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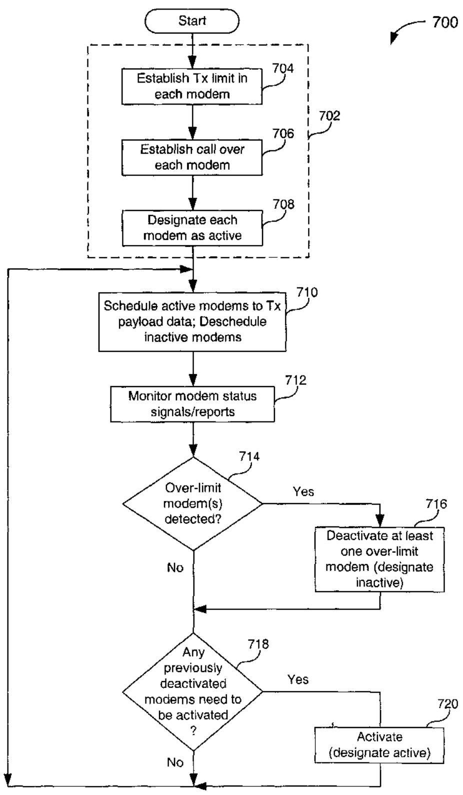
(54) **Title:** CONTROLLING MULTIPLE MODEMS IN A WIRELESS TERMINAL USING ENERGY-PER-BIT DETERMINATIONS



(57) Abstract: A mobile wireless terminal (MWT) includes multiple wireless modems. The multiple modems have their respective transmit outputs combined to produce an aggregate transmit output. The multiple modems can concurrently transmit data in a reverse link direction and receive data in a forward link direction. The MWT is constrained to operate under an aggregate transmit power limit. Each of the multiple modems has an individual transmit limit related to the aggregate transmit power limit. An MWT controller controls the total number of modems that transmit data at any given time, based on an average energy-per-transmitted bit, or alternatively, individual energy-per-transmitted bits of the modems.

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CONTROLLING MULTIPLE MODEMS IN A WIRELESS TERMINAL USING ENERGY-PER-BIT DETERMINATIONS

BACKGROUND OF THE INVENTION

I. Field of the Invention

[0001] The present invention relates generally to mobile wireless terminals, and particularly, to mobile wireless terminals having multiple modems which are constrained to operate under an aggregate transmit power limit for all of the modems.

II. Related Art

[0002] In a data call established between a mobile wireless terminal (MWT) and a remote station, the MWT can transmit data to the remote station over a "reverse" communication link. Also, the MWT can receive data from the remote station over a "forward" communication link. There is an ever pressing need to increase the transmit and receive bandwidth, that is, the data rates, available over both the forward and reverse links.

[0003] Typically, the MWT includes a transmit power amplifier to power-amplify a radio frequency (RF) input signal. The power amplifier produces an amplified, RF output signal having an output power responsive to the input power of the input signal. An inordinately high input power may over-drive the power amplifier, and thus cause the output power to exceed an acceptable operating transmit power limit of the power amplifier. In turn, this may cause undesired distortion of the RF output signal, including unacceptable out-of-band RF emissions.

[0004] Therefore, there is a need to carefully control the input and/or output power of the transmit power amplifier in an MWT so as to avoid over-driving the power amplifier. There is a related need to control the output power as just mentioned, while minimizing to the extent possible, any reduction of the forward and reverse link bandwidth (that is, data rates).

SUMMARY OF THE INVENTION

[0005] A feature of the present invention is to provide an MWT that maximizes an overall communication bandwidth in both the reverse and forward link directions using a plurality of concurrently operating communication links, each associated with a respective one of a plurality of modulator-demodulators (modems) of the MWT.

[0006] Another feature of the present invention is to provide an MWT that combines multiple modulator-demodulator (modem) transmit signals into an aggregate transmit signal (that is, an aggregate reverse link signal) so that a single transmit power amplifier can be used. This advantageously reduces power consumption, cost, and space requirements compared to known systems using multiple power amplifiers.

[0007] Another feature of the present invention is to carefully control an aggregate input and/or output power of the transmit power amplifier, thereby avoiding signal distortion at the power amplifier output. A related feature is to control the aggregate input and/or output power in such a manner as to maximize bandwidth (that is, data through-put) in both the reverse and forward link directions.

[0008] These features are achieved in several ways. First, individual transmit power limits are established in each of the plurality of modems of the wireless terminal, to limit the respective, individual modem transmit powers. Each individual transmit power limit is derived, in part, from an aggregate transmit power limit for all of the modems. Together, the individual transmit power limits collectively limit the aggregate transmit power of all of the modems.

[0009] Second, the present invention controls the total number of modems permitted to transmit data at any given time, so as to maximize an aggregate transmit data rate of the wireless terminal while maintaining the aggregate transmit power of all of the modems below the aggregate transmit power limit. To do this, the present invention collects and/or determines modem transmit statistics corresponding to a previous transmit period or cycle of the wireless terminal. The modem transmit statistics can include individual modem transmit data rates, individual modem transmit powers, the aggregate transmit data rate of all of the modems, and an aggregate transmit power for all of the modems combined.

[0010] The statistics are used to determine an average energy-per-transmitted bit across all of the modems, or alternatively, individual energy-per-transmitted bits for each of the modems, corresponding to the previous transmit cycle of the wireless terminal. Then, either the average or individual energy-per-transmitted-bits are used to determine a maximum number of "active" modems that can be scheduled to transmit data concurrently, and preferably at their respective maximum data rates, without exceeding the aggregate transmit power limit of the wireless terminal. This maximum number of active modems are scheduled to transmit data during the next transmit cycle of the wireless terminal. The invention repeats the process periodically, to update the maximum number of active modems over time. In this manner, the present invention attempts, proactively, to avoid "over-limit" conditions in the modems of the wireless terminal. An over-limit modem has an actual transmit power, or alternatively, a required transmit power, that exceeds the individual transmit power limit established in the modem.

[0011] In the present invention, only active modems are scheduled to transmit data in the reverse link direction. "Inactive" modems are modems that are not scheduled to transmit data. However, in the present invention, inactive modems are able to receive data in the forward link direction, thereby maintaining a high forward link through-put in the wireless terminal, even when modems are inactive in the reverse link direction.

[0012] The present invention is directed to an wireless terminal including a plurality (N) of wireless modems. The N modems have their respective transmit outputs combined to produce an aggregate transmit output. The N modems can concurrently transmit data in the reverse link direction and receive data in the forward link direction. The wireless terminal is constrained to operate within an aggregate transmit power limit. One aspect of the present invention is a method, comprising: scheduling a plurality, M, of active ones (that is active individual members) of the N modems to transmit payload data, where M is less than or equal to N; monitoring status reports from at least the active modems; determining, based on the status reports, whether to adjust/modify the number of active modems in order to maximize an aggregate transmit data rate of the N modems while maintaining an aggregate transmit power of the N modems at or below the aggregate transmit power limit; and modifying the number of active modems when it is determined that the number of active modems should be modified to maintain the aggregate transmit power level of the N modems at or below the aggregate transmit power level. This and further aspects of the present invention are described below.

[0013] The step of determining can comprise determining a maximum number of active modems that can concurrently transmit data, each at a predetermined maximum data rate, while maintaining the aggregate transmit power of the N modems at or below the aggregate transmit power limit, and comparing the maximum number of active modems to the number M of active modems. The maximum number can be determined by determining an average energy-per-transmitted-bit across at least the M active modems and the aggregate transmit power limit. Here, the status reports being monitored indicate a respective transmit data rate for each of the N modems while determining the average energy-per-transmitted-bit can comprise determining an aggregate transmit data rate across the N modems based on their respective transmit data rates and determining the aggregate transmit power. The status reports monitored can indicate a respective transmit power for each of the N modems.

[0014] In further aspects of the method, next active modems can be selected as the maximum number of modems having the lowest individual energy-per-transmitted-bits among the N modems, and the scheduling process is repeated using these next active modems. The number of active modems can be increased to the maximum number when the maximum number is greater than M, and decreased to the maximum number when the maximum number is less than M.

[0015] The method can include activating a selected, previously inactive one of the N modems, thereby increasing the number of active modems, and increasing the respective transmit power limit in the selected one of the N modems. Alternatively, a selected, previously active one of the N modems, is deselected thereby decreasing the number of active modems; and the respective transmit power limit in the selected one of the N modems is decreased. Each of the N modems is adapted to transmit data at at least one of a maximum transmit data rate and a minimum transmit data rate; and the maximum number of active modems is based on the minimum and maximum transmit data rates as well as the average energy-per-transmitted-bit and the aggregate transmit power limit.

[0016] The N modems can be sorted according to their respective individual energy-per-transmitted-bits and scheduling includes using the maximum number of active modems having the lowest individual energy-per-transmitted-bits among the N modems.

[0017] The invention also includes a method of dynamically calibrating a data terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, the method comprising scheduling each of the N modems to concurrently transmit respective data; receiving respective reported transmit powers $P_{Rep}(i)$ from the N modems corresponding to when the N modems concurrently transmit, where i designates a respective modem from 1 to N; measuring an aggregate transmit power P_{Agg} corresponding to when the N modems concurrently transmit;

generating an equation representing the aggregate transmit power as a cumulative function of each reported transmit power $P_{Rep}(i)$ and a corresponding, undetermined, modem dependent gain factor g(i); repeating these steps N times to generate N simultaneous equations; and determining all of the modem dependent gain factors from the N simultaneous equations. Furthermore these steps can be periodically repeated so that the modem dependent gain factors are updated periodically.

[0018] In further aspects of the invention, a wireless terminal is provided which is constrained to operate under an aggregate transmit power limit, having N wireless modems with their respective transmit outputs combined together to produce an aggregate transmit output. The terminal comprises means for scheduling a plurality, M, of active ones of the N modems to transmit payload data, where M is less than or equal to N;, means for monitoring status reports from at least the active modems; means for determining, based on the status reports, whether to modify the number of active modems in order to maximize an aggregate transmit data rate of the N modems while maintaining an aggregate transmit power of the N modems at or below the aggregate transmit power limit; and means for modifying the number of active modems when it is determined the number should be modified to maintain the aggregate transmit power level at or below the aggregate transmit power level.

[0019] The determining means in the wireless terminal may comprise means for determining a maximum number of active modems that can concurrently transmit data, each at a predetermined maximum data rate, while maintaining the aggregate transmit power of the N modems at or below the aggregate transmit power limit, and means for comparing the maximum number of active modems to the number M of active modems.

[0020] In further embodiments, the means for determining the maximum number comprises means for determining an average energy-per-transmitted-bit across at least the M active modems or an individual energy-per-transmitted-bit for each of the N modems, and means for determining the maximum number of active modems based on the average or individual energy-per-transmitted-bits, respectively, and the aggregate transmit power limit. The monitored status reports indicate a respective transmit data rate or transmit power for each of the N modems. The means for determining the average energy-per-transmitted-bit comprises means for determining an aggregate transmit data rate across the N modems based on their respective transmit data rates, means for determining the aggregate transmit power, and means for determining the average energy-per-transmitted-bit based on the aggregate transmit data rate and the aggregate transmit power.

[0021] The wireless terminal may include means for selecting as next active modems the maximum number of modems having the lowest individual energy-per-transmitted-bits among the N modems. The modifying means can comprise means for increasing the number of active modems to the maximum number when the maximum number is greater than M, or means for decreasing the number of active modems to the maximum number when the maximum number is less than M. The modifying means can include means for activating a selected, previously inactive one of the N modems, thereby increasing the number of active modems, and means for increasing the respective transmit power limit in the selected one of the N modems. The modifying means can comprise means for deactivating a selected, previously active one of the N modems, thereby decreasing the number of active modems; and decreasing the respective transmit power limit in the selected one of the N modems.

[0022] In further aspects, each of the N modems is adapted to transmit data at at least one of a maximum transmit data rate and a minimum transmit data rate, and the means for determining the maximum number comprises determining the maximum number based on the minimum and maximum transmit data rates as well as the average energy-per-transmitted-bit and the aggregate transmit power limit.

[0023] A wireless terminal constrained to operate within an aggregate transmit power limit, having N wireless modems with their respective transmit outputs combined to produce an aggregate transmit output, comprising means for determining an individual energy-per-transmitted-bit for each of the N modems that was previously transmitting, means for determining, based on individual energy-per-transmitted-bits and the aggregate transmit power limit, a maximum number of active modems that can concurrently transmit data at a maximum data rate without exceeding the aggregate transmit power limit, and means for scheduling the maximum number of active modems to transmit data.

[0024] In further aspects the wireless terminal further comprises means for sorting the N modems according to their respective individual energy-per-transmitted-bits, while the means for scheduling comprises means for scheduling the maximum number of active modems having the lowest individual energy-per-transmitted-bits among the N modems. The wireless terminal further comprises means for monitoring status reports from at least the active modems, which collectively include a transmit power estimate of each active modem, wherein the means for determining the individual energy-per-transmitted-bits comprises means for determining, from each transmit power estimate, the corresponding individual energy-per-transmitted-bit.

[0025] Apparatus for dynamically calibrating a wireless terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output. The apparatus comprises means for scheduling each of the N modems to concurrently transmit respective data, means for receiving respective reported transmit powers $P_{Rep}(i)$ from the N modems, a power meter, coupled to the aggregate transmit output, for measuring an aggregate transmit power P_{Agg} of the N modems, means for generating a representation of the aggregate transmit power as a cumulative function of each reported transmit power $P_{Rep}(i)$ and a corresponding, undetermined, modem dependent gain factor g(i), wherein the scheduling means, the receiving means, the power meter, and the generating means repeat their respective functions N times to generate N simultaneous equations, and means for determining all of the modem dependent gain factors from the N simultaneous equations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify the same or similar elements throughout and wherein:

[0027] FIG. 1 is an illustration of an example wireless communication system.

[0028] FIG. 2 is a block diagram of an example mobile wireless terminal.

[0029] FIG. 3 is a block diagram of an example modem representative of individual modems of the mobile wireless terminal of FIG. 2.

[0030] FIG. 4 is an illustration of an example data frame that may be transmitted or received by any one of the modems of FIGS. 2 and 3.

[0031] FIG. 5 is an illustration of an example status report from the modems of FIGS. 2 and 3.

[0032] FIG. 6 is a flowchart of an example method performed by each of the modems of FIGS. 2 and 3.

[0033] FIG. 7 is a flowchart of an example method performed by the mobile wireless terminal.

[0034] FIG. 8 is a flowchart expanding on the method of FIG. 7.

[0035] FIG. 9 is a flowchart expanding on the method of FIG. 7.

[0036] FIG. 10 is a flowchart of another example method performed by the mobile wireless terminal.

[0037] FIG. 11 is an example plot of Power versus Modem index(i) identifying respective ones of the modems of FIG. 2, wherein uniform modem transmit power limits are depicted. FIG. 11 also represents an example transmit scenario of the mobile wireless terminal of FIG. 2.

[0038] FIG. 12 is another example transmit scenario similar to FIG. 11.

[0039] FIG. 13 is an illustration of an alternative, tapered arrangement for the modem transmit power limits.

[0040] FIG. 14 is a flowchart of an example method of calibrating modems in the mobile wireless terminal of FIG. 2.

[0041] FIG. 15 is a flowchart of an example method of operating the mobile wireless terminal, using dynamically updated individual modem transmit power limits.

[0042] FIG. 16 is a flowchart of an example method expanding on the method of FIG. 15.

[0043] FIG. 17 is a flowchart of an example method of determining a maximum number of active modems using an average energy-per-transmitted-bit of the modems.

[0044] FIG. 18 is a flowchart of an example method of determining a maximum number of active modems, using an individual energy-per-transmitted-bit for each of the modems.

[0045] FIG. 19 is a graphical representation of different modem transmit limit arrangements.

[0046] FIG. 20 is a functional block diagram of an example controller of the mobile wireless terminal of FIG. 2, for performing the methods of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0047] A variety of multiple access communication systems and techniques have been developed for transferring information among a large number of system users.

However, spread spectrum modulation techniques, such as those used in code division multiple access (CDMA) communication systems provide significant advantages over other modulation schemes, especially when providing service for a large number of communication system users. Such techniques are disclosed in the teachings of U.S. Pat. No. 4,901,307, which issued February 13, 1990 under the title "*Spread Spectrum Multiple Access Communication System Using Satellite or Terrestrial Repeaters*," and U.S. Patent No. 5,691,174, which issued November 25, 1997, entitled "*Method and Apparatus for Using Full Spectrum Transmitted Power in a Spread Spectrum Communication System for Tracking Individual Recipient Phase Time and Energy*," both of which are assigned to the assignee of the present invention, and are incorporated herein by reference in their entirety.

[0048] The method for providing CDMA mobile communications was standardized in the United States by the Telecommunications Industry Association in TIA/EIA/IS-95-A entitled "*Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System,*" referred to herein as IS-95. Other communications systems are described in other standards such as the IMT-2000/UM, or International Mobile Telecommunications System 2000/Universal Mobile Telecommunications System, standards covering what are referred to as wideband CDMA (WCDMA), cdma2000 (such as cdma2000 1x or 3x standards, for example) or TD-SCDMA.

I. Example Communication Environment

[0049] FIG. 1 is an illustration of an exemplary wireless communication system (WCS) 100 that includes a base station 112, two satellites 116a and 116b, and two associated gateways (also referred to herein as hubs) 120a and 120b. These elements engage in wireless communications with user terminals 124a, 124b, and 124c. Typically, base stations and satellites/gateways are components of distinct terrestrial and satellite based communication systems. However, these distinct systems may inter-operate as an overall communications infrastructure.

[0050] Although FIG. 1 illustrates a single base station 112, two satellites 116, and two gateways 120, any number of these elements may be employed to achieve a desired communications capacity and geographic scope. For example, an exemplary implementation of WCS 100 includes 48 or more satellites, traveling in eight different orbital planes in Low Earth Orbit (LEO) to service a large number of user terminals 124.

[0051] The terms base station and gateway are also sometimes used interchangeably, each being a fixed central communication station, with gateways, such as gateways 120, being perceived in the art as highly specialized base stations that direct communications through satellite repeaters while base stations (also sometimes referred to as cell-sites), such as base station 112, use terrestrial antennas to direct communications within surrounding geographical regions.

