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(54) **Title**: WIRELESS LOCAL AREA NETWORK USING TV WHITE SPACE SPECTRUM AND LONG TERM EVOLUTION SYSTEM ARCHITECTURE

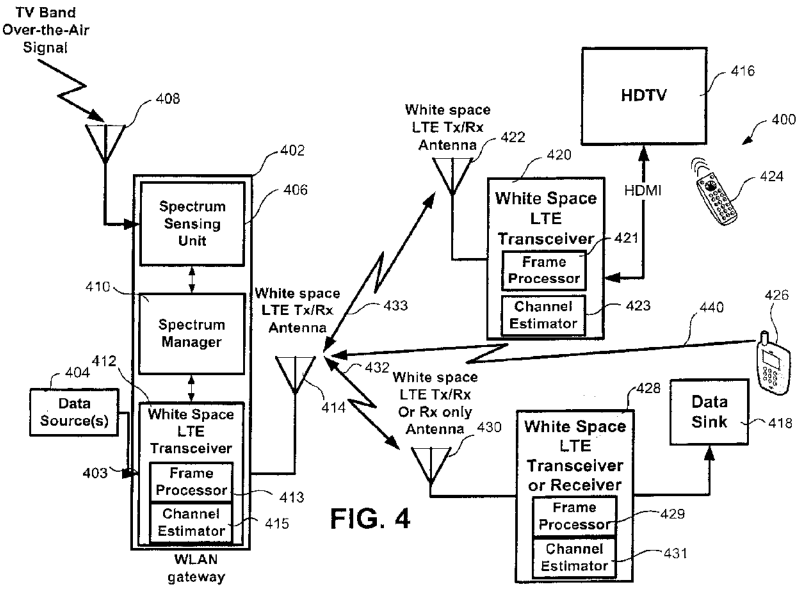

FIG. 4

(57) **Abstract**: A wireless local area network (WLAN) gateway may use a modified LTE radio frame and TV white space spectrum for data communications in a wireless local area network. In the modified LTE downlink frame a predefined subset of the pilot (reference) symbol subcarriers are used to carry information to data sinks in the WLAN.

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WIRELESS LOCAL AREA NETWORK USING TV WHITE SPACE SPECTRUM AND LONG TERM EVOLUTION SYSTEM ARCHITECTURE

FIELD OF THE INVENTION

[0001] This invention relates in general to data communications within a wireless local area network (WLAN) and, in particular, to a WLAN using available TV white space spectrum and Long Term Evolution (LTE) system architecture for data communications.

BACKGROUND OF THE INVENTION

[0002] Data communication within WLANs is now generally accomplished using WiFi implemented using one of the IEEE 802.11 standards. The 802.11b and 802.11g standards are designed to operate in the 2.4 GHz band using Direct Sequence Spread Spectrum (DSSS) technology. The 802.11n standard is designed to operate in the 2.4 GHz or the 5 GHz bands.

[0003] While WiFi works well, the high frequency signals do not readily penetrate obstructions, so a high transmit power must be used. This has raised health concerns that remain unaddressed. Furthermore, the wireless distribution of new data-intensive services such as High Definition Television (HDTV) and multimedia communications signals can undesirably degrade WLAN performance; and, the quality of service (QoS) of the HDTV or multimedia signals can be adversely affected if the WLAN is simultaneously used for the delivery of other data intensive services, such as internet access.

[0004] A radio standard called Long Term Evolution (LTE) has been developed by the 3rd Generation Partnership Project (3GPP). The goals of LTE are the provision of an all Internet Protocol (IP) packet network with faster download and upload speeds and reduced latency.

[0005] FIG. 1 is a schematic diagram of an LTE generic downlink radio frame structure 100. Each downlink radio frame 100 includes twenty time slots 102 numbered from 0 to 19 having a duration of 0.5 ms each. Two adjacent time slots make up a subframe 104 having a duration of 1 ms. Each downlink frame 100 has a duration of 10 ms.

[0006] FIG. 2 is a schematic diagram of the structure of each LTE downlink time slot 102. The smallest time-frequency unit for downlink transmission is called a resource element 106, which constitutes one symbol on one sub-carrier. A group of 12 sub-carriers that are contiguous in frequency within the time slot 102 form a resource block 108. When the downlink frame structure 100 uses a normal cyclic prefix, the 12 contiguous sub-carriers in the resource block 108 have a sub-carrier spacing of 15 kHz with 7 consecutive symbols in each downlink time slot 102. The cyclic prefix is appended to each symbol as a guard interval. The symbol plus the cyclic prefix form the resource element 106. Consequently, the resource block 108 has 84 resource elements (12 sub-carriers x 7 symbols) corresponding to one time slot 102 in the time domain and 180 kHz (12 sub-carriers x 15 kHz spacing) in the frequency domain. The size of a resource block 108 is the same for all bandwidths. In the frequency domain, the number of available sub-carriers can range from 76 sub-carriers when the transmission bandwidth is 1.25 MHz, to 1201 sub-carriers when the transmission bandwidth is 20 MHz.

[0007] LTE has been designed to be very robust and supports data rates of up to 100+ Mbps on the downlink and 50+ Mbps on the uplink. Although it is optimized for user equipment travel speeds of 0-15 km/h, travel speeds of 15-120 km/h are supported with high efficiency. To accomplish this level of performance, “reference” or “pilot” symbols are inserted in predetermined resource element positions within each transmitted resource block 108. The pilot symbols are used by receiver channel estimation algorithms to correct for received signal distortions.

[0008] FIG. 3 is a schematic diagram of some of the pilot symbols 120 transmitted in the LTE downlink frame 100, for a single antenna case. The pilot symbols 120 are transmitted at OFDM symbol positions 0 and 4 of each time slot 102.

[0009] In May of 2004, the Federal Communications Commission (FCC) approved a Notice of Proposed Rulemaking to allow a new generation of wireless devices to use vacant television frequencies (TV white spaces) on an unlicensed basis. These TV white spaces are frequency channels allocated for television broadcasting that will not be used in given geographic areas after February 17th, 2009. Specifically, the FCC will allow unlicensed operation in the spectrum used by TV channels 5 and 6 (76-88 MHz); 7 through 13 (174-213 MHz); 14 through 36 (470-608 MHz); and, 38 through 51 (614-698 MHz).

[0010] Many proposals exist for using the unlicensed TV white space spectrum. For example, it has been suggested that Wireless Regional Area Networks (WRANs) could be established to provide high-speed internet access to single family dwellings, multiple dwelling units and small businesses. The WRANs would operate using the IEEE 802.22 architecture over the TV white space spectrum with a fixed deployment and a larger coverage (25~30 km range).

[0011] While these proposals have merit, they do not provide an efficient solution to the developing congestion in WLANs due to the emerging requirement to distribute HDTV signals wirelessly in a home environment. Furthermore, they do not provide interoperability with other systems or devices that use the LTE system architecture.

SUMMARY OF THE INVENTION

[0012] Embodiments of the invention provide a wireless local area network a method of data communications within the wireless local area network using the TV white space spectrum and the LTE system architecture.

[0013] In one aspect the invention provides a wireless local area network, comprising: a local area network gateway that transmits modified Long Term Evolution (LTE) downlink frames in which at least a predetermined subset of pilot symbol positions used in the LTE downlink frames to transmit pilot symbols for channel estimation are filled with control data symbols; and a data sink that receives the modified LTE frames and extracts the control data symbols from the predetermined subset of pilot symbol positions.

[0014] The invention is based in part on the realization that, in a wireless LAN setting, the pilot positions possess a redundancy that can be exploited to carry control data without adversely affecting the quality of service in the wireless LAN.

[0015] The invention further provides a local area network gateway comprising a transceiver that transmits modified Long Term Evolution (LTE) downlink frames in which a predetermined subset of the pilot symbols used for channel estimation in the modified LTE downlink frames maybe replaced with control data symbols.

[0016] The invention yet further provides a data sink in a local area network, comprising a Long Term Evolution (LTE) frame processor that processes modified LTE downlink frames transmitted by a local area network gateway and extracts control data from a subset of pilot symbol positions used to carry the control data in the modified LTE downlink frame.

