFORMATION OF MAPPED PHYS FREQ BANDS 512
BW SCALED? 514
Y
N
ADJUST BW BY THE SCALING FACTOR 516
ADJUST SAMPLING RATE OF TRANS. SYMBOL TO MATCH RF FRONT-END 518
SHIFT FREQ. OF ALLOCATED PHYS. FREQ. BANDS 520
TRANSMIT TRANSMISSION SYMBOL ON PHYS. BASEBAND 522

FIG. 5

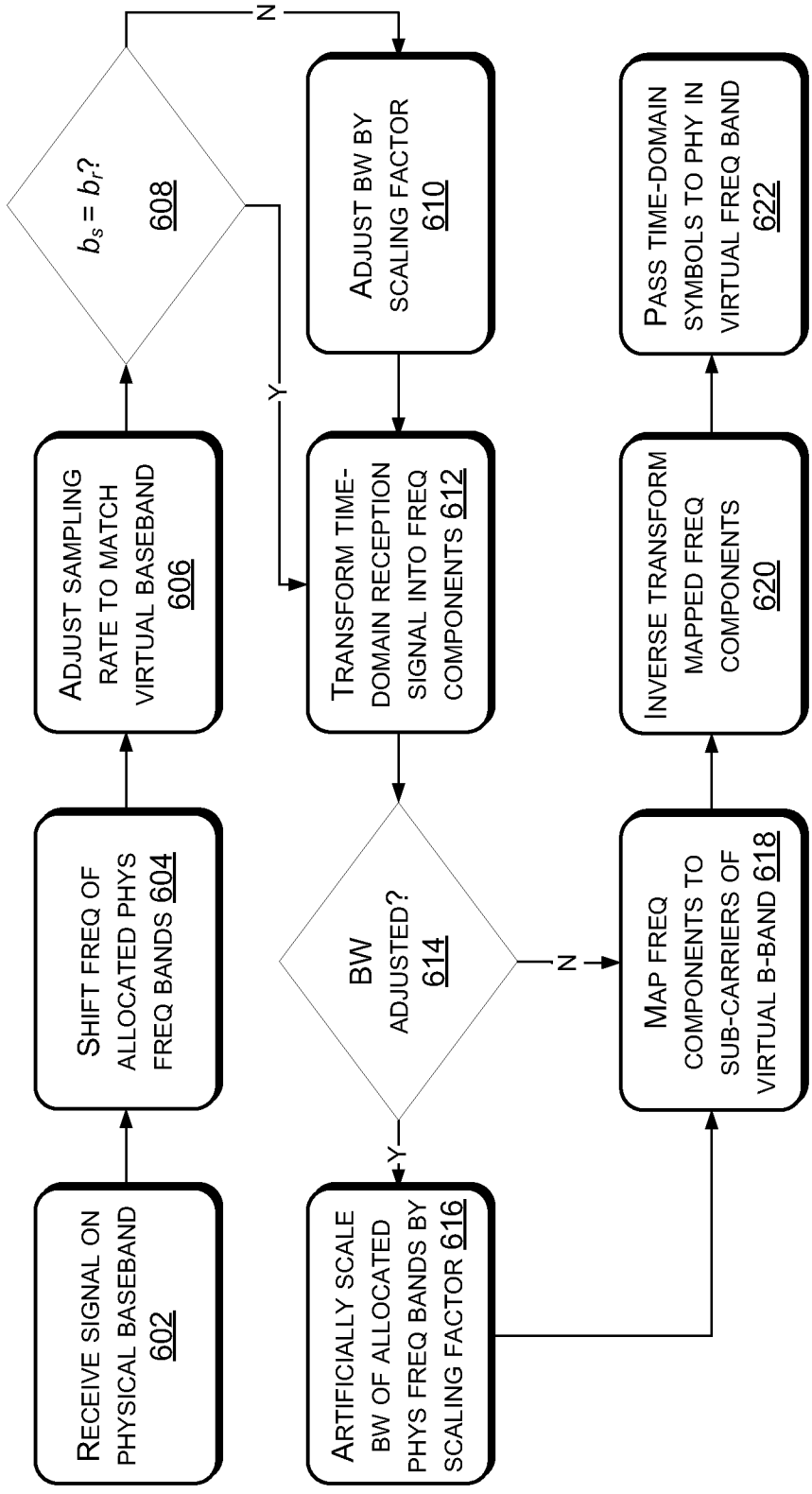
600
RECEIVE SIGNAL ON PHYSICAL BASEBAND 602
SHIFT FREQ OF ALLOCATED PHYS FREQ BANDS 604
ADJUST SAMPLING RATE TO MATCH VIRTUAL BASEBAND 606
$b_s = b_r$? 608
N
Y
ADJUST BW BY SCALING FACTOR 610
TRANSFORM TIME-DOMAIN RECEPTION SIGNAL INTO FREQ COMPONENTS 612
BW ADJUSTED? 614
N
Y
ARTIFICIALLY SCALE BW OF ALLOCATED PHYS FREQ BANDS BY SCALING FACTOR 616
MAP FREQ COMPONENTS TO SUB-CARRIERS OF VIRTUAL B-BAND 618
INVERSE TRANSFORM MAPPED FREQ COMPONENTS 620
PASS TIME-DOMAIN SYMBOLS TO PHY IN VIRTUAL FREQ BAND 622

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/064249

A. CLASSIFICATION OF SUBJECT MATTER

H04L 27/26(2006.01)i, H04L 25/02(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)

H04L 27/26; H04L 27/00; H04J 11/00; H04L 27/28; H04B 1/02; H03D 1/00

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: sub-carrier, mapping, whitespace, FFT, IFFT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007-0202816 A1 (DUNMIN ZHENG) 30 August 2007 See paragraphs [0044]-[0045], [0081], [0083], [0104]-[0111], and	1-2,5,10
A	[0123]-[0125]; and figures 1-2 and 6-7.	3-4,6-9
A	US 2005-0135308 A1 (RAJIV VIJAYAN et al.) 23 June 2005 See paragraphs [0067]-[0078]; and figures 9A-10B.	1-10
A	US 2011-0135016 A1 (JOON KUI AHN et al.) 09 June 2011 See paragraphs [0061]-[0069]; and figures 7A-8.	1-10
A	US 2010-0246377 A1 (GUODONG ZHANG et al.) 30 September 2010 See paragraphs [0010]-[0016]; and figures 1-2.	1-10
A	US 2010-0014603 A1 (RAVI PALANKI et al.) 21 January 2010 See paragraphs [0050]-[0051]; and figures 5-6.	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"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	Date of mailing of the international search report
29 March 2013 (29.03.2013)	**29 March 2013 (29.03.2013)**
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