[0052] In this example, user terminals 124 each have or include apparatus or a wireless communication device such as, but not limited to, a cellular telephone, wireless handset, a data transceiver, or a paging or position determination receiver. Furthermore each of user terminals 124 can be hand-held, portable as in vehicle-mounted (including for example cars, trucks, boats, trains, and planes), or fixed, as desired. For example, FIG. 1 illustrates user terminal 124a as a fixed telephone or data transceiver, user terminal 124b as a hand-held device, and user terminal 124c as a portable vehicle-mounted device. Wireless communication devices are also sometimes referred to as mobile wireless terminals, user terminals, mobile wireless communication devices, subscriber units, mobile units, mobile stations, mobile radios, or simply "users," "mobiles," "terminals," or "subscribers" in some communication systems, depending on preference.

[0053] User terminals 124 engage in wireless communications with other elements in WCS 100 through CDMA communications systems. However, the present invention may be employed in systems that employ other communications techniques, such as time division multiple access (TDMA), and frequency division multiple access (FDMA), or other waveforms or techniques listed above (WCDMA, CDMA2000 . . . .).

[0054] Generally, beams from a beam source, such as base station 112 or satellites 116, cover different geographical areas in predefined patterns. Beams at different frequencies, also referred to as CDMA channels, frequency division multiplexed (FDM) channels, or "sub-beams," can be directed to overlap the same region. It is also readily understood by those skilled in the art that beam coverage or service areas for multiple satellites, or antenna patterns for multiple base stations, might be designed to overlap completely or partially in a given region depending on the communication system design and the type of service being offered, and whether space diversity is being achieved.

[0055] FIG. 1 illustrates several exemplary signal paths. For example, communication links 130a-c provide for the exchange of signals between base station 112 and user terminals 124. Similarly, communications links 138a-d provide for the exchange of signals between satellites 116 and user terminals 124. Communications between satellites 116 and gateways 120 are facilitated by communications links 146a-d.

[0056] User terminals 124 are capable of engaging in bi-directional communications with base station 112 and/or satellites 116. As such, communications links 130 and 138 each include a forward link and a reverse link. A forward link conveys information signals to user terminals 124. For terrestrial-based communications in WCS 100, a forward link conveys information signals from base station 112 to a user terminal 124 across a link 130. A satellite-based forward link in the context of WCS 100 conveys information from a gateway 120 to a satellite 116 over a link 146 and from the satellite 116 to a user terminal 124 over a link 138. Thus, terrestrial-based forward links typically involve a single wireless signal path between the user terminal and base station, while satellite-based links typically involve two, or more, wireless signal paths between the user terminal and a gateway through at least one satellite (ignoring multipath).

[0057] In the context of WCS 100, a reverse link conveys information signals from a user terminal 124 to either a base station 112 or a gateway 120. Similar to forward links in WCS 100, reverse links typically require a single wireless signal path for terrestrial-based communications and two wireless signal paths for satellite-based communications. WCS 100 may feature different communications offerings across these forward links, such as low data rate (LDR) and high data rate (HDR) services. An exemplary LDR service provides forward links having data rates from 3 kilobits per second (kbps) to 9.6 kbps, while an exemplary HDR service supports typical data rates as high as 604 kbps and higher.

[0058] As described above, WCS 100 performs wireless communications according to CDMA techniques. Thus, signals transmitted across the forward and reverse links of links 130, 138, and 146 convey signals that are encoded, spread, and channelized according to CDMA transmission standards. In addition, block interleaving can be employed for these forward and reverse links. These blocks are transmitted in frames having a predetermined duration, such as 20 milliseconds.

[0059] Base station 112, satellites 116, and gateways 120 may adjust the power of the signals that they transmit over the forward links of WCS 100. This power (referred to herein as forward link transmit power) may be varied according to user terminal 124 and according to time. This time varying feature may be employed on a frame-by-frame basis. Such power adjustments are performed to maintain forward link bit error rates (BER) within specific requirements, reduce interference, and conserve transmission power.

[0060] User terminals 124 may adjust the power of the signals that they transmit over the reverse links of WCS 100, under the control of gateways 120 or basestations 112. This power (referred to herein as reverse link transmit power) may be varied according to user terminal 124 and according to time. This time varying feature may be employed on a frame-by-frame basis. Such power adjustments are performed to maintain reverse link bit error rates (BER) within specific requirements, reduce interference, and conserve transmission power.

[0061] Examples of techniques for exercising power control in CDMA communication systems are found in U. S. Patent Nos. 5,383,219, entitled *"Fast Forward Link Power Control In A Code Division Multiple Access System,"* 5,396,516, *entitled "Method And System For The Dynamic Modification Of Control Parameters In A Transmitter Power Control System,"* and 5,056,109, entitled *"Method and Apparatus For Controlling Transmission Power In A CDMA Cellular Mobile Telephone System,"* which are incorporated herein by reference.

II. Mobile Wireless Terminal

[0062] FIG. 2 is a block diagram of an example MWT 206 constructed and operated in accordance with the principles of the present invention. MWT 206 communicates wirelessly with a basestation or gateway (referred to as a remote station), not shown in FIG. 2. Also, MWT 206 may communicate with a user terminal. MWT 206 receives data from external data sources/sinks, such as a data network, data terminals, and the like, over a communication link 210, such as an Ethernet link, for example. Also, MWT 206 sends data to the external data sources/sinks over communication link 210.

[0063] MWT 206 includes an antenna 208 for transmitting signals to and receiving signals from the remote station. MWT 206 includes a controller (that is, one or more controllers) 214 coupled to communication link 210. Controller 214 exchanges data with a memory/storage unit 215, and interfaces with a timer 217. Controller 214 provides data-to-be-transmitted to, and receives data from, a plurality of wireless modems 216a-216n over a plurality of corresponding bi-directional data links 218a-218n between controller 214 and modems 216. Data connections 218 may be serial data connections. The number N of modems that may be used can be one of several values, as desired, depending on known design issues such as complexity, cost, and so forth. In an example implementation, N = 16.

[0064] Wireless modems 216a-216n provide RF signals $222a_T - 222n_T$ to and receive RF signals $222a_R - 222n_R$ from a power combiner/splitter assembly 220, over a plurality of bi-directional RF connections/cables between the modems and the power combiner/splitter assembly. In a transmit (that is, reverse link) direction, a power combiner included in assembly 220 combines together the RF signals received from all of modems 216, and provides a combined (that is, aggregate) RF transmit signal 226 to a transmit power amplifier 228. Transmit power amplifier 228 provides an amplified, aggregate RF transmit signal 230 to a duplexer 232.

[0065] Duplexer 232 provides the amplified, aggregate RF transmit signal to antenna 208. In MWT 206, duplexing may be achieved by means other than duplexer 232, such as using separate transmit and receive antennas. Also, a power monitor 234, coupled to an output of power amplifier 228, monitors a power level of amplified, aggregate transmit signal 230. Power monitor 234 provides a signal 236 indicating the power level of amplified, aggregate transmit signal 230 to controller 214. In an alternative arrangement of MWT 206, power monitor 234 measures the power level of aggregate signal 226 at the input to transmit amplifier 228. In this alternative arrangement, the aggregate transmit power limit of MWT 206 is specified at the input to transmit amplifier 228 instead of at its output, and the methods of the present invention, described below, take this into account.

[0066] In a receive (that is, forward link) direction, antenna 208 provides a received signal to duplexer 232. Duplexer 232 routes the received signal to a receive amplifier 240. Receive amplifier 240 provides an amplified received signal to assembly 220. A power splitter included in assembly 220 divides the amplified received signal into a plurality of separate received signals and provides each separate signal to a respective one of the modems 216.

[0067] MWT 206 communicates with the remote station over a plurality of wireless CDMA communication links 250a-250n established between MWT 206 and the remote station. Each of the communication links 250 is associated with a respective one of modems 216. Wireless communication links 250a-250n can operate concurrently with one another. Each of wireless communication links 250 supports wireless traffic channels for carrying data between MWT 206 and the remote station in both forward and reverse link directions. The plurality of wireless communication channels 250 form part of an air interface 252 between MWT 206 and the remote station.

[0068] In the present embodiment, MWT 206 is constrained to operate under an aggregate transmit power limit (APL) at the output of transmit amplifier 228. In other words, MWT 206 is required to limit the transmit power of signal 230 to a level that is preferably below the aggregate transmit power limit. All of modems 216, when transmitting, contribute to the aggregate transmit power of signal 230. Accordingly, the present invention includes techniques to control the transmit powers of modems 216, and thereby cause the aggregate transmit power of modems 216, as manifested in transmit signal 230, to be under the aggregate transmit power limit.

[0069] Over-driving transmit amplifier 228 causes the power level of signal 230 to exceed the aggregate transmit power limit. Therefore, the present invention establishes individual transmit power limits (also referred to as transmit limits) for each of modems 216. The individual transmit power limits are related to the aggregate transmit power limit in such a way as to prevent modems 216 from collectively over-driving transmit amplifier 228. During operation of MWT 206, the present invention controls a maximum number of active modems that can concurrently transmit data at any given time so as to maximize the aggregate transmit data rate of the MWT, while maintaining the aggregate transmit power of all of modems 216 at or below the aggregate transmit power limit. The present invention uses proactive techniques to avoid over-limit conditions in modems 216. Further aspects of the present invention are described below.

[0070] Although MWT 206 is referred to as being mobile, it is to be understood that the MWT is not limited to a mobile platform, or portable platforms. For example, MWT

206 may reside in a fixed base station or gateway. MWT 206 may also reside in a fixed user terminal 124a.

III. Modem

[0071] FIG. 3 is a block diagram of an example modem 300 representative of each of modems 216. Modem 300 operates in accordance with CDMA principles. Modem 300 includes a data interface 302, a controller 304, a memory 306, a modem signal processor or module 308, such as one or more digital signal processors (DSP) or ASICs, an intermediate frequency IF/RF subsystem 310, and an optional power monitor 312, all coupled to one another over a data bus 314. In some systems, the modems do not comprise transmit and receive processors coupled in pairs as in a more traditional modem structure, but may use an array of transmitters and receivers or modulators and demodulators which are interconnected, as desired, to handle user communications, and one or more signals, or otherwise time shared among users.

[0072] In the transmit direction, controller 304 receives data-to-be-transmitted from controller 214 over data connection 218i (where "i" indicates any one of the modems 216a-216n), and through interface 302. Controller 304 provides the data-to-be-transmitted to modem processor 308. A transmit (Tx) processor 312 of modem processor 308 encodes and modulates the data-to-be-transmitted, and packages the data into data frames that are to be transmitted. Transmit processor 312 provides a signal 314 including the data frames to IF/RF subsystem 310. Subsystem 310 frequency up-converts and amplifies signal 314, and provides a resulting frequency up-converted, amplified signal $222i_T$ to power combiner/splitter assembly 220. Optional power meter 312 monitors a power level of signal $222i_T$ (that is, the actual transmit power at which modem 300 transmits the above-mentioned data frames). Alternatively, modem 300 can determine the modem transmit power based on gain/attenuator settings of IF/RF subsystem 310 and the data rate at which modem 300 transmits the data frames.

[0073] In the receive direction, IF/RF subsystem 310 receives a received signal $222i_R$ from power combiner/splitter assembly 220, frequency down-converts signal $222i_R$ and provides the resulting frequency down-converted signal 316, including received data frames, to a receive (Rx) processor 318 of modem processor 308. Receive processor 318 extracts data from the data frames, and then controller 304 provides the extracted data to controller 214, using interface 302 and data connection 218i.

[0074] Modems 216 each transmit and receive data frames in the manner described above and further below. FIG. 4 is an illustration of an example data frame 400 that may be transmitted or received by any one of modems 216. Data frame 400 includes a control or overhead field 402 and a payload field 404. Fields 402 and 404 include data bits used to transfer either control information (402) or payload data (404). Control field 402 includes control and header information used in managing a communication link established between a respective one of modems 216 and the remote station. Payload field 404 includes payload data (bits 406), for example, data-to-be-transmitted between controller 214 and the remote station during a data call (that is, over the communication link established between the modem and the remote station). For example, data received from controller 214, over data link 218i, is packaged into payload field 404.

[0075] Data frame 400 has a duration T, such as 20 milliseconds, for example. The payload data in payload field 404 is conveyed at one of a plurality of data rates, including a maximum or full-rate (for example, 9600 bits-per-second (bps)), a half-rate (for example, 4800 bps), a quarter-rate (for example, 2400 bps), or an eighth-rate (for example, 1200 bps). Each of the modems 216 attempts to transmit data at the full-rate (that is, at a maximum data rate). However, an over-limit modem rate-limits, whereby the modem reduces its transmit data rate from the maximum rate to a lower rate, as will be discussed below. Also, each of the modems 216 may transmit a data frame (for example, data frame 400) without payload data. This is referred to as a zero-rate data frame.

[0076] In one modem arrangement, each of the data bits 406 within a frame carries a constant amount of energy, regardless of the transmit data rate. That is, within a frame, the energy-per-bit, E_b, is constant for all of the different data rates. In this modem arrangement, each data frame corresponds to an instantaneous modem transmit power that is proportional to the data rate at which the data frame is transmitted. Therefore, the lower the data rate, the lower the modem transmit power.

[0077] Each of the modems 216 provides status reports to controller 214 over respective data connections 218. FIG. 5 is an illustration of an example status report 500. Status report 500 includes a modem data rate field 502, a modem transmit power field 504, and an optional over-limit (also referred to as a rate-limiting) indicator field 506. Each modem reports the data rate of the last transmitted data frame in field 502, and the transmit power of the last transmitted data frame in field 504. In addition, each modem can optionally report whether it is in a rate-limiting condition in field 506.

[0078] In another alternative modem arrangement, the modem can provide status signals indicating the over-limit/rate-limiting condition, the transmit power, and transmit data rate of the modem.

IV. Example method

[0079] FIG. 6 is a flowchart of an example method or process 600 representative of an operation of modem 300, and thus, of each of modems 216. Method 600 assumes a data call has been established between a modem (for example, modem 216a) and the remote station. That is, a communication link including a forward link and a reverse link has been established between the modem and the remote station.

[0080] At a first step 602, a transmit power limit P_L is established in the modem (for example, in modem 216a).

[0081] At a next step 604, the modem receives a power control command from the remote station over the forward link indicating a requested transmit power P_R at which the modem is to transmit data frames in the reverse link direction. This command may be in the form of an incremental power increase or decrease command.

[0082] At a decision step 606, the modem determines whether any payload data has been received from controller 214, that is, whether or not there is any payload data to transmit to the remote station. If not, processing of the method proceeds to a next step 608. At step 608, the modem transmits a data frame at the zero-rate, that is, without payload data. The zero-rate data frame may include control/overhead information used to maintain the communication link/data call, for example. The zero-rate data frame corresponds to a minimum transmit power of the modem.

[0083] On the other hand, if there is payload data to transmit, then processing (control) proceeds from step 606 to a next step 610. At step 610, the modem determines whether or not it is not over-limit, that is, whether the modem is under-limit. In one arrangement, determining whether the modem is under-limit includes determining whether the requested transmit power P_R is less than the transmit power limit P_L. In this arrangement, the modem is considered over-limit when the requested transmit power P_R is greater than or equal to P_L. In an alternative arrangement, determining whether or not the modem is under-limit includes determining whether an actual transmit power P_T of the modem is less than the transmit power limit P_L. In this arrangement, the modem is considered over-limit when P_T is greater than or equal P_L. The modem may use power monitor 312 in determining whether its transmit power P_T, for example, the transmit power of signal $222i_T$, is less than the transmit power limit P_L.

[0084] While the modem is not-over limit, the modem transmits a data frame, including payload data and control information, at a maximum data rate (for example, the full-rate) and at a transmit power level P_T that is in accordance with the requested transmit power P_R. In other words, the modem transmit power P_T tracks the requested transmit power P_R.

[0085] When P_T or P_R is equal to or greater than P_L, the modem is over-limit, and thus rate-limits from a current rate (for example, the full-rate) to a lower transmit data rate (for example, to the half-rate, quarter-rate, eighth-rate or even the zero-rate), thereby reducing the transmit power P_T of the modem relative to when the modem was transmitting at the full-rate. Therefore, rate-limiting in response to either of the over-limit conditions described above is a form of modem self power-limiting, whereby the modem maintains its transmit power P_T below the transmit power limit P_L. Also, the over-limit/rate-limiting condition, as reported in status report 500, indicates to controller 214 that the requested power P_R, or the actual transmit power P_T in the alternative arrangement, is greater than or equal to the transmit power limit P_L. It should be appreciated that while the modem may be operating at the zero-rate in the transmit (that is, reverse link) direction, because it either is rate-limiting (for example, in step 610) or has no payload data to transmit (step 608), it may still receive full-rate data frames in the receive (that is, forward link) direction.

[0086] Although it can be advantageous for the modem to self rate-limit in response to the over-limit condition, an alternative arrangement of the modem does not rate-limit in this manner. Instead, the modem reports the over-limit condition to controller 214, and then waits for the controller to impose rate-limiting adjustments. A preferred arrangement uses both approaches. That is, the modem self rate-limits in response to the over-limit condition, and the modem reports the over-limit condition to controller 214, and in response, the controller imposes rate-limiting adjustments on the modem.

[0087] After both step 608 and step 610, the modem generates a status report (for example, status report 500) at a step 612, and provides the report to controller 214 over a respective one of data links 218.

V. Fixed Transmit Power Limit Embodiments

[0088] FIG. 7 is a flowchart of an example method performed by MWT 206, accordance with the present embodiments. Method 700 includes an initializing step 702. Step 702 includes further steps 704, 706, and 708. At step 704, controller 214 establishes an individual transmit power limit P_L in each of modems 216. The transmit power limits are fixed over time in method 700.

[0089] At step 706, controller 214 establishes a data call over each of modems 216. In other words, a communication link, including both forward and reverse links, is established between each of the modems 216 and the remote station. The communication links operate concurrently with one another. In an exemplary arrangement of the present invention, the communication links are CDMA based communication links.

[0090] In the embodiments, a modem may be designated as an active modem or as an inactive modem. Controller 214 can schedule active modems, but not inactive modems, to transmit payload data. Controller 214 maintains a list identifying currently active modems. At a step 708, controller 214 initially designates all of the modems as being active, by adding each of the modems to the active list, for example.

[0091] At a next step 710, assuming controller 214 has received data that needs to be transmitted to the remote station, controller 214 schedules each of the active modems to transmit payload data. In a first past through step 710, all of modems 216 are active (from step 708). However, in subsequent passes through step 710, some of modems 216 may be inactive, as will be described below.

[0092] Controller 214 maintains a queue of data-to-be-transmitted for each of the active modems, and supplies each data queue with data received from the external data sources over link 210. Controller 214 provides data from each data queue to the respective active modem. Controller 214 executes data-loading algorithms to ensure the respective data queues are generally, relatively evenly loaded, so that each active modem is concurrently provided with data-to-be-transmitted. After controller 214 provides data to each modem, each modem in turn attempts to transmit the data in data frames at the full-rate and in accordance with the respective requested transmit power P_R, as described above in connection with FIG. 6.