[0017] The invention still further provides a method of data communications in a wireless local area network, comprising: transmitting within the wireless local area network modified Long Term Evolution (LTE) downlink frames in which at least a predetermined subset of the pilot symbol positions used in the LTE downlink frames to transmit pilot symbols for channel estimation are filled with control data symbols; and on receipt at a data sink in the wireless local area network of a one of the modified LTE downlink frames, demodulating the modified LTE downlink frame and extracting the control data symbols from the predetermined subset of the pilot symbol positions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Having thus generally described the nature of the invention, reference will now be made to the accompanying drawings, in which:

[0019] FIG. 1 is a schematic diagram of a prior art LTE downlink frame structure of type-1;

[0020] FIG. 2 is a schematic diagram of a prior art downlink slot structure for the downlink frame shown in FIG. 1;

[0021] FIG 3 is a schematic diagram of some of the pilot (reference) symbols transmitted in two of the prior art downlink slots shown in FIG. 2;

[0022] FIG. 4 is a schematic diagram of one embodiment of a WLAN in accordance with the invention;

[0023] FIG. 5 is a flow diagram illustrating a high-level overview of some of the actions performed during startup and downlink frame processing by a WLAN gateway shown in FIG. 4;

[0024] FIG. 6 is a flow diagram illustrating a high-level overview of some of the actions performed during startup and downlink frame processing by a WLAN receiver shown in FIG. 4;

[0025] FIG. 7 is a schematic diagram of a proportion of the pilot symbols transmitted in a LTE downlink frame structure in accordance with the invention showing released pilot symbol positions used for control data transmission in the WLAN in accordance with the invention;

[0026] FIG. 8 is a schematic diagram illustrating a first step in one method of interpolating channel estimates using the LTE downlink frame structure in accordance with the invention;

[0027] FIG. 9 is a schematic diagram illustrating the results of a second step in the method of interpolating channel estimates shown in FIG. 8;

[0028] FIG. 10 is a schematic diagram illustrating a third step of the method of interpolating channel estimates shown in FIG. 8;

[0029] FIG. 11 is a schematic diagram illustrating the results of the second step of the method of interpolating channel estimates shown in FIG. 10;

[0030] FIG. 12 is a schematic diagram illustrating a method of interpolating channel estimates in the time domain using linear interpolation between computed channel estimates;

[0031] FIG. 13 is a schematic diagram illustrating a method of interpolating channel estimates in the time domain using cubic spline interpolation between computed channel estimates;

[0032] FIG. 14 is a schematic diagram illustrating a first step in another method of interpolating channel estimates using the LTE downlink frame structure in accordance with the invention, and the results of the first step; and

[0033] FIG. 15 is a schematic diagram illustrating the results of the first step of the method of interpolating channel estimates shown in FIG. 14, and a second step in that method of interpolating the channel estimates in the time domain.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] The invention provides a wireless local area network (WLAN) in which a modified LTE downlink frame and the TV white space spectrum are used for data communications. A WLAN gateway is connected to at least one data source. The WLAN gateway wirelessly distributes source data and/or control data to a LTE transceiver or receiver associated with each data sink in the WLAN. In the modified LTE downlink frame a predefined subset of the pilot (reference) symbol positions are used to carry the control data to the data sinks. The source data (payload) capacity of each modified LTE radio frame is unaffected by the transmission of the control data, so control data may be distributed without affecting network throughput. The data capacity and the efficiency of the WLAN are thereby improved. The WLAN gateway has an effective transmit range of at upto 30 meters at a fraction of the transmit power of most 802.11 access point (AP) currently in use. The WLAN gateway can also operate in the same environment as an 802.11 AP without interference because of the significant difference in operating frequencies. The WLAN has many benefits and uses, including in-home wireless distribution of high definition television (HDTV) signals, and compatibility with other LTE systems and devices,.

[0035] FIG. 4 is a schematic diagram of a WLAN 400, in accordance with one embodiment of the invention. A WLAN gateway 402 has input ports 403 that are connected to at least one data source 404. The data source(s) 404 delivers "source data" to the WLAN 400.

[0036] The term "source data" means any information in any format derived from any data source 404, including but not limited to: customer premises equipment that receives any one or more of telephone, radio, television, multimedia, data or internet content in any protocol delivered via a telephone line, coaxial cable, optical fiber, microwaves, radio waves, television signals or satellite signals.

[0037] The WLAN gateway 402 includes a spectrum sensing unit 406 equipped with a spectrum sensing antenna 408. The spectrum sensing antenna 408 is used by the spectrum sensing unit 406 to detect over-the-air TV band signals in the TV white space spectrum. Information about the detected over-the-air TV band signals is passed by the spectrum sensing unit 406 to a spectrum manager 410. The spectrum manager 410 uses the detected signal information to select available TV white space spectrum for unlicensed use by the WLAN 400, as will be explained in more detail below with reference to FIG. 5.

[0038] The TV white space spectrum selected by the spectrum manager 410 is passed to a white space LTE transceiver 412, which receives, via a white space LTE Tx/Rx Antenna 414, source data requests sent from data sinks 416, 418 in LTE uplink frames (not shown). The LTE transceiver 412 distributes the source data in LTE downlink frames prepared by a frame processor 413. The LTE downlink frames are transmitted to the data sinks 416, 418 using the TV white space LTE Tx/Rx antenna 414.

[0039] The term "data sink" means any piece of user equipment in the WLAN 400 equipped with a TV white space LTE transceiver/receiver. A data sink may include, but is not limited to: any computer; any entertainment or home theatre component or device, including a HDTV; any commercial or household appliance; any environmental control system, device or sensor; any security control system, device or sensor; any entrance control system, device or sensor; or, any access control system, device or sensor.

[0040] The WLAN gateway 402 also distributes control data to the data sinks 416, 418, as required, using the white space LTE Tx/Rx antenna 414.

[0041] The term "control data" means any information in any format transmitted in a predetermined subset of pilot positions in the modified LTE downlink frames. The control data may communicate information of any kind to the data sink, and/or control the configuration, operation or behavior of the data sink. For example, the control data may be used to enable: an identification signal for co-existence of two or more WLANs 400 that operate in close proximity; provide a Consumer Electronic Control (CEC) compliant interaction channel with a home entertainment network; provide a High-bandwidth Digital Content Protection (HDCP) or Digital Transmission Content Protection (DCTP) type content protection scheme with Copy Protection for Recordable Media (CPRM) support; provide remote appliance or system control; or, permit remote monitoring of appliance or system output or status.

[0042] In this exemplary embodiment of the WLAN 400, the data sink 416 is a high definition television (HDTV). A white space LTE transceiver 420 associated with the HDTV 416 may be a stand-alone device, or connected to or incorporated into, for example, a television set-top box of any type, a DVD or a Blu-Ray player, or any other HDTV adjunct or controller. By way of example, the white space LTE transceiver 420, or the component to which it is connected, is connected to the HDTV by a High-Definition Multi-media Interface (HDMI). Any other suitable type of interface may also be used. The type of interface between the LTE transceiver 420 and the HDTV has no effect on the operation of the invention. The white space LTE transceiver 420 is provisioned with a frame processor 421. The frame processor 421 inspects received LTE radio frames for control data and source data addressed to the HDTV 416, as will be explained below in more detail with reference to FIGs. 5 and 6. The white space LTE transceiver 420 also has a channel estimator 423, which performs channel estimation, as will be explained below with reference to FIGs. 8-15. The white space LTE transceiver 420 is also equipped with a white space LTE Tx/Rx antenna 422 that provides a wireless link 433 to the WLAN gateway 400. The white space LTE Tx/Rx antenna 422 receives LTE radio frames transmitted by the WLAN gate 402 over the wireless link 433. The white space LTE transceiver 420 transmits source data requests to the WLAN gateway 402 over the wireless link 433 using LTE uplink frames (not shown), the description of which is not within the scope of this invention.

[0043] The HDTV 416 may be controlled directly by a remote control device 424, well known in the art. The HDTV 416 may also be controlled by any appropriate LTE-enabled device 426 (cellular telephone, PDA or the like) programmed to transmit control data (channel selection, volume control, input selection, on/off commands, etc.) to the white space LTE transceiver 420 via the white space LTE Tx/Rx antenna 414 of the WLAN gateway 402 using LTE uplink frames 440, the description of the which is not within the scope of this invention.

[0044] The data sink 418 may be any computer, HDTV, appliance device or sensor, as defined above. A white space LTE transceiver or receiver 428 is connected to, or integrated into, the data sink 418. The LTE transceiver/receiver 428 is equipped with a frame processor 429. The frame processor 429 inspects received LTE frames for source data and/or control data addressed to the data sink 418, as will be explained below in more detail with reference to FIGs. 5 and 6. The LTE transceiver/receiver 428 is also provisioned with a channel estimator 431, which performs channel estimation, as will be explained below with reference to FIGs. 8-15. A white space LTE Tx/Rx or Rx only antenna 430 provides a wireless link 432 to the WLAN gateway 402. If the white space LTE transceiver/receiver 428 can process source data, it transmits source data requests to the WLAN gateway 402 over the wireless link 432 using LTE uplink frames, the description of which is not within the scope of this invention

[0045] FIG. 5 is a flow diagram presenting a high-level overview of some of the functions performed on startup and downlink frame processing by the WLAN gateway 402 shown in FIG. 4. On startup, as described above, the spectrum sensing unit 406 scans the TV band spectrum (500) to detect unused spectrum in the predefined TV white space. The scan may be delimited by reference to a table or a database (not shown) that provides a list of channels that have been assigned to other TV white space services operating within a geographic area in which the WLAN 400 is located. After the TV band spectrum scan is complete the spectrum sensing unit 406 passes information about the scan to the spectrum manager 400 (see FIG. 1). In accordance with one embodiment of the invention, the spectrum sensing manager searches the scan information for a minimum of 5 MHz unused TV white space spectrum, but any other suitable piece of vacant white space spectrum can also be used. If a piece of vacant white space spectrum of a desired bandwidth is detected (502), information about that piece of white space spectrum is passed by the spectrum manager 410 to the LTE white space transceiver 412, as described above with reference to FIG. 4. After information about the available white space spectrum has been passed to the white space LTE transceiver 412, the WLAN gateway 402 begins the execution of an endless operation loop that terminates only when the WLAN gateway 402 is switched off.