[0093] At step 710, controller 214 also de-schedules inactive modems by diverting data-to-be-transmitted away from such inactive modems and toward the active modems. However, there are no inactive modems in the first pass through step 710, since all of the modems are initially active after step 708, as mentioned above.

[0094] At a next step 712, controller 214 monitors the modem status reports from all of the inactive and active modems.

[0095] At a next step 714, controller 214 determines whether any of the modems 216 are over-limit, and thus rate-limiting, based on the modem status reports. If controller 214 determines that one or more (that is, at least one) of the modems are over-limit, then controller 214 deactivates only these over-limit modems, at a step 716. For example, controller 214 can deactivate an over-limit modem by removing it from the active list.

[0096] If none of the modems are determined to be over-limit at step 714, the method or processing proceeds to a step 718. Processing also proceeds to step 718 after any over-limit modems are deactivated in step 716. At step 718, controller 214 determines whether or not any of the modems previously deactivated at step 716 need to be activated (that is, reactivated). Several techniques for determining whether modems should be activated are discussed below. If the answer at step 718 is yes (modems need to be reactivated), then processing proceeds to a step 720, and controller 214 activates the previously deactivated modems that need to be activated, for example, by reinstating the modems on the active list.

[0097] If none of the previously deactivated modems need to be activated, then processing proceeds from step 718 back to step 710. Also, processing proceeds from step 720 to step 710. Steps 710 through 720 are repeated over time, whereby over-limit ones of modems 216 are deactivated at step 716 and then reactivated at step 718 as appropriate, and correspondingly de-scheduled and re-scheduled at step 710.

[0098] When an over-limit modem is deactivated at step 716 (that is, becomes inactive), and remains deactivated through step 718, the modem will be de-scheduled in the next pass through step 710. In other words, controller 214 will no longer provide data to the deactivated modem. Instead, controller 214 will divert data to active modems. If it is assumed that the data call associated with the deactivated modem has not been torn-down (that is, terminated), then de-scheduling the modem at step 710 will cause the deactivated modem to have no payload data to transmit, and will thus cause the modem to operate at the zero-rate and at a corresponding minimum transmit power level on the reverse link (see steps 606 and 608, described above in connection with FIG. 6). This keeps the data call alive or active on the deactivated/descheduled modem, so the modem can still receive full-rate data frames on the forward link. When a data call associated with a modem is torn-down, that is, terminated or ended, the modem stops transmitting and receiving data altogether.

[0100] Deactivating the over-limit modem at step 716 ultimately causes the modem to reduce its transmit data rate and corresponding transmit power in the reverse link direction. In this manner, controller 214 individually controls the modem transmit power limits (and thus modem transmit powers), and as a result, can maintain the aggregate transmit power of signal 230 at a level below the aggregate transmit power limit of MWT 206.

[0101] Alternative arrangements of method 700 are possible. As described above, deactivating step 716 includes deactivating an over-limit modem by designating the modem as inactive, for example, by removing the modem from the active list. Conversely, activating step 720 includes reinstating the deactivated modem to the active list. In an alternative arrangement of method 700, deactivating step 716 further includes tearing-down (that is, terminating) the data call (that is, the communication link) associated with the over-limit modem. Also, in this alternative arrangement, activating step 720 further includes establishing another data call over the previously deactivated modem, so that the modem can begin to transmit data to and receive data from the remote station.

[0102] In another alternative arrangement of method 700, deactivating step 716 further includes deactivating all of the modems, whether over-limit or not over-limit, when any one of the over-limit modems is detected at step 714. In this arrangement, deactivating the modems may include designating all of the modems as inactive, and may further include tearing-down all of the data calls associated with the modems.

[0103] FIG. 8 is a flowchart expanding on transmit limit establishing step 704 of method 700. At a first step 802, controller 214 derives the transmit power limit for each of modems 216. For example, controller 214 may calculate the transmit power limits, or simply access predetermined limits stored in a memory look-up table. At a next step 804, controller 214 provides each of the modems 216 with a respective one of the transmit power limits, and in response, the modems store their respective transmit power limits in their respective memories.

[0104] FIG. 9 is a flowchart expanding on determining step 718 of method 700. Controller 214 monitors (at step 712, for example) the respective reported transmit powers of the deactivated/inactive modems that are transmitting at the zero-rate. At a step 902, controller 214 derives, from the reported modem transmit powers, respective extrapolated modem transmit powers representative of when the modems transmit at the maximum transmit data rate.

[0105] At a next step 904, controller 214 determines whether each extrapolated transmit power is less than the respective modem transmit power limit P_L. If yes, then processing proceeds to step 720 where the respective modem is activated, because it is likely the modem will not exceed the power limit. If not, the modem remains deactivated, and the method proceeds back to step 710.

[0106] FIG. 10 is a flowchart of another example method 1000 performed by MWT 206. Method 1000 includes many of the method steps described previously in connection with FIG. 7, and such method steps will not be described again. However, method 1000 includes a new step 1004 following step 716, and a corresponding determining step 1006. At step 1004, controller 214 initiates an activation timeout period (for example, using timer 217) corresponding to each modem deactivated at step 716. Alternatively, controller 214 can schedule a future activation time/event corresponding to each modem deactivated in step 716.

[0107] At determining step 1006, controller 214 determines whether it is time to activate any of the previously deactivated modems. For example, controller 214 determines whether any of the activation timeout periods have expired, thereby indicating it is time to activate the corresponding deactivated modem. Alternatively, controller 214 determines whether the activation time/event scheduled at step 1004 has arrived.

[0108] Alternative arrangements of method 1000, similar to the alternative arrangements discussed above in connection with method 700, are also envisioned.

VI. Fixed Transmit Power Limit Arrangements

1. Uniform Limits

[0109] In one fixed limit arrangement, a uniform set of fixed transmit power limits is established across all of modems 216. That is, each modem has the same transmit power limit as each of the other modems. FIG. 11 is an example plot of Power versus

Modem index(i) identifying respective ones of the modems 216, wherein uniform, modem transmit power limits P_{Li} are depicted. As depicted in FIG. 11, modem(1) corresponds to power limit P_{L1}, modem(2) corresponds to power limit P_{L2}, and so on.

[0110] In one arrangement of uniform limits, each transmit power limit P_L is equal to the aggregate transmit power limit APL divided by the total number N of modems 216. Under this arrangement of uniform limits, when all of the modems have respective transmit powers equal to their respective transmit power limits, the aggregate transmit power for all of the modems will just meet, and not exceed, the APL. An example APL in the present invention is approximately 10 or 11 decibel-Watts (dBW).

[0111] FIG. 11 also represents an example transmit scenario for MWT 206. Depicted in FIG. 11 are representative, requested modem transmit powers P_{R1} and P_{R2} corresponding to modem(1) and modem(2). The example transmit scenario depicted in FIG. 11 corresponds to the scenario in which all of the requested modem transmit powers are below the respective, uniform transmit power limits. In this situation, none of the modems are over-limit, and thus rate-limiting.

[0112] FIG. 12 is another example transmit scenario similar to FIG. 11, except that modem(2) has a requested power P_{R2} exceeding respective transmit power limit P_{L2}. Therefore, modem(2) is over-limit, and thus rate-limiting. Since modem(2) is over-limit, controller 214 deactivates modem(2) in accordance with method 700 or method 1000, thereby causing modem(2) to transmit at a zero-data rate, and at a correspondingly reduced transmit power level 1202.

2. Tapered Limits

[0113] FIG. 13 is an illustration of an alternative, tapered arrangement for the fixed modem transmit power limits. As depicted, the tapered arrangement includes progressively decreasing transmit power limits P_{Li} in respective successive ones of the N modems, where i = 1 . . N. For example, transmit power limit P_{L1} for modem(1) is less than transmit power limit P_{L2} for modem(2), which is less than transmit power limit P_{L3}, and so on down the line.

[0114] In one tapered arrangement, each of the transmit power limits P_{Li} is equal to the APL divided by the total number of modems having transmit power limits greater than or equal to P_{Li}. For example, transmit power limit P_{L5} is equal to the APL divided by five (5), which is the number of modems having transmit power limits greater than or equal to P_{L5}. In another tapered arrangement, each transmit power limit P_{Li} is equal to the transmit power limit mentioned above (that is, the APL divided by the total number of modems having transmit power limits greater than or equal to P_{Li}) less a predetermined amount, such as one, two or even three decibels (dB). This permits a safety margin in the event that the modems tend to transmit at an actual transmit power level that is slightly higher than the respective transmit power limits, before they are deactivated.

[0115] Assume a transmit scenario where all of the modems transmit at approximately the same power, and all of the transmit powers are increasing over time. Under the tapered arrangement, modem(N) rate-limits first, modem(N-1) rate limits next, modem(N-2) rate-limits third, and so on. In response, controller 214 deactivates/deschedules modem(N) first, modem(N-1) second, modem(N-3) third, and so on.

VII. Modem Calibration – Determining Gain Factors g(i)

[0116] As described above in connection with FIG. 2, each modem 216i generates a transmit signal $222i_T$ having a respective transmit power level. Also, each modem 216i generates a status report including a modem transmit power estimate $P_{Rep}(i)$ of the respective transmit power level. Each modem transmit signal $222i_T$ traverses a respective transmit path from modem 222i to the output of transmit amplifier 228. The respective transmit path includes RF connections, such as cables and connectors, power combiner/splitter assembly 220, and transmit amplifier 228. Therefore, transmit signal $222i_T$ experiences a respective net power gain or loss g(i) along the respective transmit path. An example gain for the above-mentioned transmit path is approximately 29 dB.

[0117] Accordingly, the gain or loss g(i) of the respective transmit path may cause the power level of respective transmit signal $222i_T$ at the output of modem 222i to be different from the transmit power level at the output of transmit amplifier 228. Therefore, the respective modem transmit power estimate $P_{Rep}(i)$ may not accurately represent the respective transmit power at the output of transmit amplifier 228. A more accurate estimate $P_O(i)$ of the transmit power at the output of transmit amplifier 228 (due to modem 222i), is the reported power $P_{Rep}(i)$ adjusted by the corresponding gain/loss amount g(i). Therefore, g(i) is referred to as a modem dependent gain correction factor g(i), or the modem gain factor g(i) for modem 222i.

[0118] When reported modem transmit power estimate $P_{Rep}(i)$ and modem gain correction factor g(i) both represent power terms (as expressed in decibels or Watts, for example), the corrected transmit power estimate $P_O(i)$ is given by:

$$P_O(i) = g(i) + P_{Rep}(i).$$

[0119] Alternatively, when reported transmit power estimate $P_{Rep}(i)$ and modem gain correction factor g(i), in Watts, for example, the transmit power $P_O(i)$ is given by:

$$P_O(i) = g(i)P_{Rep}(i).$$

[0120] It is useful to be able to calibrate MWT 206 dynamically, to determine the gain correction factors g(i) corresponding to all of the N modems. Once the factors g(i) are determined, they can be used to calculate more accurate individual and aggregate modem transmit power estimates from the modem transmit power reports.

[0121] FIG. 14 is a flowchart of an example method of calibrating modems 216 in MWT 206. At a first step 1405, controller 214 schedules all N modems 216 to transmit data, so as to cause all of the modems to transmit data, concurrently.

[0122] At a next step 1410, controller 214 collects status reports 500, including respective reported transmit powers $P_{Rep}(i)$, where i represents modem i, and i = 1 . . N.

[0123] At a next step 1420, controller 214 receives an aggregate transmit power measurement P_{Agg} for all of the N modems, for example, as determined by transmit power monitor 234.

[0124] At a next step 1425, controller 214 generates an equation representing the aggregate transmit power as a cumulative function of reported transmit powers $P_{Rep}(i)$ and corresponding unknown, modem dependent gain correction factors g(i). For example, aggregate transmit power P_{Agg} is represented as:

$$P_{Agg} = \sum_{i=1}^{N_N} g(i)P_{Rep}(i).$$

[0125] At a next step 1430, previous steps 1405, 1410, 1420 and 1425 are repeated N times to generate N simultaneous equations in $P_{Rep}(i)$ and unknown gain correction factors g(i).

[0126] At a next step 1435, controller 214 determines the N gain correction factors g(i) by solving the N equations generated in step 1430. Determined gain correction factors g(i) are stored in memory 215 of MWT 206, and used as needed to adjust/correct modem transmit power estimates $P_{Rep}(i)$ in the methods of the invention, described below. Method 1400 may be scheduled to repeat periodically to update factors g(i) over time.

VIII. Methods Using Dynamically Updated Transmit Limits

[0127] FIG. 15 is a flowchart of an example method 1500 of operating MWT 206, using dynamically updated individual modem transmit power limits. In method 1500, controller 214 initializes (step 702), schedules and deschedules active and inactive ones of modems 216 (step 710), and monitors status reports from the modems (step 712), as described above. At a next step 1502, controller 214 determines whether to modify (for example, increase or decrease) or maintain the number of active modems of MWT 206, in order to maximize an aggregate reverse link data rate (that is, the aggregate transmit data rate) without exceeding the aggregate transmit power limit of the MWT.

[0128] At a next step 1504, controller 214 increases, decreases, or maintains the number of active modems, as necessary, in accordance with step 1502. To increase the number of active modems, controller 214 adds one or more previously inactive modems to the active list. Conversely, to decrease the number of active modems, controller 214 deletes one or more previously active modems from the active list.

[0129] At a next step 1506, controller 214 updates/adjusts individual transmit power limits in at least some of modems 216, as necessary. Techniques for adjusting individual transmit power limits will be described further below. In step 1506, the individual transmit power limits are adjusted across modems 216 such that when all of the individual transmit limits are combined together into a combined transmit power limit, the combined transmit power limit does not exceed the aggregate transmit power limit of MWT 206. Exemplary transmit power limit arrangements that may be used with method 1500 are described later in connection with Table 1 and FIG. 19. A reason for varying modem transmit power limits in method 1500 is to avoid rate-limiting conditions in the modems. Also, a reason for deactivating modems (that is, decreasing the number of active modems) includes avoiding rate-limiting conditions so as to increase the overall transmit data rate on the reverse-link while operating under the aggregate transmit power limit.

[0130] At first blush, it might appear that deactivating modems would decrease, not increase, the transmit data rate. However, operating a number of modems, for example, 16 modems, at their rate-limited data rates (for example, at 4800 bps) achieves a lower effective data rate than operating a lesser number modems, for example 8 modems, at their full rates (for example, 9600 bps), even though each case may have the same aggregate transmit power. This is because the ratio of overhead information (used to manage the data calls, for example) to actual/useful data (used by end users, for example) is disadvantageously greater for rate limiting modems compared to non-rate limiting modems.

[0131] FIG. 16 is a flowchart of an example method 1600 expanding on method 1500. Method 1600 includes a step 1602 expanding on step 1502 of method 1500. Step 1602 includes further steps 1604 and 1606. At step 1604, controller 214 determines a maximum number N_{Max} of active modems that can concurrently transmit at their respective maximum data rates (for example, at 9600 bps), without exceeding the aggregate transmit power limit of MWT 206. It is assumed that N_{Max} is less than or equal to a total number N of modems 216.

[0132] At next step 1606, controller 214 compares the maximum number N_{Max} to a number M of previously active modems (that is, the number of active modems used in a previous pass through step 710, described above).

[0133] A next step 1610, corresponding to step 1504 of method 1500, includes further steps 1612, 1614 and 1616. If the maximum number N_{Max} of active modems from step 1604 is greater than the number M of previously active modems, then the method proceeds from step 1606 to next step 1612. At step 1612, controller 214 increases the number M of active modems to the maximum number N_{Max} of active modems. To do this, controller 214 selects an inactive modem to activate from among the N modems.

[0134] Alternatively, if the maximum number N_{Max} of modems is less than M, then processing proceeds from step 1606 to step 1614. At step 1614, controller 214 decreases the number of active modems. To do this, controller 214 selects an active modem to deactivate. Steps 1612 and 1614 together represent an adjusting step (also referred to as a modifying step) where the number M of previously active modems is modified in preparation for a next pass through steps 710, 712, and so on.

[0135] Alternatively, if the maximum number N_{Max} is equal to M, then processing proceeds from step 1606 to step 1616. In step 1616, controller 214 simply maintains the number of active modems at M, for the next pass through steps 710, 712, and so on.

[0136] The method proceeds from both modifying steps 1612 and 1614 to a next, limit adjusting step 1620. At step 1620, controller 214 increases the individual transmit power limits in the one or more modems that were activated at step 1612. Conversely, controller 214 decreases the individual power limits in the one or more modems that were deactivated in step 1614.

[0137] The method proceeds from steps 1610 and 1620 back to scheduling/descheduling step 710, and the process described above repeats.

[0138] FIG. 17 is a flowchart of an example method 1700 of determining the maximum number N_{Max} of active modems using an average energy-per-transmitted-bit of the N modems. Method 1700 expands on step 1604 of method 1600. At a first step 1702, controller 214 determines an aggregate transmit data rate based on the respective transmit data rates reported by the N modems. For example, controller 214 adds together all of the transmit data rates reported by the N modems in respective status reports 500.

[0139] At a next step 1704, controller 214 determines an aggregate power level of transmit signal 230, at the output of transmit amplifier 228. For example, controller 214 may receive transmit power measurements (signal 236) from transmit power monitor 234. Alternatively, controller 214 may aggregate individual modem transmit power estimates $P_{Rep}(i)$ (as corrected using factors g(i)) received from the individual modems in respective status reports 500.

[0140] At a next step 1706, controller 214 determines the average energy-per-transmitted-bit across the N modems 216 based on the aggregate data rate and the aggregate transmit power. In one arrangement of the embodiments, controller 214 determines the average energy-per-transmitted-bit in accordance the following relationships:

$BE_{b\_avg} = P(t)\Delta t = E_T$, and, therefore,

$E_{b\_avg} = (P(t)\Delta t)/B = E_T/B$,

where:

Δt is a predetermined measurement time interval (for example, the duration of a transmitted frame, such as 20 ms),

B is the aggregate data rate during time interval Δt,

E_{b_avg} is the average energy-per-transmitted-bit during time interval Δt,

P(t) is the aggregate transmit power during time interval Δt, and

E_T is the total energy of all the bits transmitted during time interval Δt.

[0141] At a next step 1708, controller 214 determines the maximum number N_{Max} based on the average energy-per-transmitted-bit and the aggregate transmit power limit. In one arrangement, controller 214 determines the maximum number N_{Max} in accordance with the following equations:

$((R_{max}N_{Max} + R_{min}(N - N_{Max}))E_{b\_avg} = APL$, and, therefore,

$N_{Max} = ((APL/E_{b\_avg}) - P_{min}N)/(R_{max} - R_{min})$,

where:

APL is the aggregate transmit power limit of MWT 206 (for example, 10 or 11 decibel-Watts (dBW)),

R_{max} is a maximum data rate of the N modems (for example, 9600 bps),

R_{min} is a minimum data rate of the N modems (for example, 2400 bps),

E_{b_avg} is the average energy-per-transmitted-bit during time interval Δt,

N is the total number of modems 216, and

N_{Max} is the maximum number of active modems to be determined.

[0142] FIG. 18 is a flowchart of an example method 1800 of determining the maximum number N_{Max} of active modems, using an individual energy-per-transmitted-bit for each of modems 216. Method 1800 expands on step 1604 of method 1600. At a first step 1802, controller 214 determines an individual energy-per-transmitted-bit $E_b(i)$ for each modem using modem reports 500. In one arrangement of the embodiment, controller

214 determines each energy-per-transmitted-bit $E_b(i)$ in accordance the following relationship:

$$E_b(i) = g(i)P_{Rep}(i)\Delta t/Bi,$$

where:

Δt is a predetermined measurement time interval,

$E_b(i)$ is the individual energy-per-transmitted-bit for modem i, where i = 1 . . N, over time interval Δt,

$P_{Rep}(i)$ is a reported modem transmit power (that is, a transmit power estimate for modem i), and

g(i) is a modem dependent gain correction factor, also referred to as a gain calibration factor (described above in connection with FIG. 14), and

Bi is the transmit data rate of modem i.

[0143] At a step 1804, controller 214 sorts the modems according to their respective energy-per-transmitted-bits $E_b(i)$.

[0144] At a next step 1805, controller 214 determines the maximum number N_{Max} of active modems based on the individual modem energy-per-transmitted-bits, using an iterative process. In one arrangement, the iterative process of step 1805 determines the maximum number N_{Max} of active modems that can be supported, using the following equation:

$$APL = \sum_{i=1}^{N_{Max}} P_{max}E_b(i) + \sum_{i=N_{Max}}^{N} P_{min}E_b(i),$$

where:

APL is the aggregate transmit power limit,

P_{max} is the maximum data rate for each modem,

P_{min} is the minimum data rate for each modem, and

$E_b(i)$ is the individual energy-per-transmitted-bit for modem i.

[0145] Step 1805 is now described in further detail. A step 1806 within step 1805 is an initializing step in the iterative process, wherein modem 214 sets a test number N_{Act} of active modems equal to one (1). Test number N_{Act} represents a test, maximum number of active modems. At a next step 1808, modem 214 determines an expected transmit power P_{Exp} using the test number N_{Act} of modems. In step 1808, it is assumed that the test number N_{Act} of modems having the lowest individual energy-per-transmitted-bits among the N modems each transmit at a maximum data rate (for example, 9600 bps). In the arrangement mentioned above, step 1808 determines the expected transmit power in accordance with the following relationship:

$$P_{Exp} = \sum_{i=1}^{N_{act}} P_{max}E_b(i) + \sum_{i=N_{act}}^{N} P_{min}E_b(i),$$

[0146] At a next step 1809, controller 214 compares the expected transmit power P_{Exp} to the APL. If P_{Exp} < APL, then more active modems can be supported. Thus, the test number N_{Act} of active modems is incremented (step 1810), and the method proceeds back to step 1808.

[0147] Alternatively, if P_{Exp} = APL, then the maximum number N_{Max} of active modems is set equal to the present test number N_{Act} (step 1812).

[0148] Alternatively, if P_{Exp} > APL, then the maximum number N_{Max} is set equal to the previous test number of active modems, that is, $N_{Act} - 1$ (step 1814).

[0149] If P_{Exp} is neither equal to nor greater than APL then the process returns to step 1810 and step 1809. At some point a maximum number of modems may be reached or exceeded and either step 1812 or 1814, respectively, are reached. The process for recalculating APL checking the current N (number of access terminals in use), or checking P_{Exp} relative to APL, may be repeated every so often or on a periodic basis as part of an iterative procedure to prevent overdriving the power amplifier.

IX. Example Transmit Power Limits

[0150] Table 1, below, includes exemplary modem transmit power limits that may be used in the present invention.

TABLE 1

A	B	C	D
No. active modems (Total N = 16)	Active Modem Limits (dBm) APL = 10 dBW	Active Modem Limits (dBm) APL = 11dBW	Active Modem Limits (dBm) APL = 10 dBW
1.0	5.0	5.2	4.2
2.0	5.0	4.6	3.6
3.0	5.0	4.0	3.0
4.0	5.0	3.5	2.5
5.0	4.0	3.1	2.1
6.0	3.2	2.7	1.7
7.0	2.5	2.3	1.3
8.0	2.0	2.0	1.0
9.0	1.5	1.7	0.7
10.0	1.0	1.4	0.4
11.0	0.6	1.1	0.1
12.0	0.2	0.9	-0.1
13.0	-0.1	0.6	-0.4
14.0	-0.5	0.4	-0.6
15.0	-0.8	0.2	-0.8
16.0	-1.0	0.0	-1.0

[0151] The transmit power limits of Table 1 may be stored in memory 215 of MWT 206. Table 1 assumes MWT 206 includes a total of N = 16 modems. Each row of table 1 represents a corresponding number (such as 1, 2, 3, and so on, down the rows) of active ones of the N modems, at any given time. Each row of Column A identifies a given number of active modems. The number of inactive modems corresponding to any given row of Table 1 is the difference between the total number of modems (16) and the number of active modems specified in the given row.

[0152] Columns B, C and D collectively represent three different individual transmit power limit arrangements of the present invention. The transmit limit arrangement of column B assumes an APL of 10 dBW in MWT 206. Also, the arrangement of column B assumes that, in any given row, all of the active modems receive a common maximum transmit limit, while all of the inactive modems receive a common minimum transmit limit equal to zero. For example in column B, when the number of active modems is six (6), a common maximum transmit limit of 3.2 decibel-milliwatt (dBm) is established in each of the active modems, and a common minimum transmit limit of zero is established in each of the ten (10) inactive modems. The sum of the maximum transmit power limits in all of the active modems corresponding to any given row is equal to the APL.

[0153] The transmit limit arrangement of column C assumes an APL of 11 dBW in MWT 206. Also, the arrangement of column C assumes that, for any given number of active modems (that is, for each row in Table 1), all of the active modems receive a common maximum transmit limit, while all of the inactive modems receive a common minimum transmit limit equal to the maximum transmit limit less six (6) dB. For example in column C, when the number of active modems is six (6), a maximum transmit limit of 2.7 dBm is established in each of the six (6) active modems, and a minimum transmit limit of (2.7 – 6) dBm is established in each of the ten (10) inactive modems. The sum of the maximum transmit power limits in all of the active modems, together with the sum of the minimum transmit power limits in all of the inactive modems, corresponding to any given row is equal to the APL. Since the transmit power limit in each of the inactive modems is greater than zero, the inactive modems may be able to transmit at respective minimum data rates, or at least at the zero-data rate, in order to maintain their respective data links active.

[0154] The transmit limit arrangement of column D is similar to that of column C, except a lower APL of 10 dBW is assumed in the arrangement of column D. The arrangement of column D assumes that, for any given number of active modems (that is, for each row in Table 1), all of the active modems receive a common maximum transmit limit, while all of the inactive modems receive a common minimal transmit limit equal to the maximum transmit limit less six (6) dB. For example, from column D, when the number of active modems is six (6), a maximum transmit limit of 1.7 dBm is established in each of the active modems, and a transmit limit of (1.7 – 6) dBm is established in each of the ten (10) inactive modems.

[0155] Controller 214 can use the limits specified in Table 1 to establish and adjust individual transmit limits in modems 216 in methods 1500 and 1600, described above in connection with FIGS. 15 and 16. For example, assume the transmit limit arrangement of Table 1, column D, is being used with method 1600. Assume the number of active modems in a previous pass through step 710 is seven. During the previous pass, a transmit limit of 1.3 dBm is established in each of the seven active modems, and a transmit limit of (1.3 –6) dBm is established in the other nine, inactive modems (see the entry in column D corresponding to seven active modems). Also assume that in the next pass through steps 1602 and 1614, the number of active modems is decreased from seven down to six. Then, at limit adjusting step 1620, a new transmit limit of 1.7 dB is established in each of the six active modems, and a transmit limit of (1.7 – 6) dB is established in each of the ten remaining inactive modems.

[0156] FIG. 19 is a graphical representation of the information presented in Table 1. FIG. 19 is a plot of transmit limit power (in dBm) versus the number of active modems (labeled as N) for each of the transmit limit arrangements listed in columns B, C and D of Table 1. In FIG. 19, the transmit limit arrangement of column B is represented by a curve COL B, the limit arrangement of column C is represented by a curve COL C, and the limit arrangement of column D is represents by a curve COL D.

X. MWT Computer Controller

[0157] FIG. 20 is a functional block diagram of an example controller (which can also be a plurality of controllers) 2000 representing controller 214. Controller 2000 includes a series of controller modules for performing the various method steps of the embodiments discussed above.

[0158] A scheduler/descheduler 2002 schedules active modems to transmit payload data, and de-schedules inactive modems; a call manager 2004 establishes data calls and tears-down data calls over the plurality of modems 216; and a status monitor 2006 monitors status reports from modems 216, for example, to determine when various ones of the modems are over-limit, and to collect modem transmit data rates and transmit powers. Status monitor 2006 may also determine an aggregate data rate and an aggregate transmit power based on the modem reports.

[0159] A deactivator/activator module 2008 acts to deactivate over-limit ones (in the fixed limit arrangement of the present invention) of the modems (for example by removing the modems from the active list) and to activate deactivated ones of the modems by reinstating the modems on the active list. Module 2008 also activates/deactivates selected ones of the modems in accordance with steps 1504, 1612, and 1614 of methods 1500 and 1600.

[0160] A limit calculator 2010 operates to calculate/derive transmit power limits for each of the modems 216. Limit calculator also accesses predetermined transmit power limits stored in memory 215, for example.

[0161] An initializer 2012 supervises/manages initialization of the system, such as establishing initial transmit power limits in each modem, setting up calls over each modem, initializing various lists and queues in MWT 206, and so on.

[0162] A modem interface 2014 receives data from and transmits data to modems 216, and a network interface 2016 receives and transmits data over interface 210.

[0163] A module 2020 determines whether to modify the number of active modems in accordance with steps 1502 and 1602 of methods 1500 and 1600. Module 2020 includes a sub-module 2022 for determining a maximum number of active modems that can be supported based on either an average-energy-per-transmitted-bit or individual modem energy-per-transmitted-bits. Sub-module 2022 includes comparison or comparing logic (such as a comparator) configured to operate in accordance with comparing step 1606 of method 1600. Module 2020 also includes sub-modules 2024 and 2026 for determining the average-energy-per-transmitted-bit and the individual modem energy-per-transmitted-bits, respectively. Sub-modules 2024 and 2026, or alternatively, status monitor 2006, also determine an aggregate data rate and an aggregate transmit power based on modem reports.

[0164] A calibration module 2040 controls calibration in MWT 206 in accordance with method 1400, for example. The calibration module includes an equation generator to generate simultaneous equations and an equation solver to solve the equations to determine modem correction factors g(i). The calibration module can also call/incorporate other modules, as necessary, to perform calibration of MWT 206.

[0165] A software interface 2050 is used for interconnecting all of the above mentioned modules to one another.

[0166] Features of the present invention can be performed and/or controlled by processor/controller 214, which in effect comprises a programmable or software-controllable element, device, or computer system. Such a computer system includes, for example, one or more processors that are connected to a communication bus. Although telecommunication-specific hardware can be used to implement the present invention, the following description of a general purpose type computer system is provided for completeness.

[0167] The computer system can also include a main memory, preferably a random access memory (RAM), and can also include a secondary memory and/or other memory. The secondary memory can include, for example, a hard disk drive and/or a removable storage drive. The removable storage drive reads from and/or writes to a removable storage unit in a well known manner. The removable storage unit, represents a floppy disk, magnetic tape, optical disk, and the like, which is read by and written to by the removable storage drive. The removable storage unit includes a computer usable storage medium having stored therein computer software and/or data.

[0168] The secondary memory can include other similar means for allowing computer programs or other instructions to be loaded into the computer system. Such means can include, for example, a removable storage unit and an interface. Examples of such can include a program cartridge and cartridge interface (such as that found in video game devices), a removable memory chip (such as an EPROM, or PROM) and associated socket, and other removable storage units and interfaces which allow software and data to be transferred from the removable storage unit to the computer system.

[0169] The computer system can also include a communications interface. The communications interface allows software and data to be transferred between the computer system and external devices. Software and data transferred via the communications interface are in the form of signals that can be electronic, electromagnetic, optical or other signals capable of being received by the communications interface. As depicted in FIG. 2, processor 214 is in communications with memory 215 for storing information. Processor 214, together with the other components of MWT 206 discussed in connection with FIG. 2, performs the methods of the present invention.

[0170] In this document, the terms "computer program medium" and "computer usable medium" are used to generally refer to media such as a removable storage device, a removable memory chip (such as an EPROM, or PROM) within MWT 206, and signals. Computer program products are means for providing software to the computer system.

[0171] Computer programs (also called computer control logic) are stored in the main memory and/or secondary memory. Computer programs can also be received via the communications interface. Such computer programs, when executed, enable the computer system to perform certain features of the present invention as discussed herein. For example, features of the flow charts depicted in FIGS. 7, 8, 9 and 10, can be implemented in such computer programs. In particular, the computer programs, when executed, enable processor 214 to perform and/or cause the performance of features of the present invention. Accordingly, such computer programs represent controllers of the computer system of MWT 206, and thus, controllers of the MWT.

[0172] Where the embodiments are implemented using software, the software can be stored in a computer program product and loaded into the computer system using the removable storage drive, the memory chips or the communications interface. The control logic (software), when executed by processor 214, causes processor 214 to perform certain functions of the invention as described herein.

[0173] Features of the invention may also or alternatively be implemented primarily in hardware using, for example, a software-controlled processor or controller programmed to perform the functions described herein, a variety of programmable electronic devices, or computers, a microprocessor, one or more digital signal processors (DSP), dedicated function circuit modules, and hardware components such as application specific integrated circuits (ASICs) or programmable gate arrays (PGAs). Implementation of the hardware state machine so as to perform the functions described herein will be apparent to persons skilled in the relevant art(s).

[0174] The previous description of the preferred embodiments is provided to enable a person skilled in the art to make or use the present invention. While the invention has been particularly shown and described with reference to embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

XI. Conclusion

[0175] The present invention has been described above with the aid of functional building blocks illustrating the performance of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed. Any such alternate boundaries are thus within the scope and spirit of the claimed invention. One skilled in the art will recognize that these functional building blocks can be implemented by discrete components, application specific integrated circuits, processors executing appropriate software and the like or many combinations thereof. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

CLAIMS

What we claim as our invention is:

1. A method of operating a wireless device within an aggregate transmit power limit, the wireless device including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, comprising:

(a) scheduling a plurality, M, of active ones of the N modems to transmit payload data, where M is less than or equal to N;

(b) monitoring status reports from at least the active modems;

(c) determining, based on the status reports, whether to modify the number of active modems in order to maximize an aggregate transmit data rate of the N modems while maintaining an aggregate transmit power of the N modems at or below the aggregate transmit power limit; and

(d) modifying the number of active modems when it is determined in step (c) that the number of active modems should be modified to maintain the aggregate transmit power level of the N modems at or below the aggregate transmit power level.

2. The method of claim 1, wherein step (d) comprises modifying the number of active modems to a modified number of active modems when it is determined that the number of active modems should be modified, the method further comprising:

(e) repeating steps (a), (b), and (c) for the modified number of active modems.

3. The method of claim 1, wherein step (c) comprises:

(c)(i) determining a maximum number of active modems that can concurrently transmit data, each at a predetermined maximum data rate, while maintaining the aggregate transmit power of the N modems at or below the aggregate transmit power limit; and

(c)(ii) comparing the maximum number of active modems to the number M of active modems.

4. The method of claim 3, wherein step (c)(i) comprises:

determining an average energy-per-transmitted-bit across at least the M active modems; and

determining the maximum number of active modems based on the average energy-per-transmitted-bit and the aggregate transmit power limit.

5. The method of claim 4, wherein the status reports monitored in step (b) indicate a respective transmit data rate for each of the N modems, said step of determining the average energy-per-transmitted-bit comprising:

determining an aggregate transmit data rate across the N modems based on their respective transmit data rates;

determining the aggregate transmit power; and

determining the average energy-per-transmitted-bit based on the aggregate transmit data rate and the aggregate transmit power.

6. The method of claim 3, wherein step (c)(i) comprises:

determining an individual energy-per-transmitted-bit for each of the N modems; and

determining the maximum number of active modems based on the individual energy-per-transmitted-bits and the aggregate transmit power limit.

7. The method of claim 6, wherein the status reports monitored in step (b) indicate a respective transmit power for each of the N modems, said step of determining the individual energy-per-transmitted-bit comprising determining the individual energy-per-transmitted-bit for each of the N modems based on the respective transmit power.

8. The method of claim 6, further comprising:

selecting as next active modems the maximum number of modems having the lowest individual energy-per-transmitted-bits among the N modems; and

repeating step (a) using the next active modems.

9. The method of claim 3, wherein step (d) comprises increasing the number of active modems to the maximum number when the maximum number is greater than M.

10. The method of claim 3, wherein step (d) comprises decreasing the number of active modems to the maximum number when the maximum number is less than M.

11. The method of claim 1, further comprising:

prior to step (a), establishing a respective transmit power limit for each of the N modems to limit the respective transmit powers of each of the N modems, wherein all of the transmit power limits, when combined, represent a combined transmit power limit that is less than or equal to the aggregate transmit power limit.

12. The method of claim 1, wherein:

a respective transmit power limit is established in each of the N modems to limit the respective transmit powers of each of the N modems;

step (d) comprises activating a selected, previously inactive one of the N modems, thereby increasing the number of active modems; and

the method further comprises increasing the respective transmit power limit in the selected one of the N modems.

13. The method of claim 1, wherein:

a respective transmit power limit is established in each of the N modems to limit the respective transmit powers of each of the N modems;

step (d) comprises deactivating a selected, previously active one of the N modems, thereby decreasing the number of active modems; and

the method further comprises decreasing the respective transmit power limit in the selected one of the N modems.