[0046] In a first step of the endless operation loop, the WLAN gateway 402 determines whether there is a pending or unfulfilled source data request (506) received from any of the data sinks 416, 418 in the WLAN 400. If a pending or unfulfilled source data request exists, the required source data is captured (508) from an appropriate data source 404. The source data is then processed (510) by the frame processor 413 as required (demodulated and reformatted, for example) and inserted (512) by the frame processor 413 into a LTE downlink frame in accordance with the invention. The WLAN gateway 402 then determines (514) whether it has control data to transmit. If so, the frame processor 413 inserts (516) the control data into a predetermined subset of pilot positions in the modified LTE frame, as will be explained below with reference to FIG. 7. The WLAN gateway 402 then transmits (518) the LTE frame. If it is determined at 506 that no unfulfilled or pending source data request exists, the WLAN gateway 402 determines whether there is control data to transmit (514).

If so, steps 516 and 518 are performed as described above. If there is no control data to transmit, an LTE frame containing idle cells is transmitted at 518.

[0047] FIG. 6 is a flow diagram presenting a high-level overview of some of the actions performed by the white space LTE transceivers/receivers 420, 428 shown in FIG. 4 during startup and frame processing. On startup the LTE transceiver/receiver scans (600) the TV band spectrum to identify TV white space transmission channel(s) currently being used by the WLAN gateway 402, using methods well known in the art. Once the TV white space channel(s) have been identified, the LTE transceiver/receiver begins an endless operational loop that terminates until the scheduled task being completed. In a first step of the endless operational loop, the LTE transceiver/receiver receives and demodulates (602) the next transmitted LTE frame. The frame processor 421, 429 then inspects (604) a predefined subset of the pilot positions in the LTE frame to determine if the LTE frame carries control data. If control data exists there will be some identifier (address) in the control data to indicate its intended receiver. Consequently, the LTE transceiver/receiver tests (606) for an address match. The implementation of the address and the address match test is a matter of design choice. If there is an address match, the control data is passed (608) to a control data handler. If there is not an address match, the process proceeds to optional process 610, or loops back to 602.

[0048] Any given transceiver/receiver in the WLAN 400 may or may not be configured to process source data. Some transceivers/receivers, such as household appliances, etc. may only be configured to process control data. If the transceiver/receiver is configured to process source data, the frame processor 421, 429 inspects (610) the LTE frame for source data. If source data is present, the frame processor 421, 429 extracts the source data from the LTE frame. The frame processor then performs a source data address match test (612). As understood by those skilled in the art, the source data is delivered in internet protocol (IP) packets, the addressing of which is well known in the art. If it is determined that a source data address match exists, the source data is passed to a source data handler (614) and the process loops back to 602. Likewise, if as determined at 610 that the frame does not contain a source data packet, or it is determined at 612 that the source data address does not match that of the data sink 420, 428, the process loops back to 602.

[0049] FIG. 7 is a schematic diagram of a proportion of the pilot symbols transmitted in the modified LTE downlink frame in accordance with the invention, showing released pilot symbol positions 700 used for control data transmission in the WLAN 400. As explained above with reference to FIG. 3, the LTE system architecture provides a very robust downlink structure designed to provide excellent QoS to highly mobile user devices. In the WLAN 400 environment, the wireless channel can be characterized as a slowly time-varying channel. Experimentation has established that the frequency and spacing of channel estimations in the standard LTE pilot (reference) symbol structure displays redundancy that can be exploited to enhance performance within the WLAN 400. A predetermined subset 700 of at least one half of the pilot positions 120 can be used to carry control data without adversely affecting QoS in the WLAN 400. To ensure a high level of QoS in the WLAN 400, channel estimation interpolation is performed in the frequency domain and the time domain to provide a channel estimate at each received symbol position in the modified LTE downlink frame, so that the predetermined subset of the pilot positions 700 can carry the control data.

[0050] FIG. 8 is a schematic diagram illustrating a first step in one method of interpolating channel estimates using the LTE downlink frame structure in accordance with the invention. In a first step of this method, channel estimates 801, 804 are computed for each existing pilot symbol in an LTE downlink frame received by an LTE transceiver/receiver in accordance with the invention. The channel estimates 804 in the 4^{th} symbol position are then interleaved with the channel estimates 801 in the 1^{st} symbol position, as shown in FIG. 8.

[0051] FIG. 9 is a schematic diagram illustrating the results of a second step in the method of interpolating channel estimates shown in FIG. 8. In the second step, interpolation is performed in the frequency domain between the interleaved channel estimates. The interpolation in the frequency domain may be performed using, for example: a linear interpolation between channel estimates; a quadratic interpolation between channel estimates; or a spline interpolation between channel estimates, all of which are known in the art.

[0052] FIG. 10 is a schematic diagram illustrating a third step in the method of interpolating channel estimates shown in FIG. 8. After the channel estimates 801 are interleaved with the channel estimates 804 and the interpolation in the frequency domain has been completed, an interpolation in the time domain is performed to complete the channel estimate computations. The interpolation in the time domain may be performed using, for example: polynomial interpolation such as cubic spline interpolation between channel estimates, which is also known in the art.

[0053] FIG. 11 is a schematic diagram illustrating two results 810, 812 of the third step of the method of interpolating channel estimates in the time domain shown in FIG. 10 using linear, polynomial or cubic spline interpolation between frequency domain interpolations performed in the second step of this method. Although time domain interpolation is performed for all sub-carriers, and for the duration in time of the entire frame, for simplicity of illustration only the time domain interpolation for one sub-carrier in two time slots is shown.

[0054] FIG. 12 is a schematic diagram illustrating interpolation of channel estimates in the time domain using linear interpolation between computed (E) or frequency domain interpolated (I) channel estimates. The linear interpolation is performed using the known equation:

[0055] $$\hat{h}_j(n)=\left(\frac{\hat{h}_j(n_k)-\hat{h}_j(n_{k-1})}{n_k-n_{k-1}}\right)(n-n_{k-1})+\hat{h}_j(n_{k-1})$$

[0056] where: $\hat{h}_j(n_k), \hat{h}_j(n_{k-1})$ represent the computed (E) or frequency domain interpolated (I) channel estimates as illustrated in FIG. 9. $\hat{h}_j(n)$ represents the time domain interpolated channel estimates 810 computed using the above linear interpolation formula at positions illustrated in FIG. 11.

[0057] j = 1, . . ., L, and L is the number of sub-carriers in the LTE frame.

[0058] FIG. 13 is a schematic diagram illustrating interpolation of channel estimates in the time domain using cubic spline interpolation between computed and interpolated frequency domain channel estimates. The cubic spline interpolation is performed using the known equations:

[0059] $$\hat{h}_j(n) = a_{k-1}\left(n - n_{k-1}\right)^3 + b_{k-1}\left(n - n_{k-1}\right)^2 + c_{k-1}\left(n - n_{k-1}\right) + d_{k-1}; n_{k-1} \le n < n_k$$

and

[0060] $$\hat{h}_j(n) = a_k\left(n - n_k\right)^3 + b_k\left(n - n_k\right)^2 + c_k\left(n - n_k\right) + d_k; n_k \le n < n_{k+1}.$$

[0061] where:

[0062] j = 1, . . . , L, and L is the number of sub-carriers in the LTE frame.

[0063] FIG. 14 is a schematic diagram illustrating a first step in another method of interpolating channel estimates using the modified LTE downlink frame structure in accordance with the invention, and the results of the first step in this method. In accordance with this method, interpolation in the frequency domain is performed without interleaving the channel estimates in the 4th character position with those in the 1st character position. Consequently, the channel estimates are computed at their transmitted pilot symbol positions. As noted above, the interpolation in the frequency domain can be performed using any known method, for example a polynomial interpolation such as cubic spline interpolation between channel estimates.

[0064] FIG. 15 is a schematic diagram illustrating the results of a second step of the method shown in FIG. 14, in which the channel estimates are interpolated in the time domain. Although time domain interpolation is performed for all sub-carriers, and for the duration in time of the entire frame, for simplicity of illustration only the time domain interpolation for one sub-carrier in two time slots is shown. In the first time slot, the interpolations 816 and 818 are computed. In the second time slot, the interpolations 820 and 822 are computed. As noted above, the interpolation in the time domain can be performed using any one of: linear interpolation between channel estimates; polynomial interpolation between channel estimates; or, cubic spline interpolation between channel estimates.

[0065] The embodiments of the invention described above are only intended to be exemplary of the WLAN 400, WLAN gateway 402, the data sinks 416, 418 and the modified LTE downlink frame structure in accordance with the invention, and not a complete description of every possible configuration of any one of those. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.

I Claim:

1. A wireless local area network, comprising:

a local area network gateway (402) configured to transmit Long Term Evolution (LTE) downlink frames (Fig. 7) in which a predetermined subset of pilot symbol positions (700) normally used in the LTE downlink frames to transmit pilot symbols for channel estimation are made available for carrying control data symbols to increase the data capacity of each of the LTE downlink frames; and

a data sink (420, 416, 428, 418) configured to receive the modified LTE frames (Fig. 7) and extract the control data symbols from the predetermined subset of pilot symbol positions (700).

2. A wireless local area network as claimed in claim 1, wherein the local area network gateway (402) further comprises a TV white space transceiver (412) for transmitting the modified LTE frames(Fig. 7) using unlicensed TV white space spectrum.

3. A wireless local area network as claimed in claim 2, wherein the local area network gateway (402) further comprises a spectrum sensing unit (406) equipped with an antenna (408) for sensing TV band over-the-air signals.

4. A wireless local area network as claimed in claim 3, wherein the local area network gateway (402) further comprises a spectrum manager (410) that receives from the spectrum sensing unit (406) information about the sensed TV band over-the-air signals and selects available TV white space spectrum for use by the local area network.