14. The method of claim 1, further comprising:

prior to step (a), establishing an individual communication link between a remote station and each of the N modems, each communication link including a forward link and a reverse link, whereby each modem is able to transmit data in the reverse link direction and receive data in the forward link direction; and

maintaining all of the communication links during steps (a), (b), (c) and (d).

15. The method of claim 14, wherein each communication link is a Code Division Multiple Access (CDMA) based communication link.

16. A method of operating a wireless terminal within an aggregate transmit power limit, the wireless terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, the method comprising:

(a) determining an average energy-per-transmitted-bit across a plurality of previously active ones of the N modems that were previously transmitting;

(b) determining, based on the average energy-per-transmitted-bit and the aggregate transmit power limit, a maximum number of active modems that can concurrently transmit data at a maximum data rate without exceeding the maximum aggregate transmit power limit; and

(c) scheduling data-to-be-transmitted over the determined maximum number of active modems.

17. The method of claim 16, further comprising:

prior to step (a):

determining an aggregate transmit power of the N modems corresponding to when the plurality of active modems were previously transmitting data;

monitoring status reports from the N modems, the status reports indicating a respective transmit data rate for each of the N modems; and

determining, based on the respective transmit data rates, an aggregate data rate of the N modems corresponding to the aggregate transmit power; and

wherein step (a) comprises determining the average energy-per-transmitted-bit based on the aggregate transmit power and the aggregate data rate.

18. The method of claim 16, wherein:

each of the N modems is adapted to transmit data at at least one of a maximum transmit data rate and a minimum transmit data rate; and

step (b) comprises determining the maximum number of active modems based on the minimum and maximum transmit data rates as well as the average energy-per-transmitted-bit and the aggregate transmit power limit.

19. The method of claim 16, comprising:

repeating steps (a), (b) and (c) periodically, thereby causing the maximum of active modems to vary over time in correspondence with the average energy-per-transmitted bit.

20. A method of operating a wireless terminal within an aggregate transmit power limit, the wireless terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, the method comprising:

(a) determining an individual energy-per-transmitted-bit for each of the N modems that was previously transmitting;

(b) determining, based on all of the individual energy-per-transmitted-bits and the aggregate transmit power limit, a maximum number of active modems that can concurrently transmit data at a maximum data rate without exceeding the aggregate transmit power limit; and

(c) scheduling the maximum number of active modems to transmit data.

21. The method of claim 20, further comprising:

prior to step (c), sorting the N modems according to their respective individual energy-per-transmitted-bits; and

wherein step (c) comprises scheduling the maximum number of active modems having the lowest individual energy-per-transmitted-bits among the N modems.

22. The method of claim 20, further comprising, prior to step (a), monitoring status reports from at least the active modems, the status reports collectively including a transmit power estimate of each active modem,

wherein step (a) comprises determining, from each transmit power estimate, the corresponding individual energy-per-transmitted-bit.

23. A method of dynamically calibrating a wireless terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, the method comprising:

(a) scheduling each of the N modems to concurrently transmit respective data, thereby causing each of the N modems to concurrently transmit;

(b) receiving respective reported transmit powers $P_{Rep}(i)$ from the N modems corresponding to when the N modems concurrently transmit, where i designates a respective modem from 1 to N;

(c) measuring, at the aggregate transmit output, an aggregate transmit power P_{Agg} of the N modems corresponding to when the N modems concurrently transmit;

(d) generating an equation representing the aggregate transmit power as a cumulative function of each reported transmit power $P_{Rep}(i)$ and a corresponding, undetermined, modem dependent gain factor g(i);

(e) repeating steps (a), (b), (c) and (d) N times to generate N simultaneous equations; and

(f) determining all of the modem dependent gain factors from the N simultaneous equations.

24. The method of claim 23, further comprising:

repeating steps (a) through (f) periodically, whereby the modem dependent gain factors are updated periodically.

25. A wireless terminal constrained to operate under an aggregate transmit power limit, the wireless terminal including N wireless modems having their respective transmit outputs combined together to produce an aggregate transmit output, comprising:

means for scheduling a plurality, M, of active ones of the N modems to transmit payload data, where M is less than or equal to N;

means for monitoring status reports from at least the active modems;

means for determining, based on the status reports, whether to modify the number of active modems in order to maximize an aggregate transmit data rate of the N modems while maintaining an aggregate transmit power of the N modems at or below the aggregate transmit power limit; and

means for modifying the number of active modems when it is determined that the number of active modems should be modified to maintain the aggregate transmit power level of the N modems at or below the aggregate transmit power level.

26. The wireless terminal of claim 25, wherein:

said modifying means comprises means for modifying the number of active modems to an modified number of active modems when it is determined that the number of active modems should be modified; and

the scheduling means, the monitoring means, and the modifying means repeat their respective functions using the modified number of active modems.

27. The wireless terminal of claim 25, wherein the determining means comprises:

means for determining a maximum number of active modems that can concurrently transmit data, each at a predetermined maximum data rate, while maintaining the aggregate transmit power of the N modems at or below the aggregate transmit power limit; and

means for comparing the maximum number of active modems to the number M of active modems.

28. The wireless terminal of claim 27, wherein the means for determining the maximum number comprises:

means for determining an average energy-per-transmitted-bit across at least the M active modems; and

means for determining the maximum number of active modems based on the average energy-per-transmitted-bit and the aggregate transmit power limit.

29. The wireless terminal of claim 28, wherein the status reports monitored by the monitoring means indicate a respective transmit data rate for each of the N modems, said means for determining the average energy-per-transmitted-bit comprising:

means for determining an aggregate transmit data rate across the N modems based on their respective transmit data rates;

means for determining the aggregate transmit power; and

means for determining the average energy-per-transmitted-bit based on the aggregate transmit data rate and the aggregate transmit power.

30. The wireless terminal of claim 27, wherein the means for determining the maximum number comprises:

means for determining an individual energy-per-transmitted-bit for each of the N modems; and

means for determining the maximum number of active modems based on the individual energy-per-transmitted-bits and the aggregate transmit power limit.

31. The wireless terminal of claim 30, wherein the status reports monitored by the monitoring means indicate a respective transmit power for each of the N modems, the means for determining the individual energy-per-transmitted-bit comprising means for determining the individual energy-per-transmitted-bit for each of the N modems based on the respective transmit power.

32. The wireless terminal of claim 30, further comprising:

means for selecting as next active modems the maximum number of modems having the lowest individual energy-per-transmitted-bits among the N modems; and

wherein the means for scheduling repeats its respective function using the next active modems.

33. The wireless terminal of claim 27, wherein the modifying means comprises means for increasing the number of active modems to the maximum number when the maximum number is greater than M.

34. The wireless terminal of claim 27, wherein the modifying means comprises means for decreasing the number of active modems to the maximum number when the maximum number is less than M.

35. The wireless terminal of claim 25, further comprising:

means for establishing a respective transmit power limit for each of the N modems to limit the respective transmit powers of each of the N modems, wherein all of the transmit power limits, when combined, represent a combined transmit power limit that is less than or equal to the aggregate transmit power limit.

36. The wireless terminal of claim 25, wherein:

a respective transmit power limit is established in each of the N modems to limit the respective transmit powers of each of the N modems;

the modifying means comprises means for activating a selected, previously inactive one of the N modems, thereby increasing the number of active modems; and

the wireless terminal further comprises means for increasing the respective transmit power limit in the selected one of the N modems.

37. The wireless terminal of claim 25, wherein:

a respective transmit power limit is established in each of the N modems to limit the respective transmit powers of each of the N modems;

the modifying means comprises means for deactivating a selected, previously active one of the N modems, thereby decreasing the number of active modems; and

the wireless terminal further comprises decreasing the respective transmit power limit in the selected one of the N modems.

38. The wireless terminal of claim 25, further comprising:

means for establishing an individual communication link between a remote station and each of the N modems, each communication link including a forward link and a reverse link, whereby each modem is able to transmit data in the reverse link direction and receive data in the forward link direction; and means for maintaining all of the communication links while the scheduling means, the monitoring means, the determining means, and the modifying means perform their respective functions.

39. The wireless terminal of claim 38, wherein each communication link is a Code Division Multiple Access (CDMA) based communication link.

40. A wireless terminal constrained to operate within an aggregate transmit power limit, the wireless terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, comprising:

means for determining an average energy-per-transmitted-bit across a plurality of previously active ones of the N modems that were previously transmitting;

means for determining, based on the average energy-per-transmitted-bit and the aggregate transmit power limit, a maximum number of active modems that can concurrently transmit data at a maximum data rate without exceeding the maximum aggregate transmit power limit; and

means for scheduling data-to-be-transmitted over the determined maximum number of active modems.

41. The wireless terminal of claim 40, further comprising:

means for determining an aggregate transmit power of the N modems corresponding to when the plurality of active modems were previously transmitting data;

means for monitoring status reports from the N modems, the status reports indicating a respective transmit data rate for each of the N modems; and

means for determining, based on the respective transmit data rates, an aggregate data rate of the N modems corresponding to the aggregate transmit power, wherein the means for determining the maximum number comprises means for determining the average energy-per-transmitted-bit based on the aggregate transmit power and the aggregate data rate.

42. The wireless terminal of claim 40, wherein:

each of the N modems is adapted to transmit data at at least one of a maximum transmit data rate and a minimum transmit data rate; and

the means for determining the maximum number comprises determining the maximum number based on the minimum and maximum transmit data rates as well as the average energy-per-transmitted-bit and the aggregate transmit power limit.

43. The wireless terminal of claim 40, wherein the means for determining the average energy-per-transmitted-bit, the means for determining the maximum number of active modems, and the means for scheduling repeat their respective functions periodically, thereby causing the maximum number of active modems to vary over time in correspondence with the average energy-per-transmitted bit.

44. A wireless terminal constrained to operate within an aggregate transmit power limit, the wireless terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, comprising:

means for determining an individual energy-per-transmitted-bit for each of the N modems that was previously transmitting;

means for determining, based on all of the individual energy-per-transmitted-bits and the aggregate transmit power limit, a maximum number of active modems that can concurrently transmit data at a maximum data rate without exceeding the aggregate transmit power limit; and

means for scheduling the maximum number of active modems to transmit data.

45. The wireless terminal of claim 44, further comprising:

means for sorting the N modems according to their respective individual energy-per-transmitted-bits, the means for scheduling comprises means for scheduling the maximum number of active modems having the lowest individual energy-per-transmitted-bits among the N modems.

46. The wireless terminal of claim 44, further comprising means for monitoring status reports from at least the active modems, the status reports collectively including a transmit power estimate of each active modem, wherein the means for

determining the individual energy-per-transmitted-bits comprises means for determining, from each transmit power estimate, the corresponding individual energy-per-transmitted-bit.

47. An apparatus for dynamically calibrating a wireless terminal, the wireless terminal including N wireless modems having their respective transmit outputs combined to produce an aggregate transmit output, comprising:

means for scheduling each of the N modems to concurrently transmit respective data, thereby causing each of the N modems to concurrently transmit;

means for receiving respective reported transmit powers $P_{Rep}(i)$ from the N modems corresponding to when the N modems concurrently transmit, where i designates a respective modem from 1 to N;

a power meter, coupled to the aggregate transmit output, for measuring an aggregate transmit power P_{Agg} of the N modems corresponding to when the N modems concurrently transmit;

means for generating an equation representing the aggregate transmit power as a cumulative function of each reported transmit power $P_{Rep}(i)$ and a corresponding, undetermined, modem dependent gain factor g(i), wherein the scheduling means, the receiving means, the power meter, and the generating means repeat their respective functions N times to generate N simultaneous equations; and

means for determining all of the modem dependent gain factors from the N simultaneous equations.

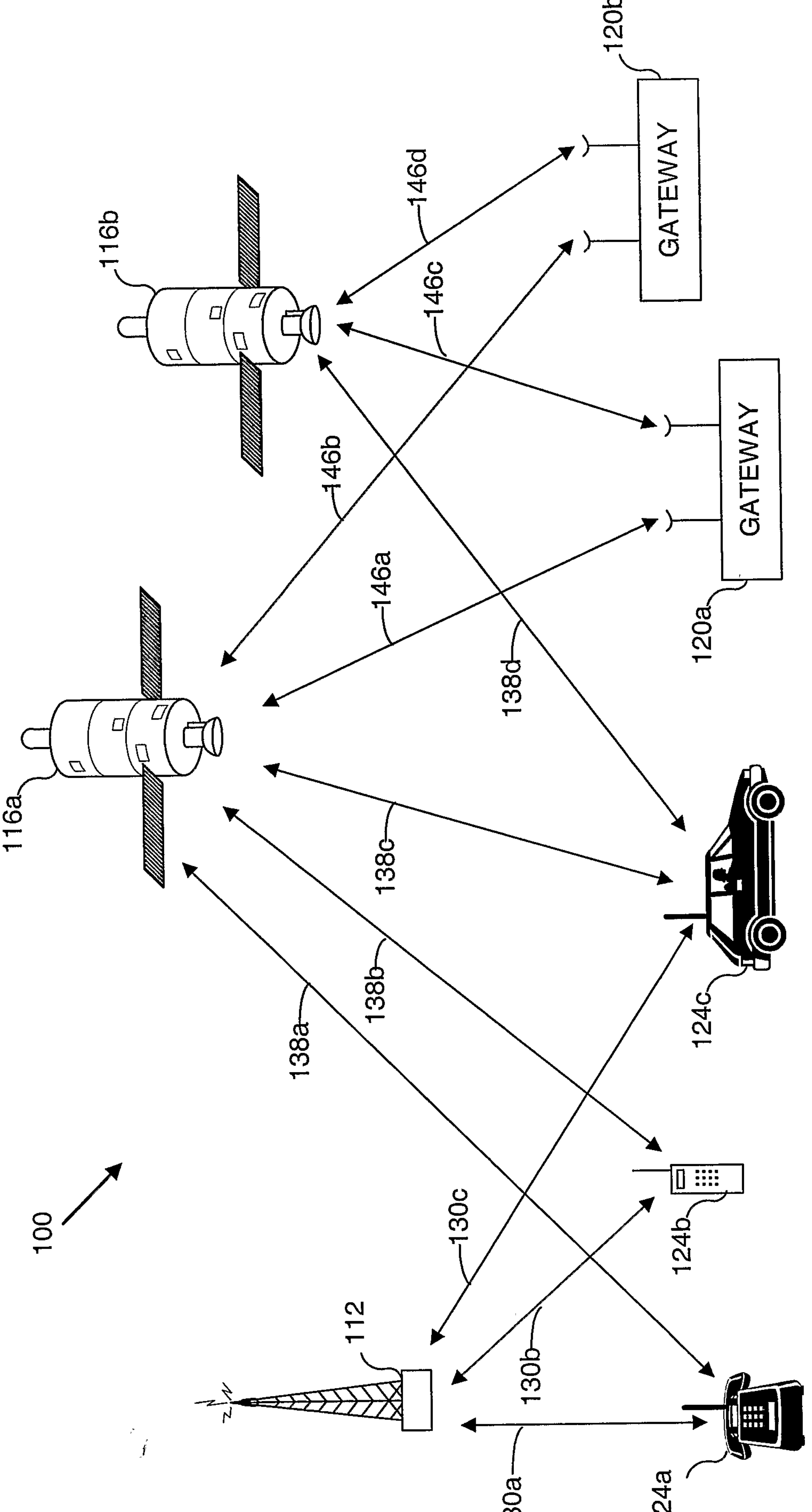

100
112
116a
116b
120a
120b
GATEWAY
GATEWAY
124a
124b
124c
130a
130b
130c
138a
138b
138c
138d
146a
146b
146c
146d

FIG. 1

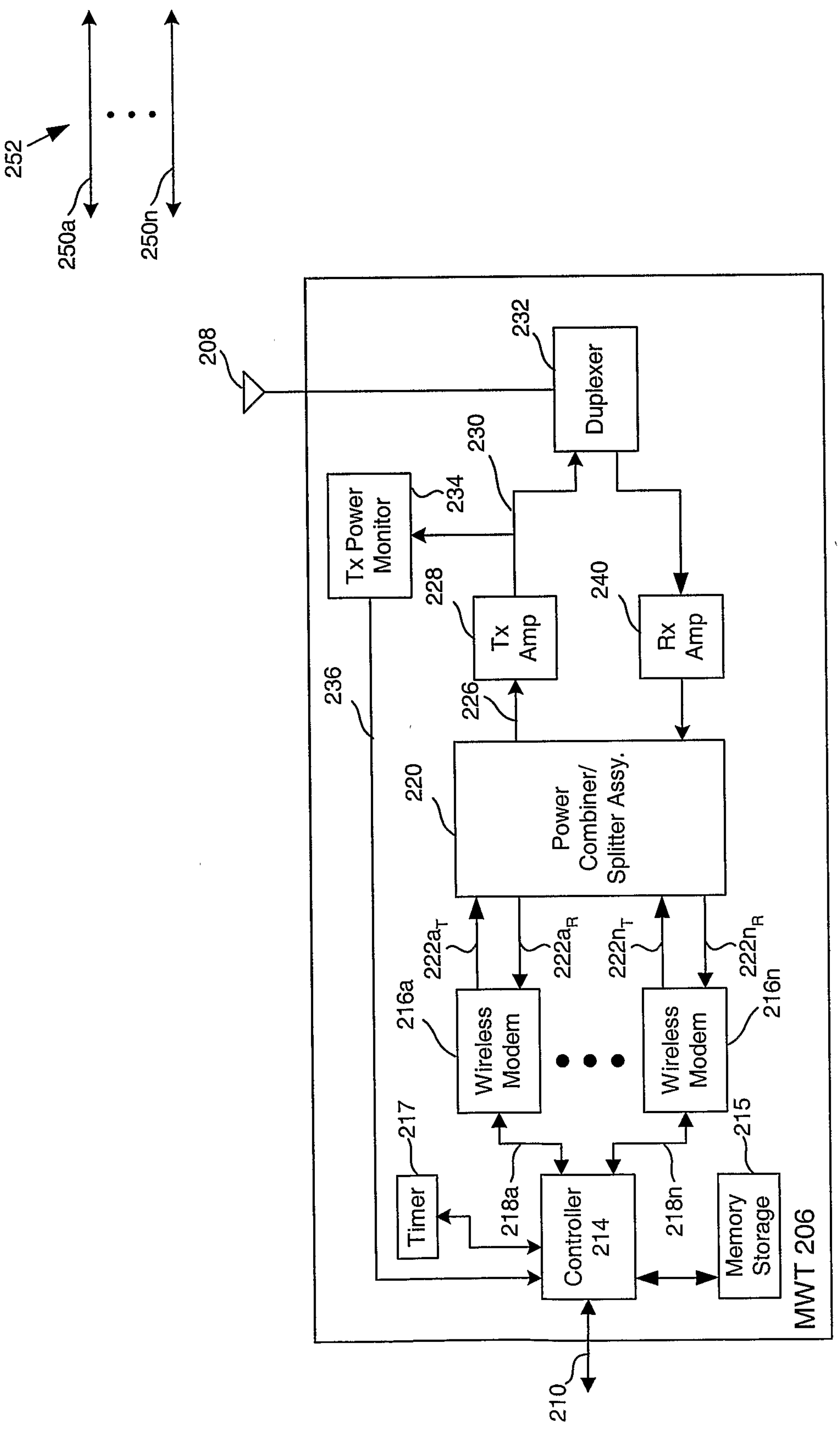

252
250a
250n
208
232
Duplexer
230
Tx Power Monitor
234
228
Tx Amp
240
Rx Amp
236
226
220
Power Combiner/ Splitter Assy.
216a
222a$_T$
222a$_R$
222n$_T$
222n$_R$
216n
Wireless Modem
Wireless Modem
217
215
Timer
218a
Controller 214
218n
Memory Storage
MWT 206
210