5. A wireless local area network as claimed in any one of claims 2 to 4, wherein the data sink (420, 416, 428, 418) is associated with a TV white

space receiver (420, 428) for receiving the modified LTE downlink frames (Fig. 7) transmitted by the local area network gateway (402).

6. A wireless local area network as claimed in claim 5, wherein the TV white space receiver (420, 428) further comprises a frame processor (421, 429) that demodulates the received LTE downlink frames (Fig. 7) and extracts the data from the predetermined subset of pilot positions (700).

7. A wireless local area network as claimed in claim 5 or 6, wherein the TV white space receiver (420, 428) further comprises a channel estimator (423, 431) for computing channel estimations using pilot symbols in the received LTE downlink frames (Fig. 7) and interpolation algorithms that interpolate the computed channel estimations in the frequency domain and the time domain to provide a channel estimate at each received symbol position in the modified LTE downlink frame.

8. A local area network gateway comprising a transceiver (412) configured to transmit modified Long Term Evolution (LTE) downlink frames)Fig. 7) in which a predetermined subset of the pilot symbols (700) used for channel estimation in the LTE downlink frames are replaced with control data symbols to increase the spectrum efficiency.

9. A local area network gateway as claimed in claim 9, wherein the transceiver (412) is a TV white space transceiver that uses TV white space spectrum for transmitting the modified LTE downlink frames (Fig. 7).

10. A local area network gateway as claimed in claim 9, further comprising a spectrum sensing unit (406) equipped with an antenna (408) for sensing TV band over-the-air signals.

11. A local area network gateway as claimed in claim 10, further comprising a spectrum manager (410) that receives information about the sensed TV band over-the-air signals from the spectrum sensing unit and selects available TV white space spectrum for use by the local area network gateway.

12. A data sink in a local area network, comprising a Long Term Evolution (LTE) frame processor (421, 429) configured to process modified LTE downlink frames (Fig. 7) transmitted by a local area network gateway and extract control data symbols from a subset of pilot symbol positions used to carry the control data in the modified LTE downlink frame.

13. A data sink as claimed in claim 12, further comprising a TV white space antenna (422, 430) connected to a TV white space receiver (420, 428) that receives the modified LTE downlink frames.

14. A data sink as claimed in claim 12 or 13, further comprising a channel estimator (423, 431) that computes channel estimations using pilot symbols transmitted in each of the modified LTE downlink frames (Fig. 7).

15. A data sink as claimed in claim 14, wherein the channel estimator (423, 431) is configured to use channel estimation interpolation algorithms to interpolate the computed channel estimations in the frequency domain and the time domain to provide a channel estimate at each received symbol position in the modified LTE downlink frame.

16. A method of data communications in a wireless local area network (WLAN), wherein modified Long Term Evolution (LTE) downlink frames (Fig. 7), in which a predetermined subset of the pilot symbol positions (700) used in LTE downlink frames to transmit pilot symbols for channel estimation carry control data symbols to increase a data capacity of each of the LTE downlink frames, are transmitted within the wireless

local area network (WLAN), and the modified LTE downlink frames (Fig. 7) are received and demodulated at a data sink (420, 416, 428, 418), where the control data symbols are extracted from the predetermined subset of the pilot symbol positions (700).

17. A method as claimed in claim 16, wherein the modified LTE downlink frames (Fig. 7) are transmitted using available TV whitespace spectrum.

18. A method as claimed in claim 17, wherein before commencement of the transmission of the modified LTE downlink frames (Fig. 7), TV band over-the-air signals are sensed, and unused TV white space spectrum is selected for transmitting the modified LTE downlink frames.

19. A method as claimed in claim 18, wherein before transmission of a modified LTE downlink frame (Fig 7), inserting at least one source data packet is inserted into the modified LTE downlink frame.

20. A method as claimed in claim 19, wherein after extraction of the control data symbols from the predetermined subset of the pilot symbol positions (700), the data sink (420, 416, 428, 418) inspects the modified LTE downlink frame (Fig. 7) for a source data packet.

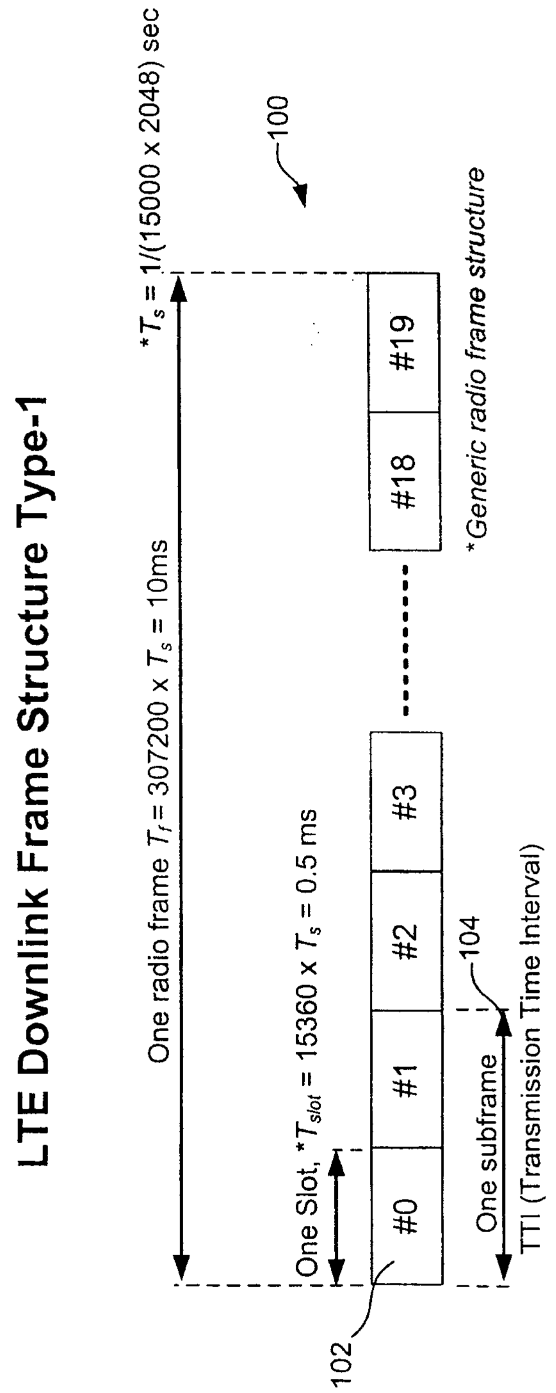
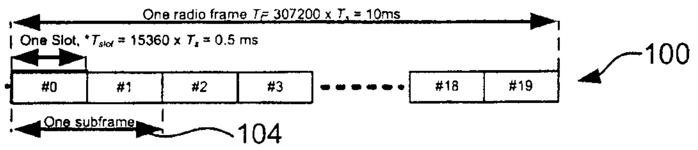
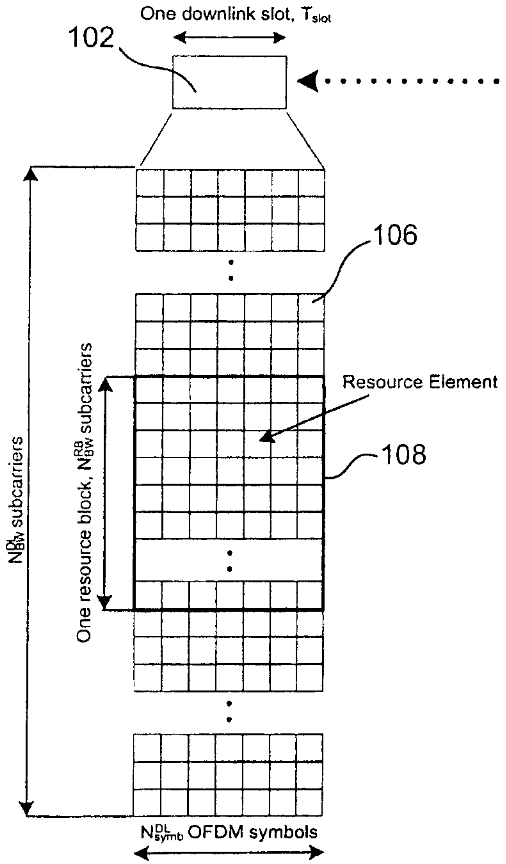


FIG. 1
(Prior Art)

LTE Downlink Slot Structure





Transmission BW		1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Slot Duration		0.5 ms					
Sub-carrier spacing		15 KHz					
Sampling Frequency		1.92 MHz (1/2 x 3.84 MHz)	3.84 MHz	7.68 MHz (2 x 3.84 MHz)	15.36 MHz (4 x 3.84 MHz)	23.04 MHz (6 x 3.84 MHz)	30.72 MHz (8 x 3.84 MHz)
FFT Size		128	256	512	1024	1536	2048
Number of occupied sub-carriers		76	151	301	601	901	1201
Number of OFDM symbols per sub-frame (Short/Long CP)		6/7					
CP length (μs/ samples)	Short	(4.69/9) x 6, (5.21/10) x 1*	(4.69/18) x 6, (5.21/20) x 1	(4.69/36) x 6, (5.21/40) x 1	(4.69/72) x 6, (5.21/80) x 1	(4.69/108) x 6, (5.21/120) x 1	(4.69/144) x 6, (5.21/160) x 1
	Long	16.67/32	16.67/64	16.67/128	16.67/156	16.67/384	16.67/512

*3 GPP TR 25.814

FIG. 2
(Prior Art)

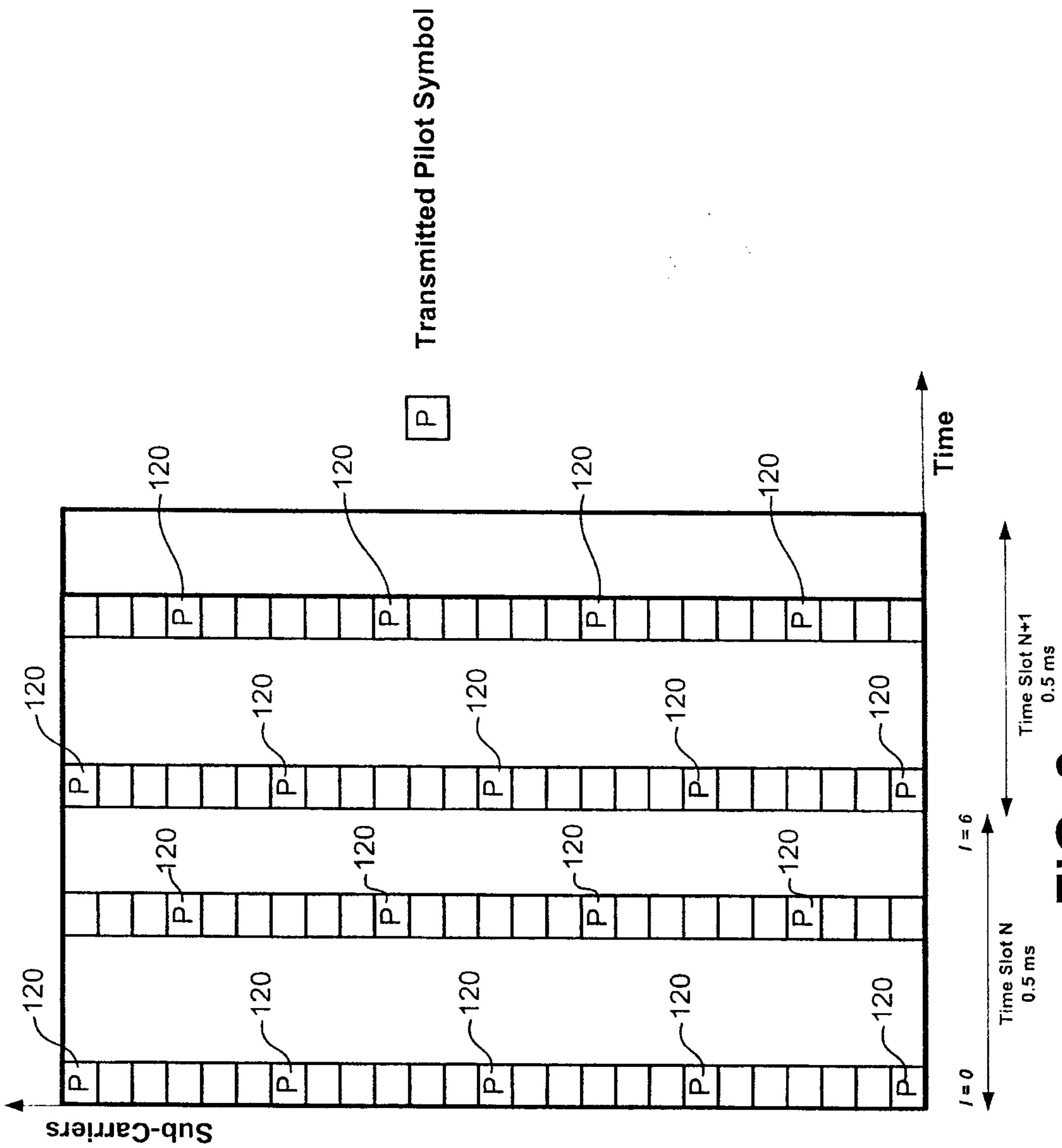


FIG. 3
(Prior Art)

LTE Pilot Symbol Positions

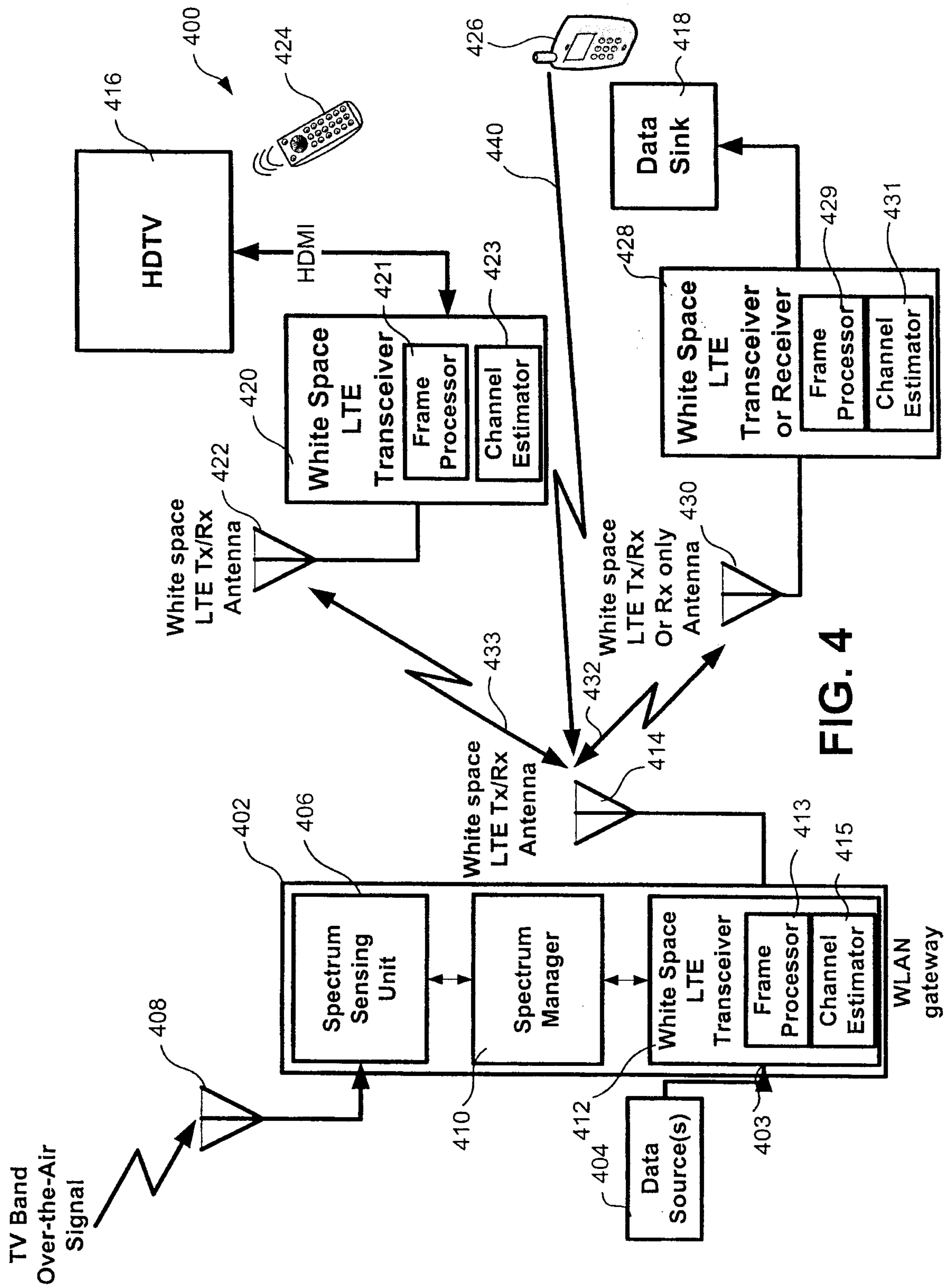

400
HDTV
416
424
HDMI
426
440
Data Sink
418
White Space LTE Transceiver
420
Frame Processor
421
Channel Estimator
423
White Space LTE Transceiver or Receiver
428
Frame Processor
429
Channel Estimator
431
White space LTE Tx/Rx Antenna
422
White space LTE Tx/Rx Or Rx only Antenna
430
433
432
White space LTE Tx/Rx Antenna
414
402
406
Spectrum Sensing Unit
Spectrum Manager
White Space LTE Transceiver
Frame Processor
Channel Estimator
413
415
WLAN gateway
408
410
412
403
404
Data Source(s)
TV Band Over-the-Air Signal