FIG. 2

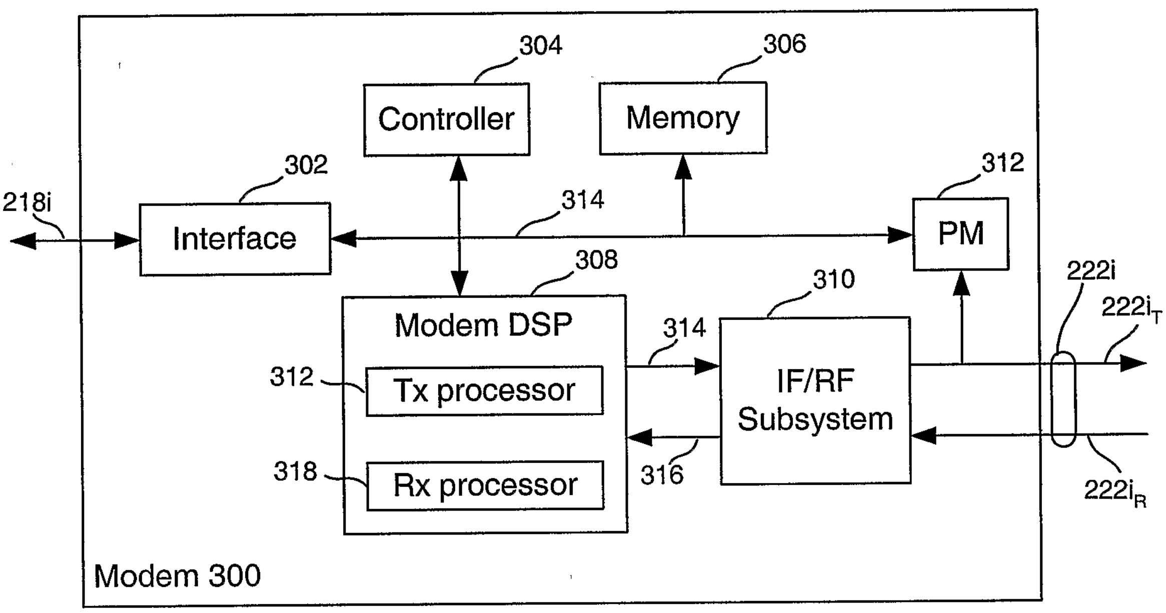
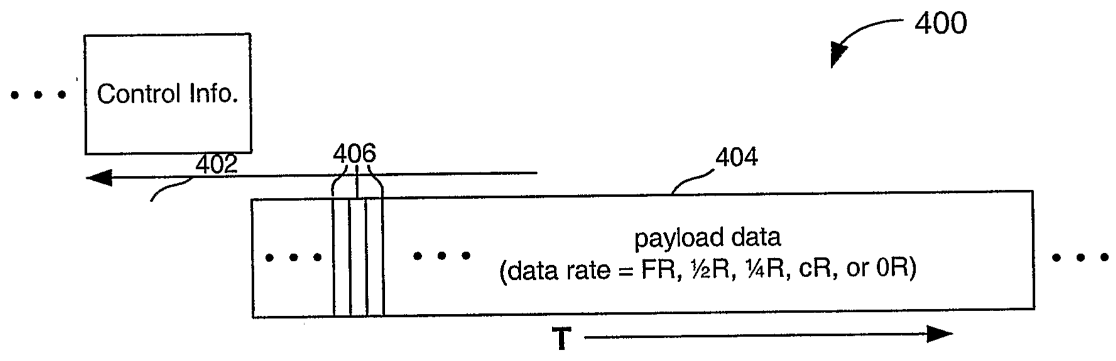
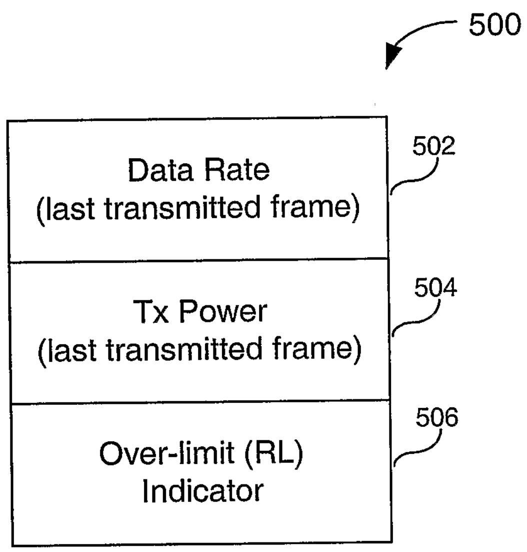

304
306
Controller
Memory
302
312
218i
314
Interface
PM
308
310
222i
222iT
Modem DSP
314
312
Tx processor
IF/RF
Subsystem
318
Rx processor
316
222iR
Modem 300

FIG. 3



400
Control Info.
402
406
404
payload data
(data rate = FR, ½R, ¼R, cR, or 0R)
T

FIG. 4



500
Data Rate
(last transmitted frame)
502
Tx Power
(last transmitted frame)
504
Over-limit (RL)
Indicator
506

FIG. 5

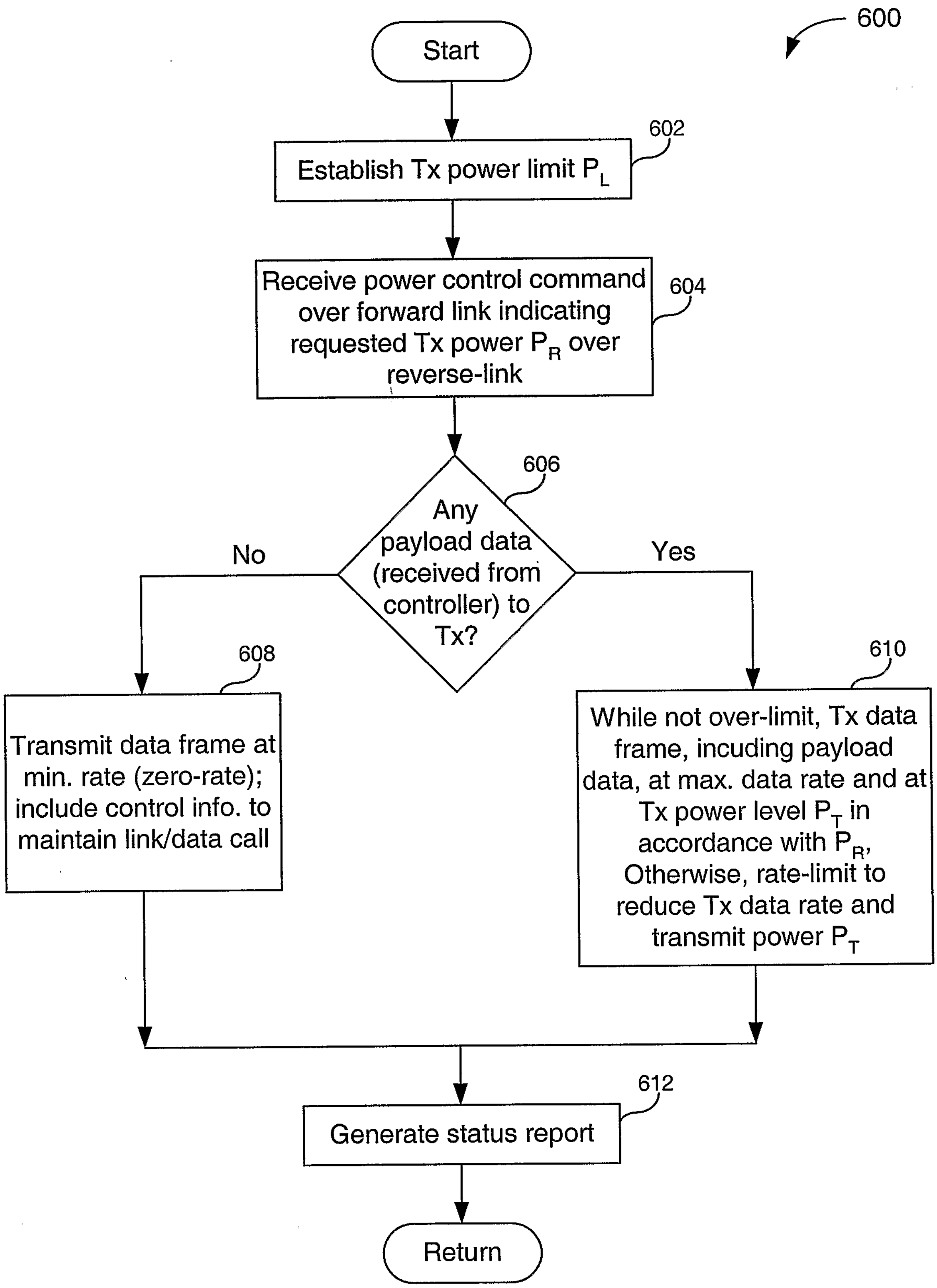

600
Start
Establish Tx power limit P_L
602
Receive power control command over forward link indicating requested Tx power P_R over reverse-link
604
Any payload data (received from controller) to Tx?
606
No
Yes
Transmit data frame at min. rate (zero-rate); include control info. to maintain link/data call
608
While not over-limit, Tx data frame, incuding payload data, at max. data rate and at Tx power level P_T in accordance with P_R, Otherwise, rate-limit to reduce Tx data rate and transmit power P_T
610
Generate status report
612
Return

FIG. 6

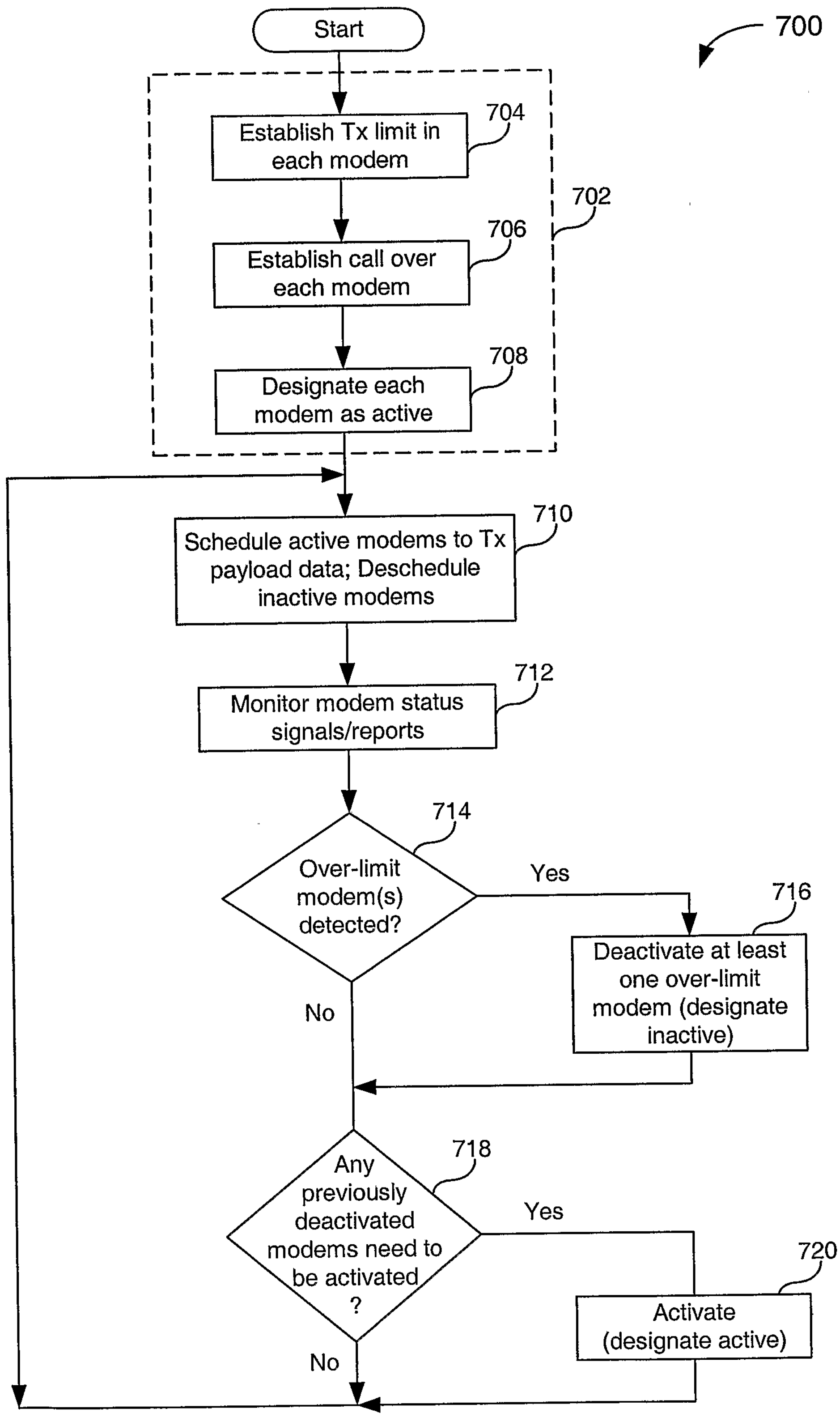

700
Start
Establish Tx limit in each modem
704
Establish call over each modem
706
702
Designate each modem as active
708
Schedule active modems to Tx payload data; Deschedule inactive modems
710
Monitor modem status signals/reports
712
Over-limit modem(s) detected?
714
Yes
No
Deactivate at least one over-limit modem (designate inactive)
716
Any previously deactivated modems need to be activated ?
718
Yes
No
Activate (designate active)
720

FIG. 7

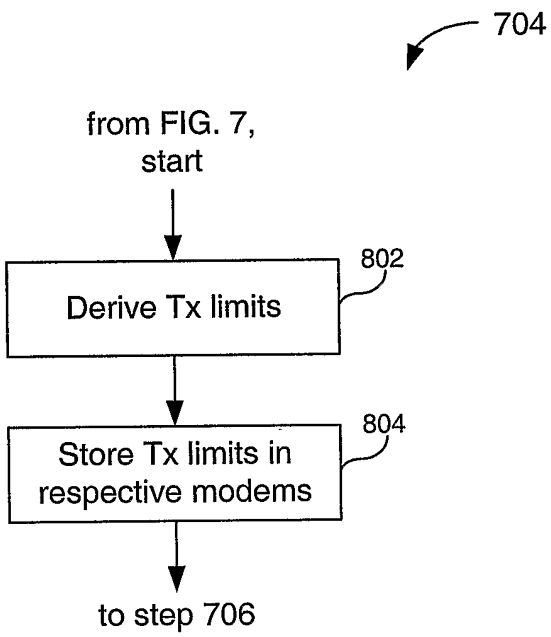

704
from FIG. 7,
start
Derive Tx limits
802
Store Tx limits in
respective modems
804
to step 706

FIG. 8

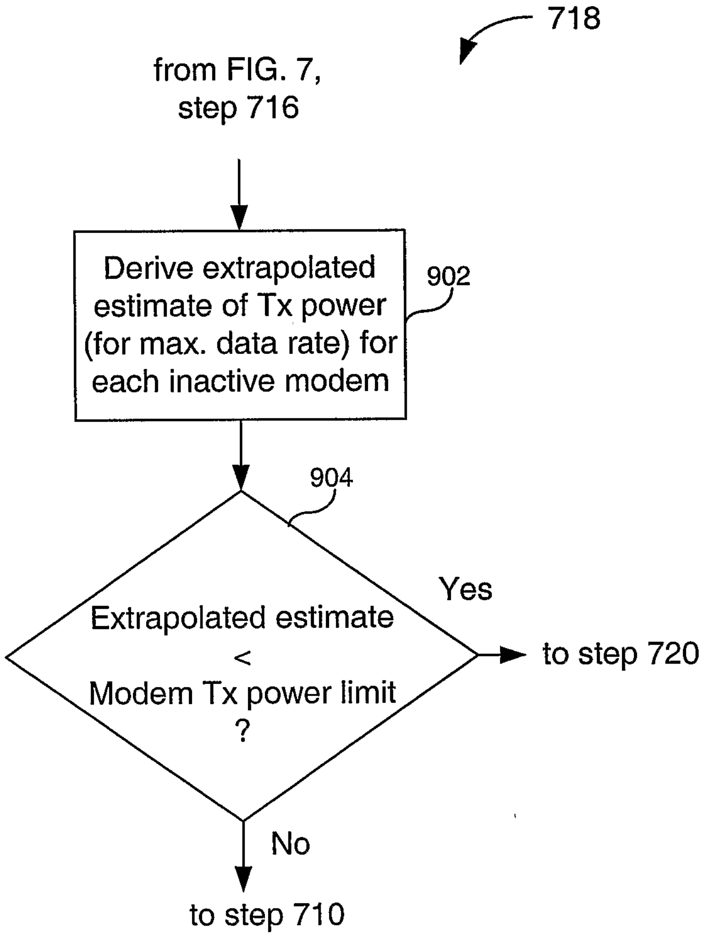

718
from FIG. 7,
step 716
Derive extrapolated estimate of Tx power (for max. data rate) for each inactive modem
902
904
Extrapolated estimate
<
Modem Tx power limit
?
Yes
to step 720
No
to step 710