FIG. 4

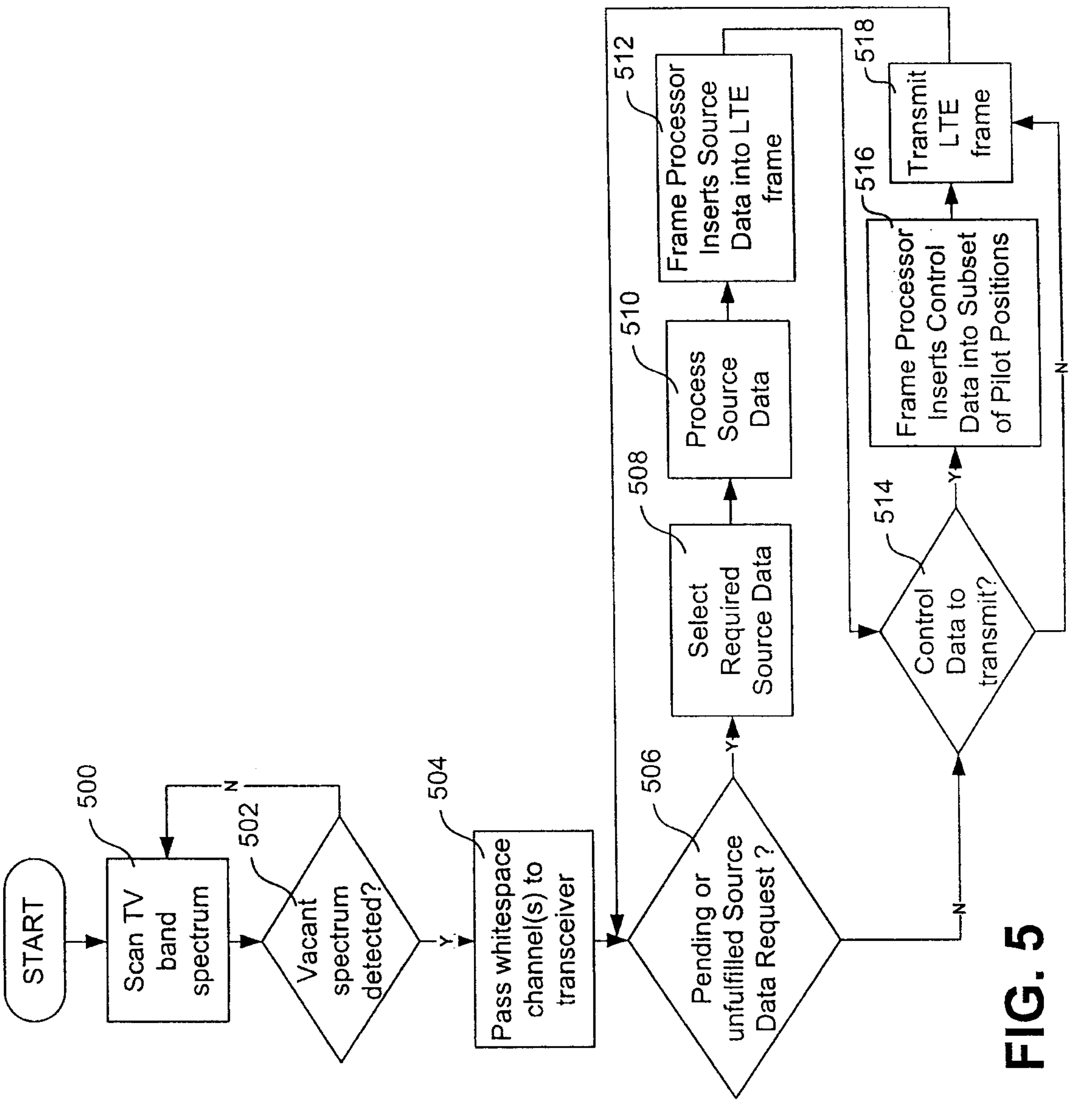

START
500
Scan TV band spectrum
502
Vacant spectrum detected?
N
Y
504
Pass whitespace channel(s) to transceiver
506
Pending or unfulfilled Source Data Request ?
Y
N
508
Select Required Source Data
510
Process Source Data
512
Frame Processor Inserts Source Data into LTE frame
514
Control Data to transmit?
Y
N
516
Frame Processor Inserts Control Data into Subset of Pilot Positions
518
Transmit LTE frame

FIG. 5

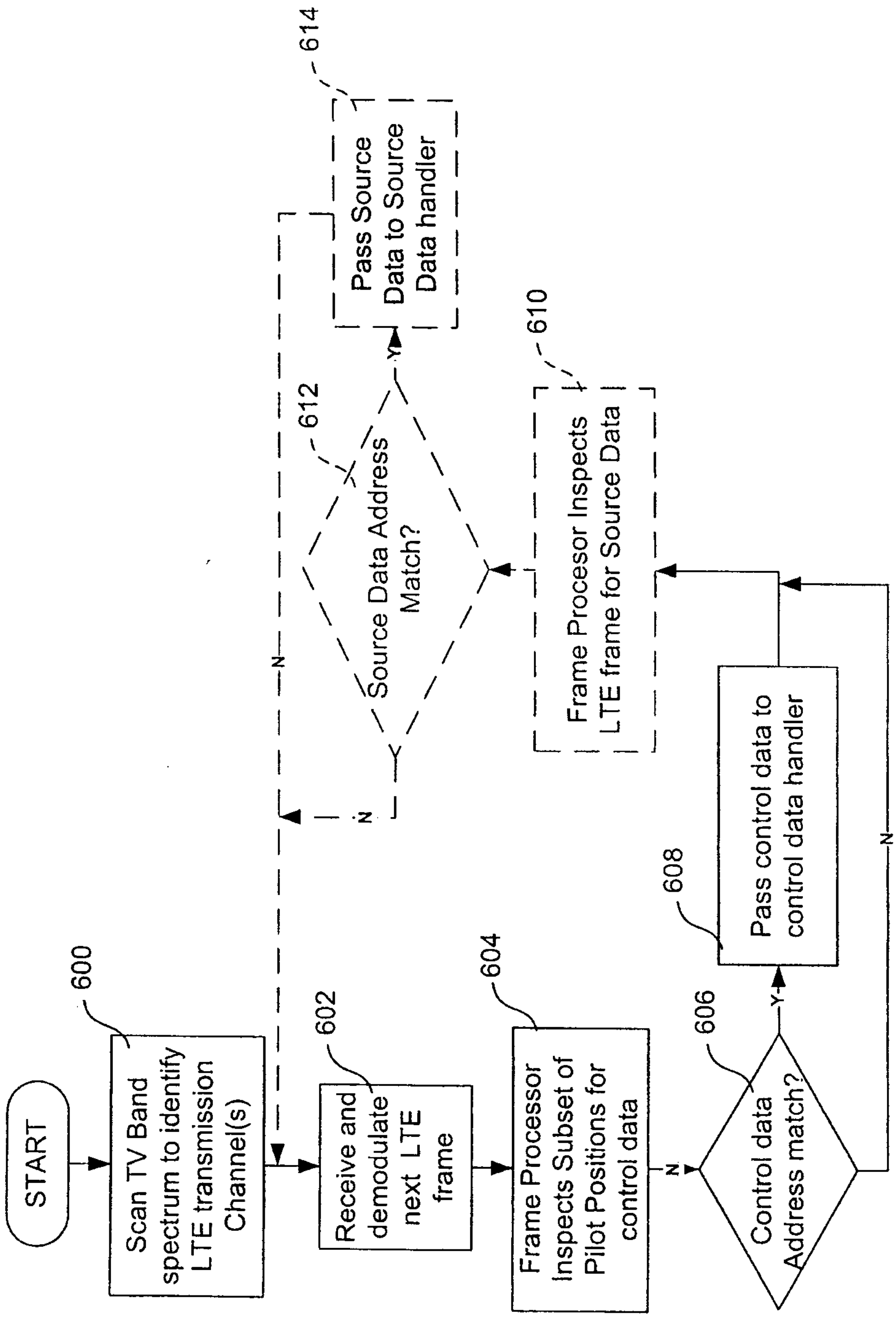

START
600
Scan TV Band spectrum to identify LTE transmission Channel(s)
602
Receive and demodulate next LTE frame
604
Frame Processor Inspects Subset of Pilot Positions for control data
606
Control data Address match?
608
Pass control data to control data handler
610
Frame Procesor Inspects LTE frame for Source Data
612
Source Data Address Match?
614
Pass Source Data to Source Data handler
Y
N

FIG. 6

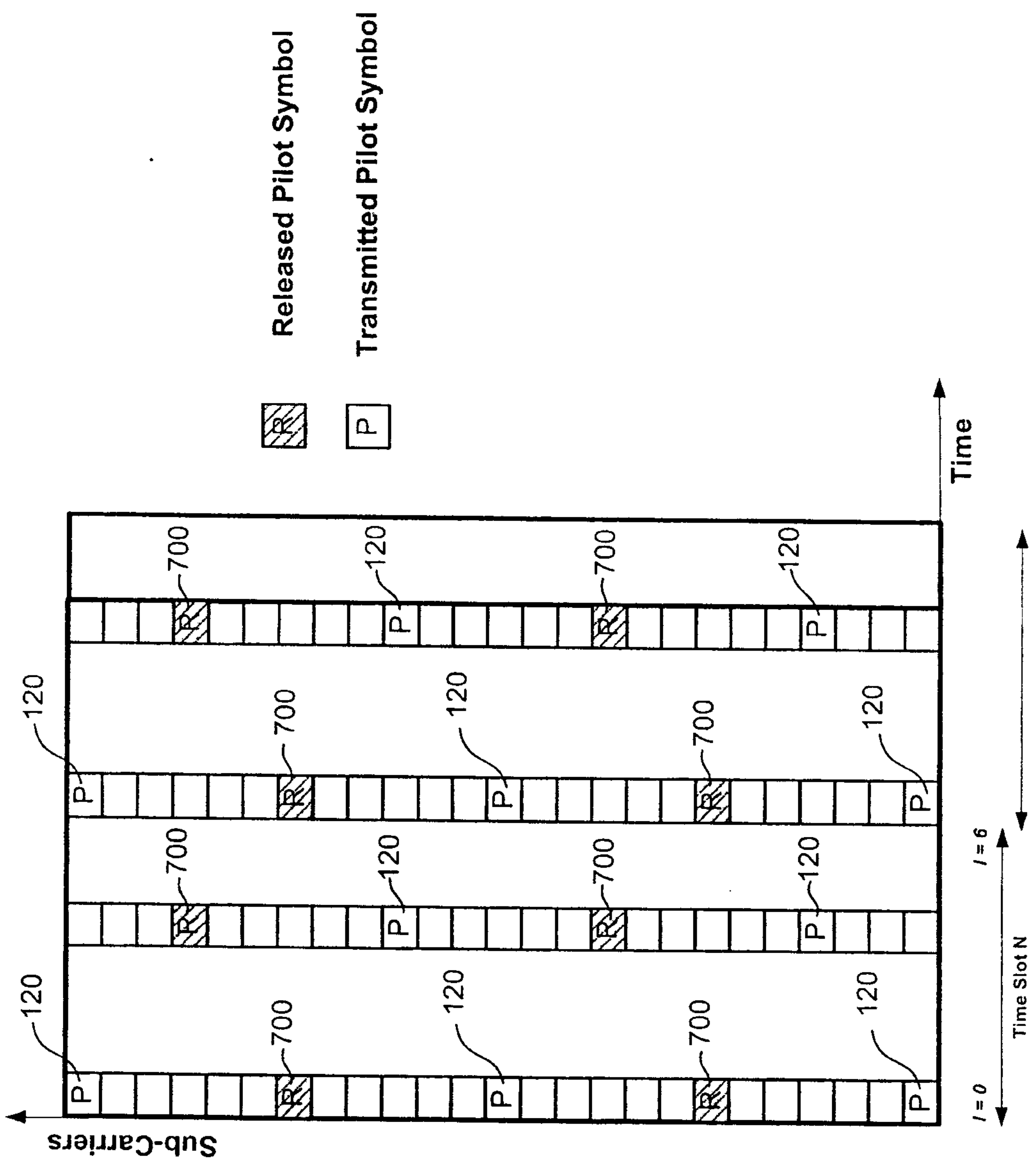

Released Pilot Symbol
Transmitted Pilot Symbol
R
P
Time
Sub-Carriers
120
700
Time Slot N
0.5 ms
Time Slot N+1
0.5 ms
l = 0
l = 6

FIG. 7

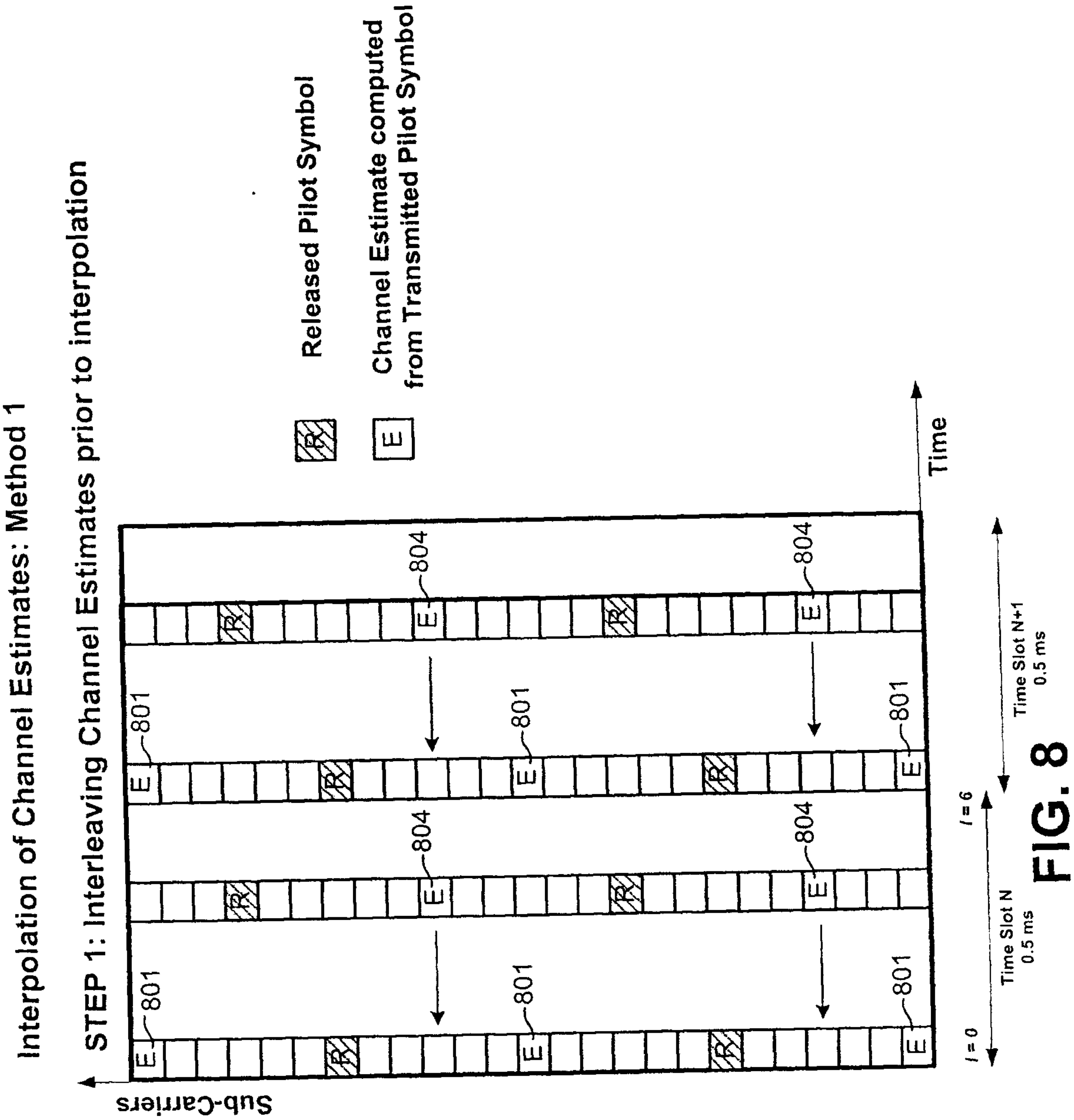

Interpolation of Channel Estimates: Method 1
STEP 1: Interleaving Channel Estimates prior to interpolation
R Released Pilot Symbol
E Channel Estimate computed from Transmitted Pilot Symbol
Sub-Carriers
Time
801
804
Time Slot N 0.5 ms
Time Slot N+1 0.5 ms
l = 0
l = 6

FIG. 8

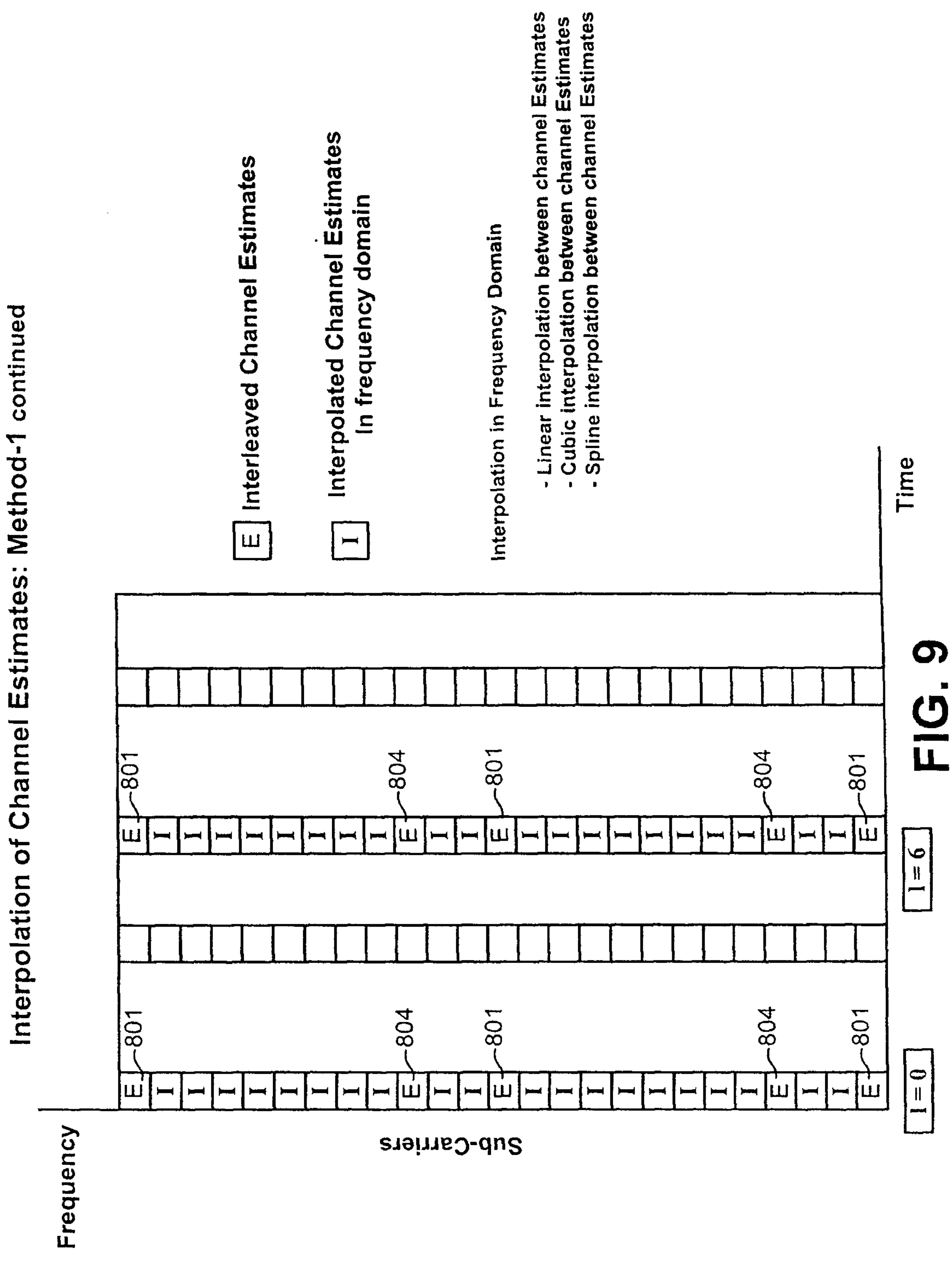

Interpolation of Channel Estimates: Method-1 continued
E Interleaved Channel Estimates
I Interpolated Channel Estimates
In frequency domain
Interpolation in Frequency Domain
- Linear interpolation between channel Estimates
- Cubic interpolation between channel Estimates
- Spline interpolation between channel Estimates
Frequency
Sub-Carriers
Time
l = 0
l = 6
801
804