FIG. 9

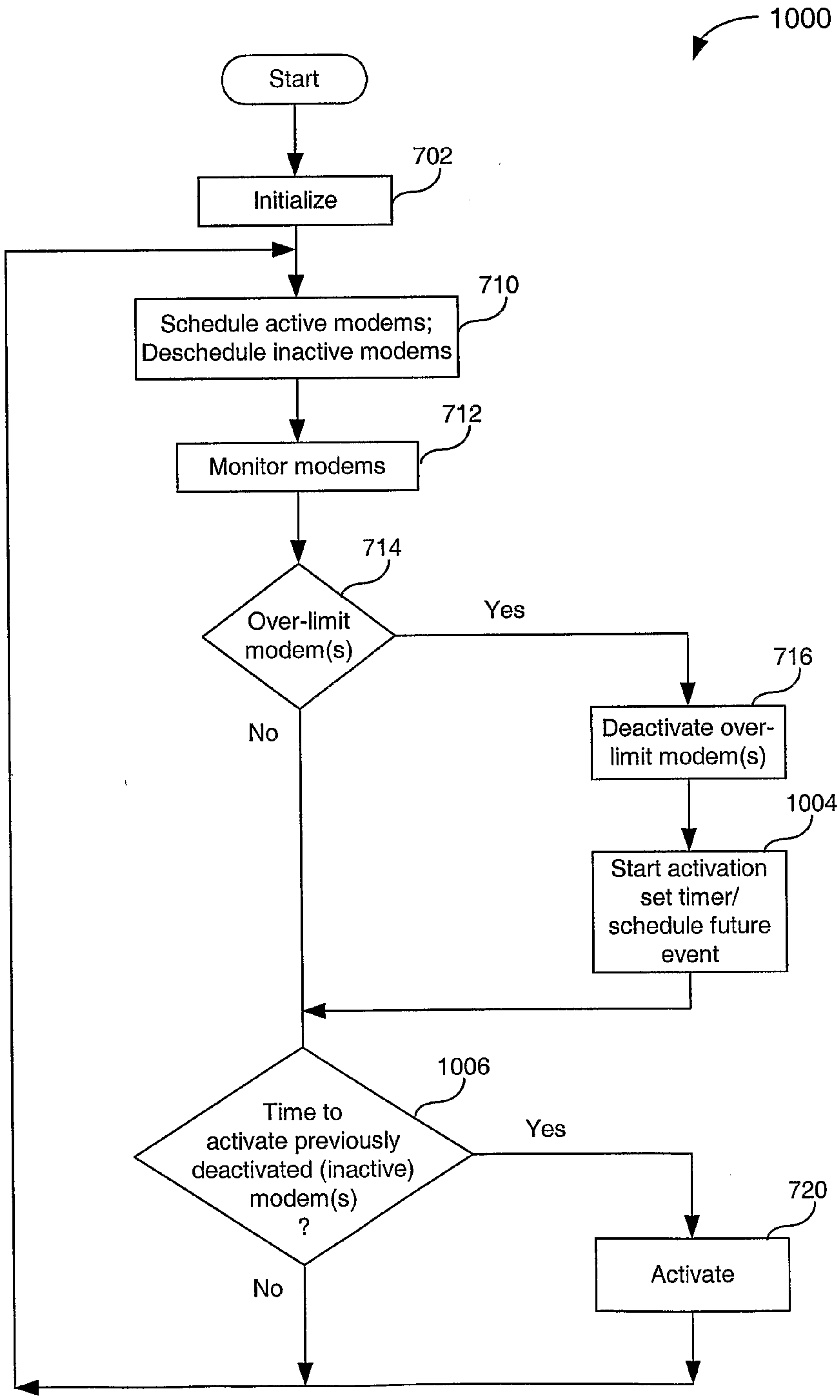

1000
Start
702
Initialize
710
Schedule active modems; Deschedule inactive modems
712
Monitor modems
714
Over-limit modem(s)
Yes
No
716
Deactivate over-limit modem(s)
1004
Start activation set timer/ schedule future event
1006
Time to activate previously deactivated (inactive) modem(s) ?
Yes
No
720
Activate

FIG. 10

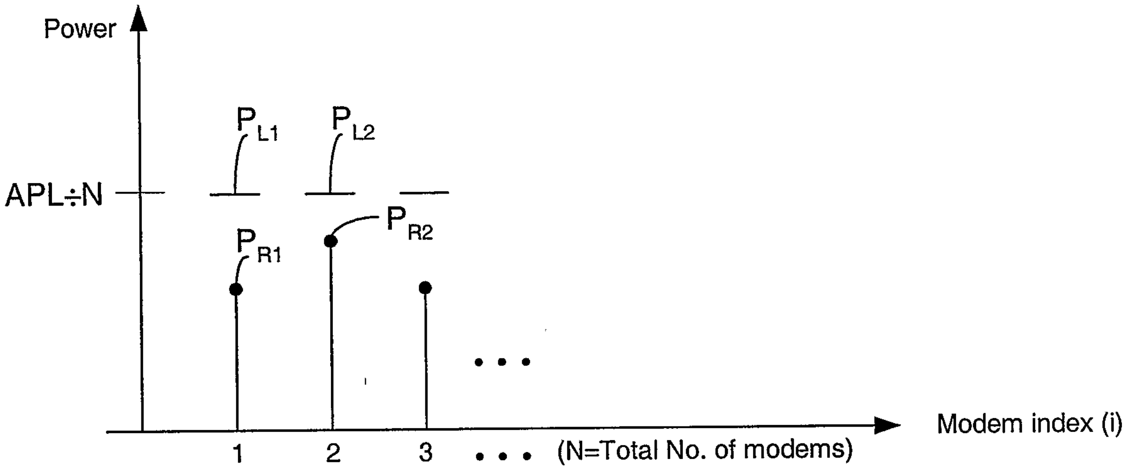


FIG. 11

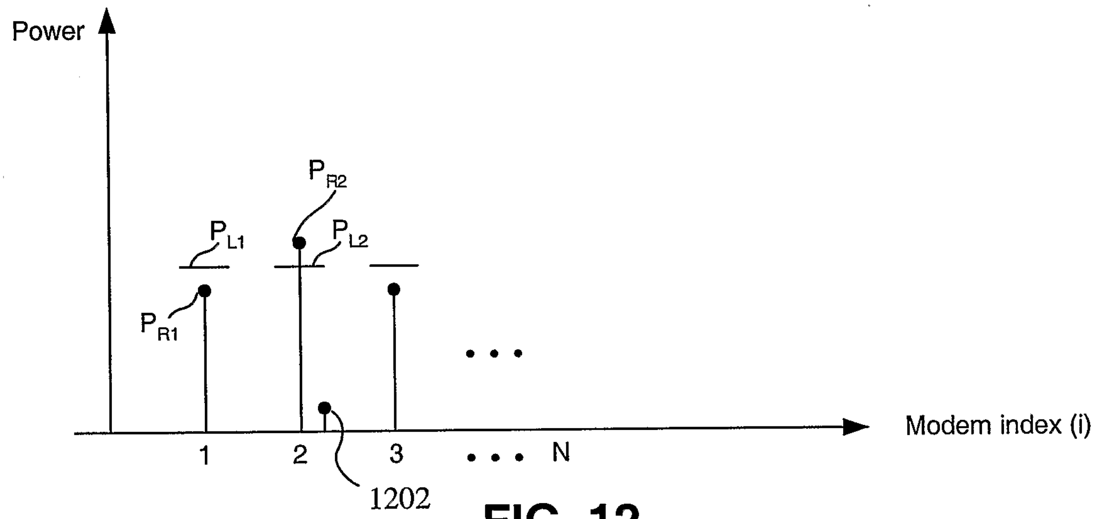


FIG. 12

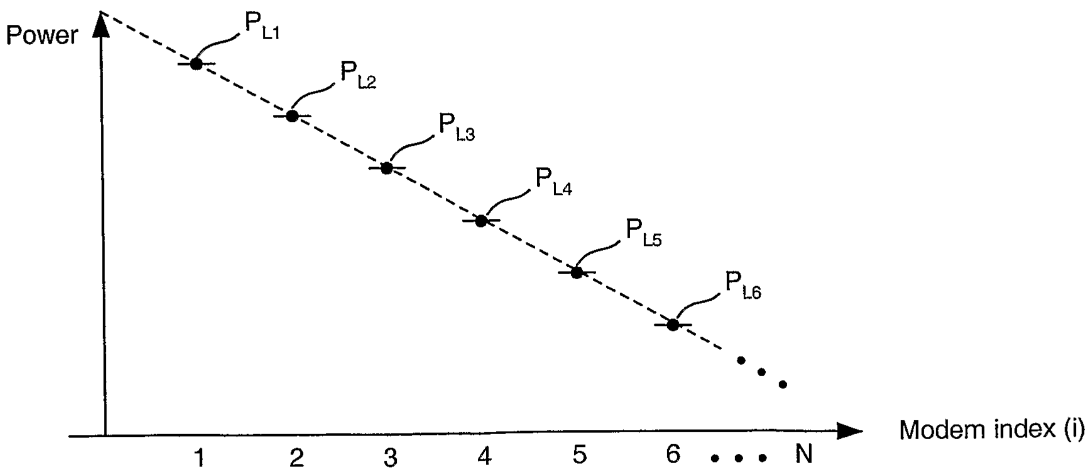


FIG. 13

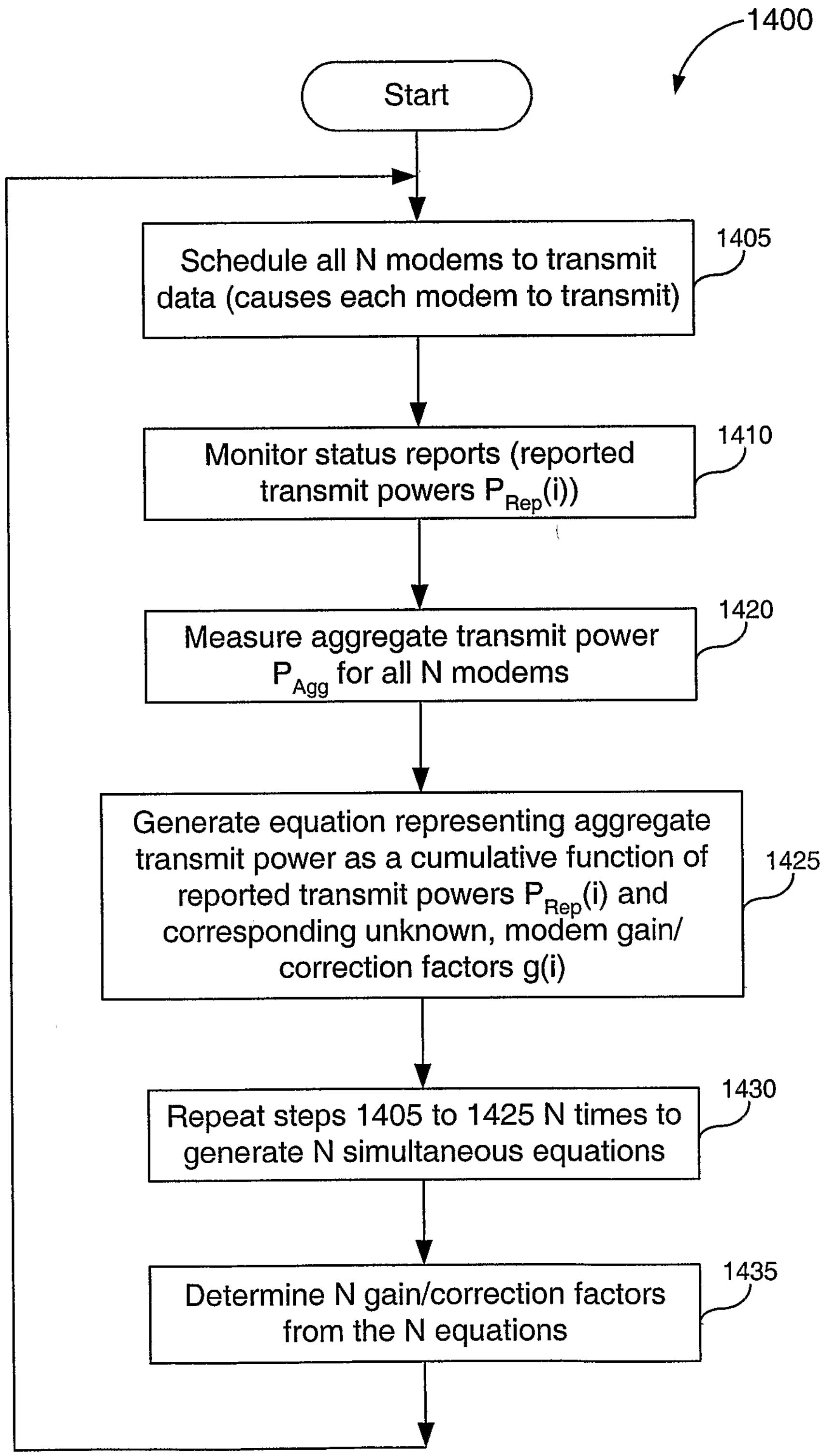

1400
Start
Schedule all N modems to transmit data (causes each modem to transmit)
1405
Monitor status reports (reported transmit powers $P_{Rep}(i)$)
1410
Measure aggregate transmit power P_{Agg} for all N modems
1420
Generate equation representing aggregate transmit power as a cumulative function of reported transmit powers $P_{Rep}(i)$ and corresponding unknown, modem gain/ correction factors g(i)
1425
Repeat steps 1405 to 1425 N times to generate N simultaneous equations
1430
Determine N gain/correction factors from the N equations
1435

FIG. 14

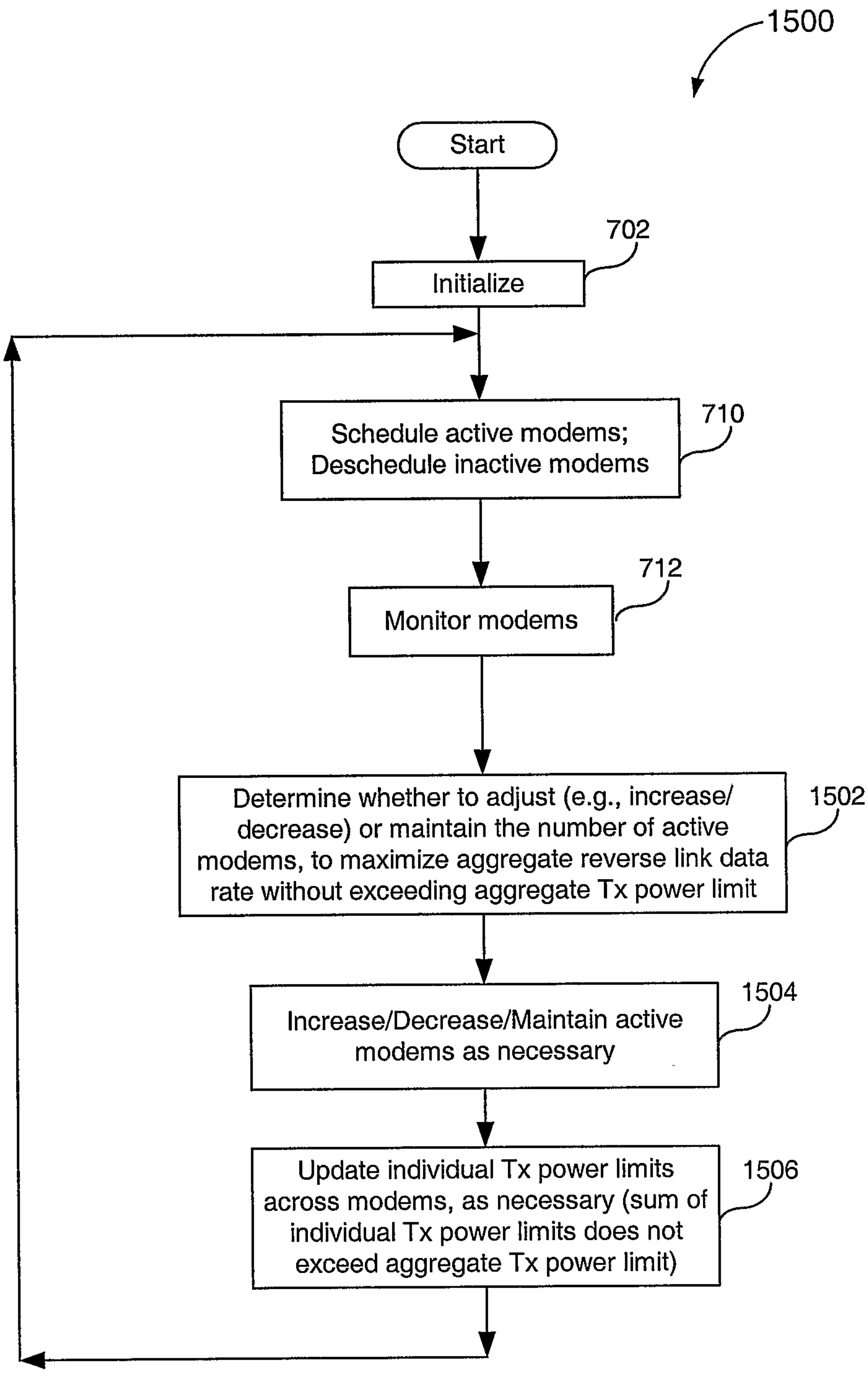

1500
Start
702
Initialize
710
Schedule active modems;
Deschedule inactive modems
712
Monitor modems
1502
Determine whether to adjust (e.g., increase/ decrease) or maintain the number of active modems, to maximize aggregate reverse link data rate without exceeding aggregate Tx power limit
1504
Increase/Decrease/Maintain active modems as necessary
1506
Update individual Tx power limits across modems, as necessary (sum of individual Tx power limits does not exceed aggregate Tx power limit)

FIG. 15

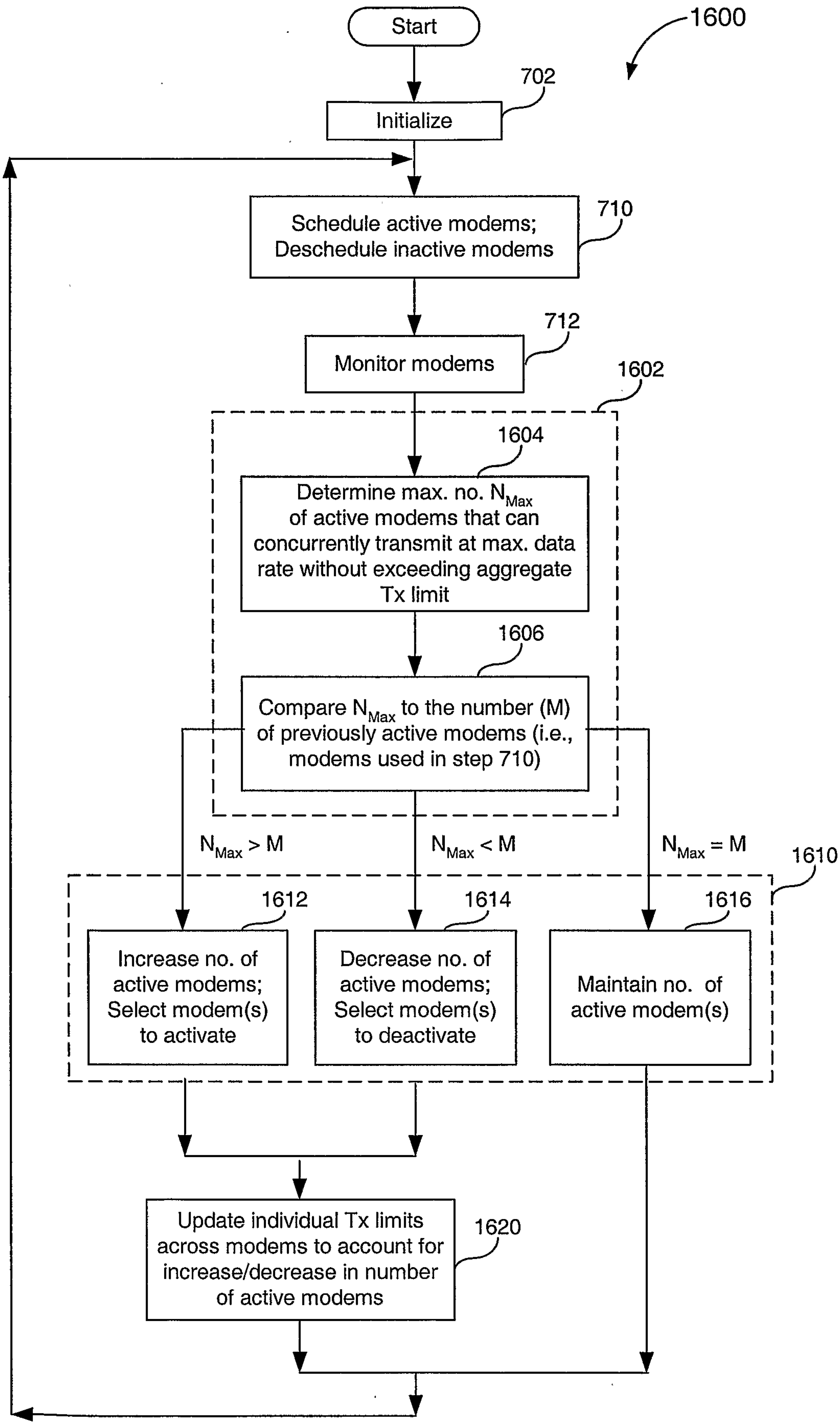

1600
Start
702
Initialize
710
Schedule active modems;
Deschedule inactive modems
712
Monitor modems
1602
1604
Determine max. no. N_Max of active modems that can concurrently transmit at max. data rate without exceeding aggregate Tx limit
1606
Compare N_Max to the number (M) of previously active modems (i.e., modems used in step 710)
N_Max > M
N_Max < M
N_Max = M
1610
1612
Increase no. of active modems; Select modem(s) to activate
1614
Decrease no. of active modems; Select modem(s) to deactivate
1616
Maintain no. of active modem(s)
Update individual Tx limits across modems to account for increase/decrease in number of active modems
1620

FIG. 16

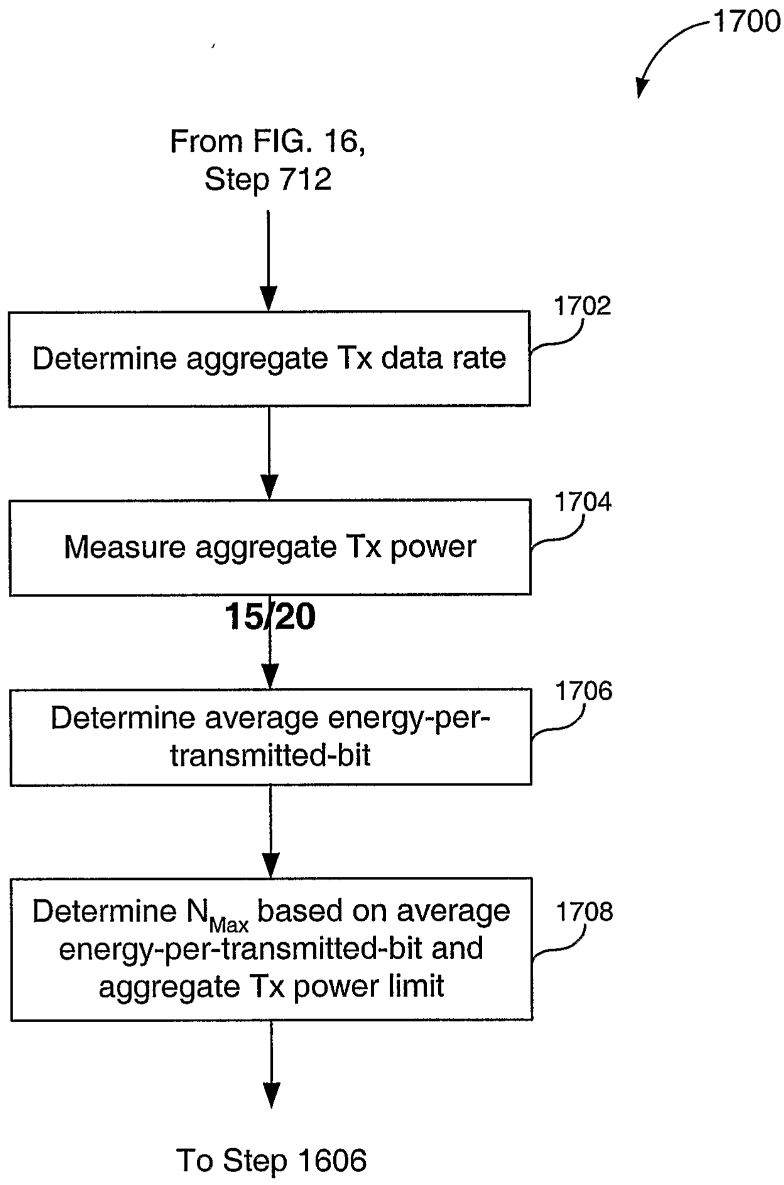

1700
From FIG. 16,
Step 712
Determine aggregate Tx data rate
1702
Measure aggregate Tx power
1704
15/20
Determine average energy-per-transmitted-bit
1706
Determine N$_{Max}$ based on average energy-per-transmitted-bit and aggregate Tx power limit
1708
To Step 1606

FIG. 17

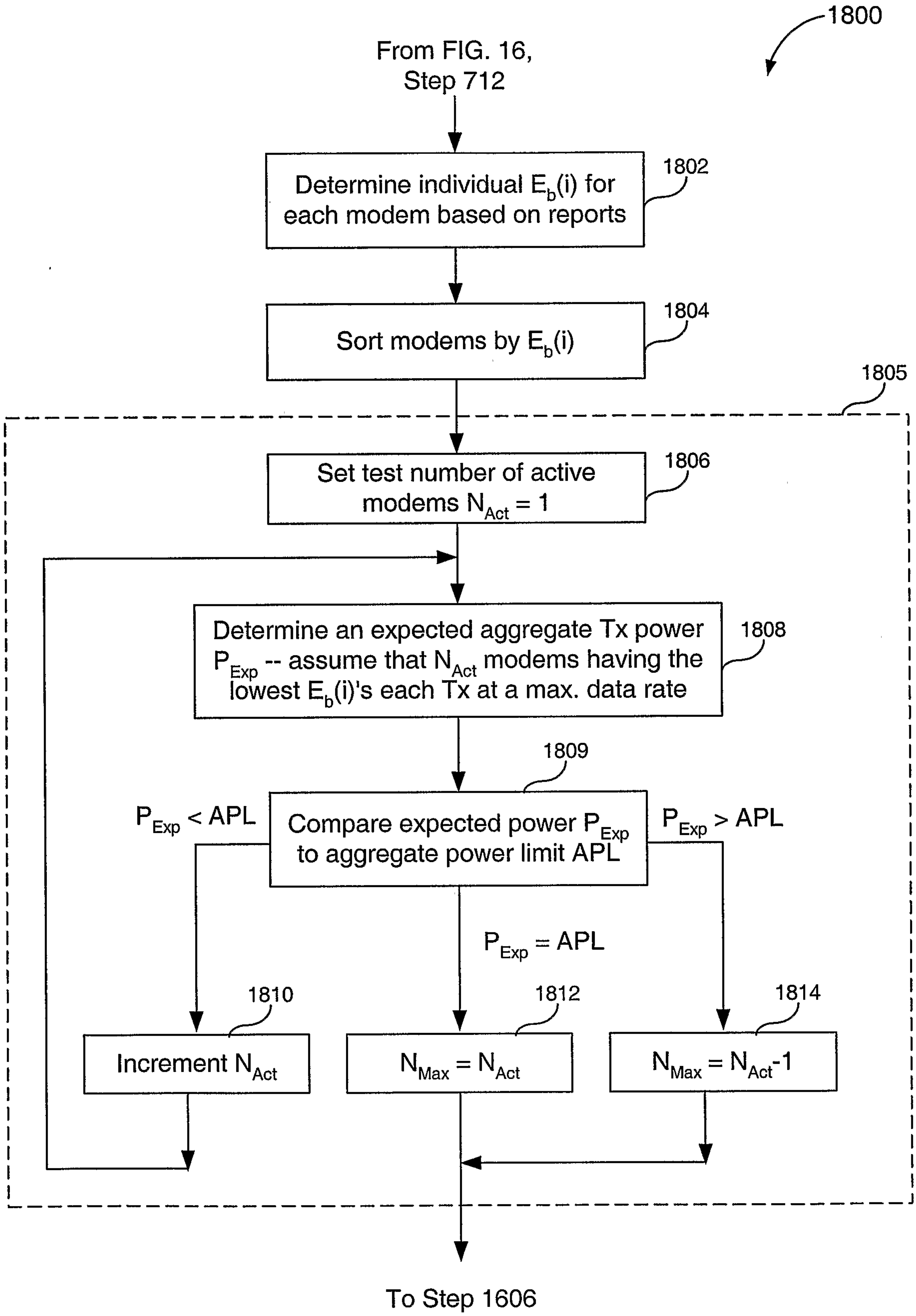

1800
From FIG. 16,
Step 712
Determine individual $E_b(i)$ for each modem based on reports
1802
Sort modems by $E_b(i)$
1804
1805
Set test number of active modems $N_{Act} = 1$
1806
Determine an expected aggregate Tx power P_{Exp} -- assume that N_{Act} modems having the lowest $E_b(i)$'s each Tx at a max. data rate
1808
1809
Compare expected power P_{Exp} to aggregate power limit APL
P_{Exp} < APL
P_{Exp} > APL
P_{Exp} = APL
1810
1812
1814
Increment N_{Act}
$N_{Max} = N_{Act}$
$N_{Max} = N_{Act}-1$
To Step 1606

FIG. 18

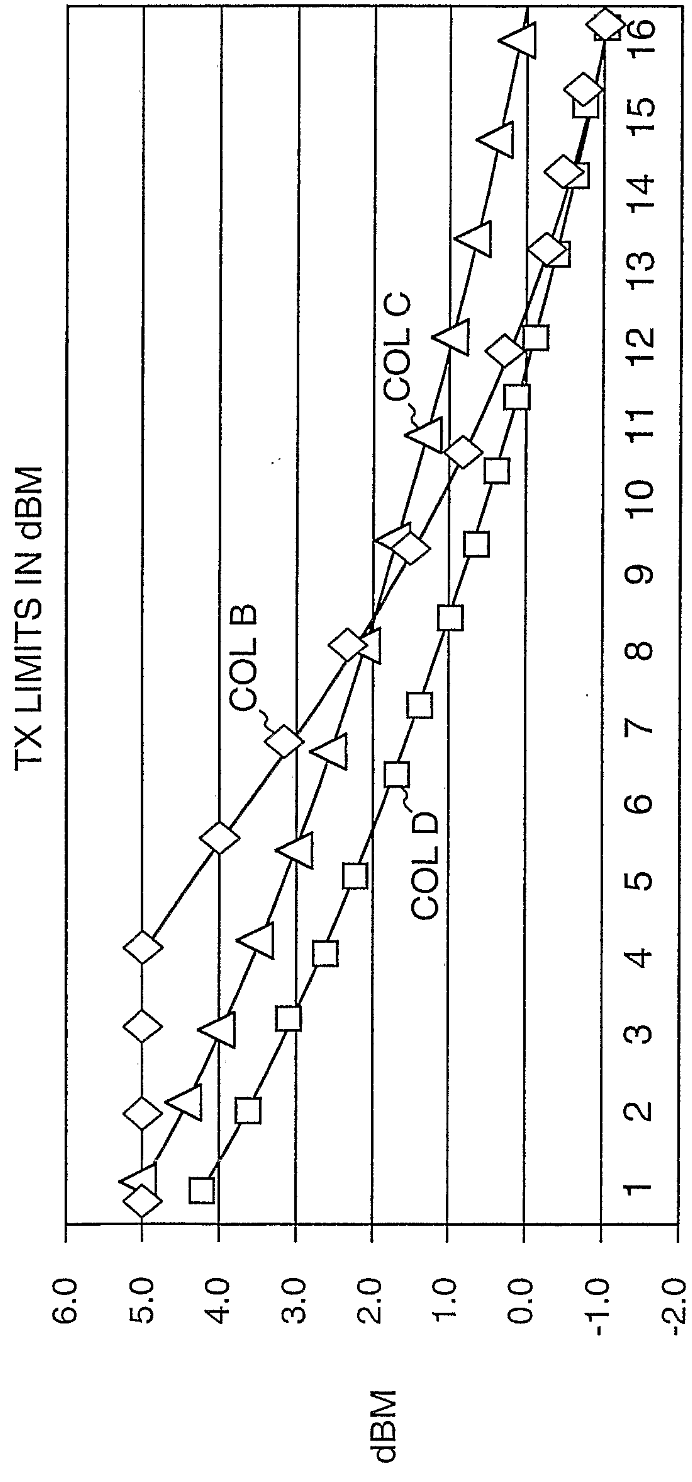

TX LIMITS IN dBM
dBM
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
N
COL B
COL C
COL D

FIG. 19

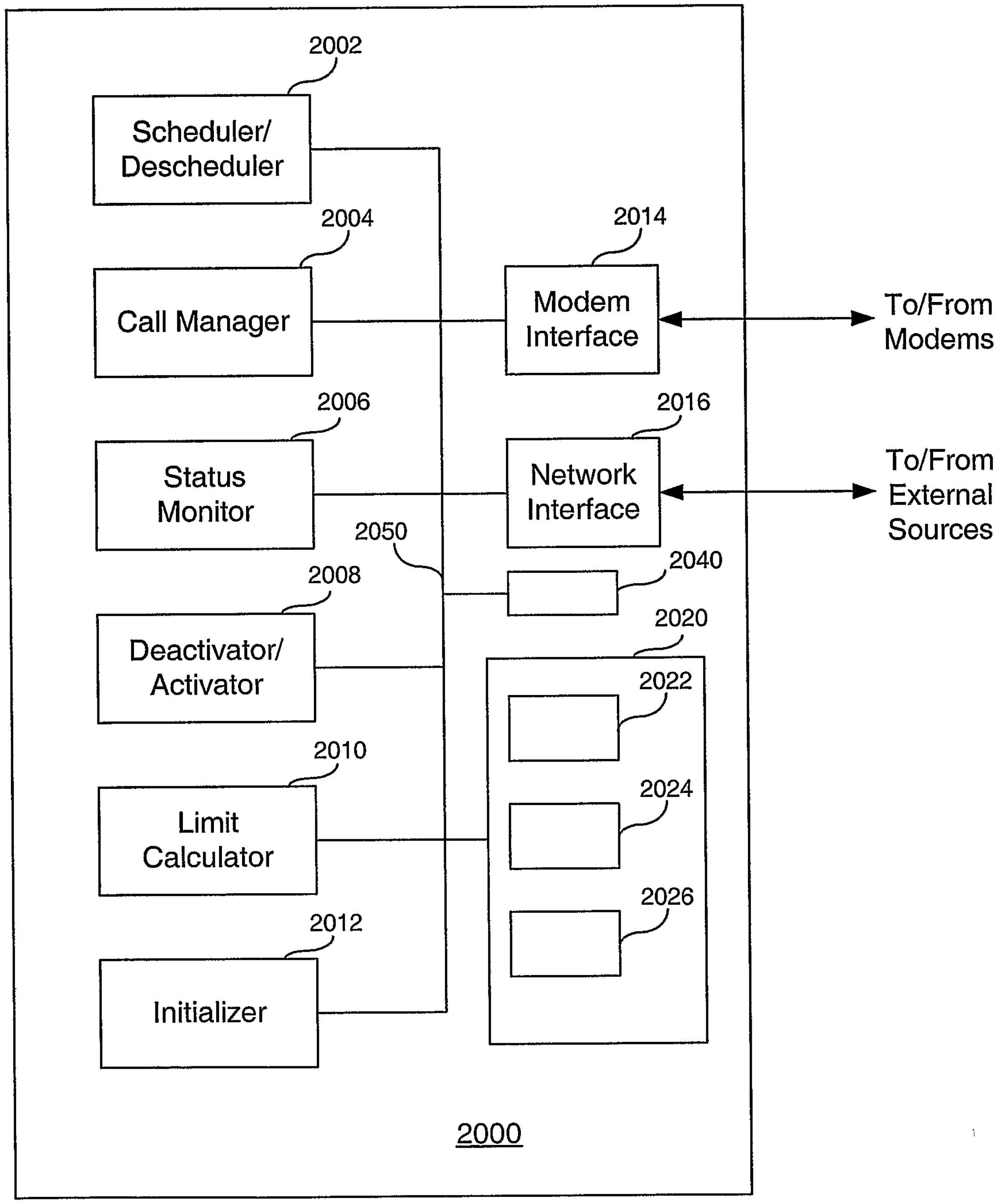

2002
Scheduler/
Descheduler
2004
Call Manager
2006
Status
Monitor
2008
Deactivator/
Activator
2010
Limit
Calculator
2012
Initializer
2014
Modem
Interface
To/From
Modems
2016
Network
Interface
To/From
External
Sources
2050
2040
2020
2022
2024
2026
2000

FIG. 20