FIG. 9

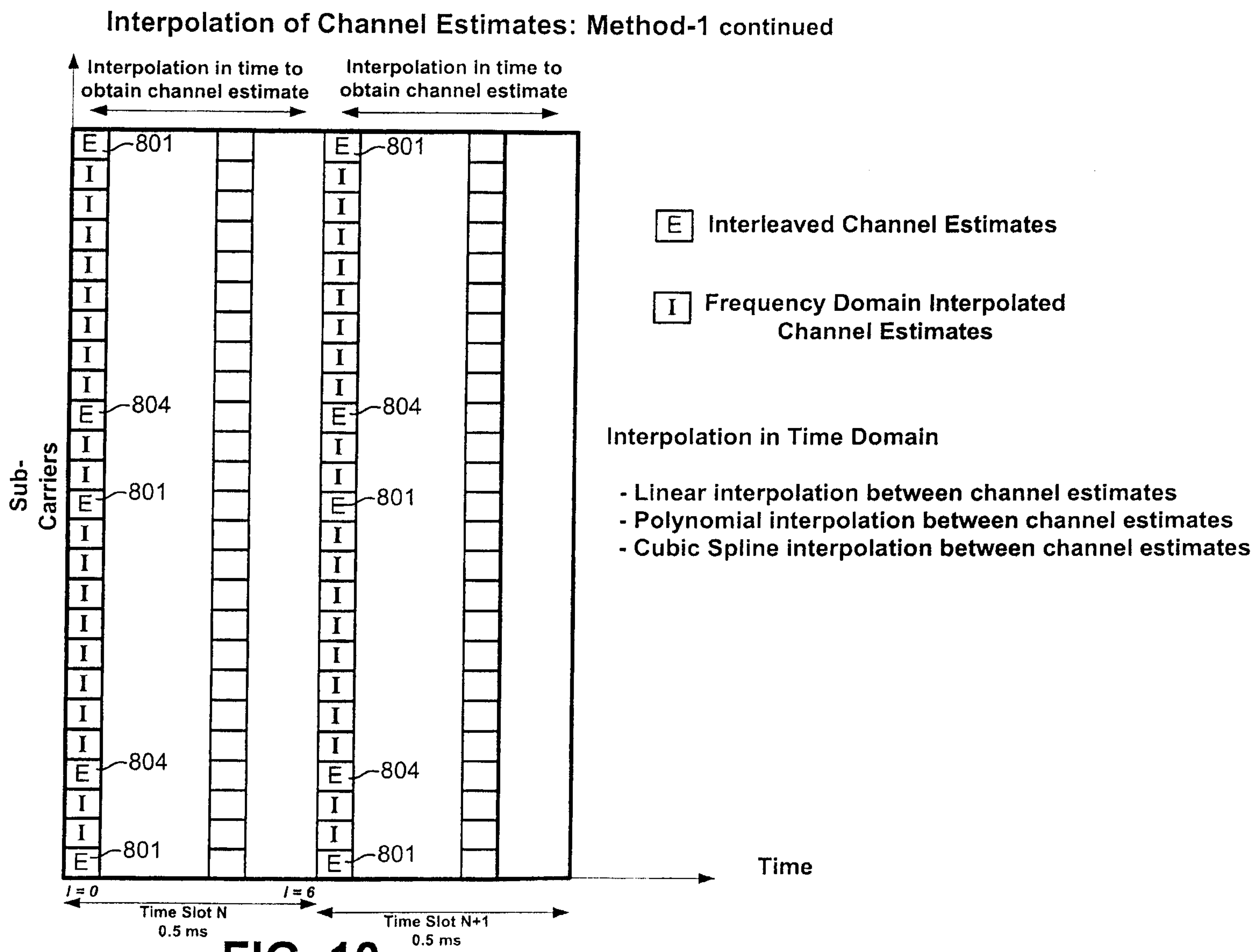

Interpolation of Channel Estimates: Method-1 continued
Interpolation in time to obtain channel estimate
Interpolation in time to obtain channel estimate
Sub-Carriers
E
I
801
804
l = 0
l = 6
Time Slot N
0.5 ms
Time Slot N+1
0.5 ms
Time
E Interleaved Channel Estimates
I Frequency Domain Interpolated Channel Estimates
Interpolation in Time Domain
- Linear interpolation between channel estimates
- Polynomial interpolation between channel estimates
- Cubic Spline interpolation between channel estimates

FIG. 10

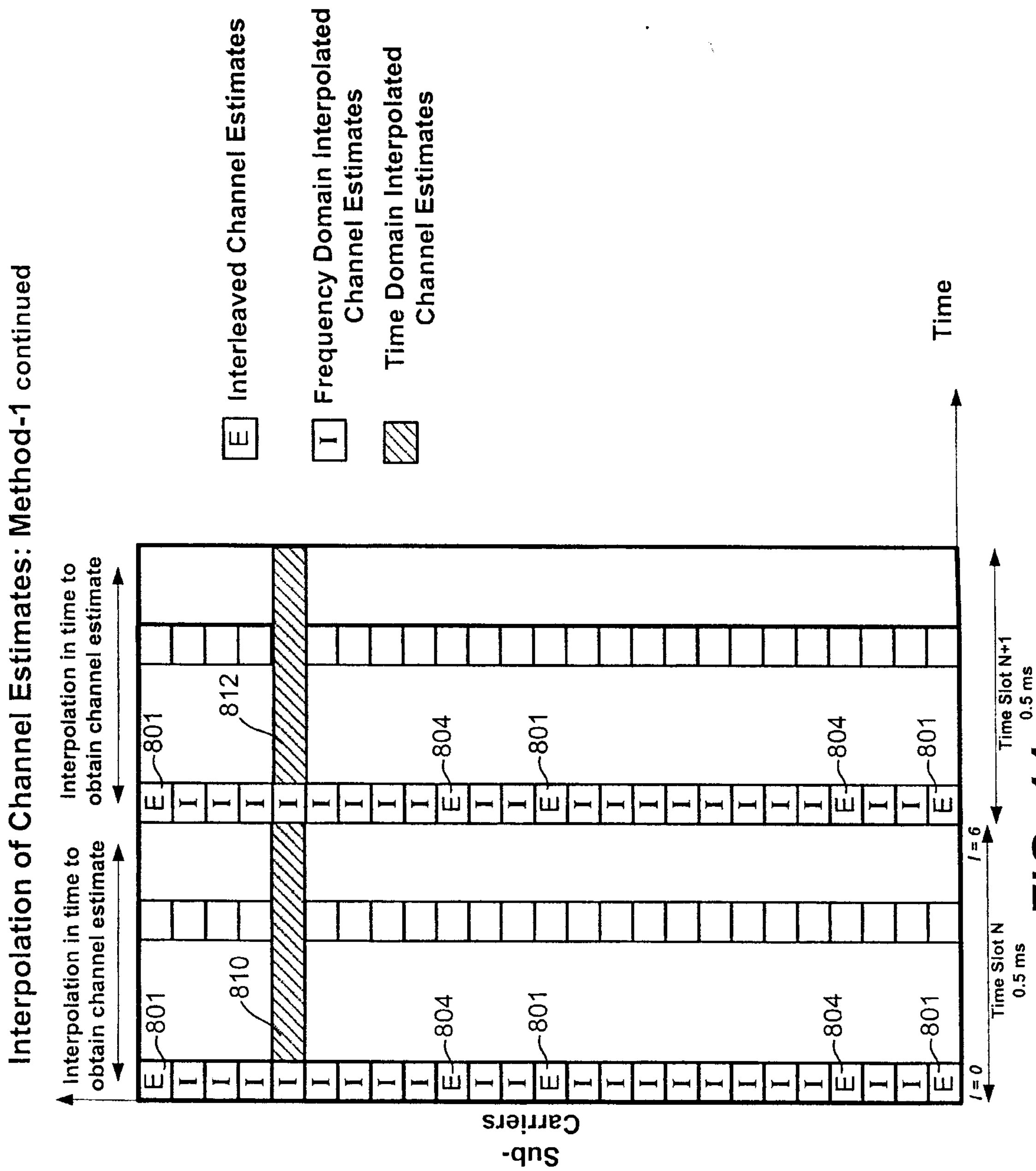
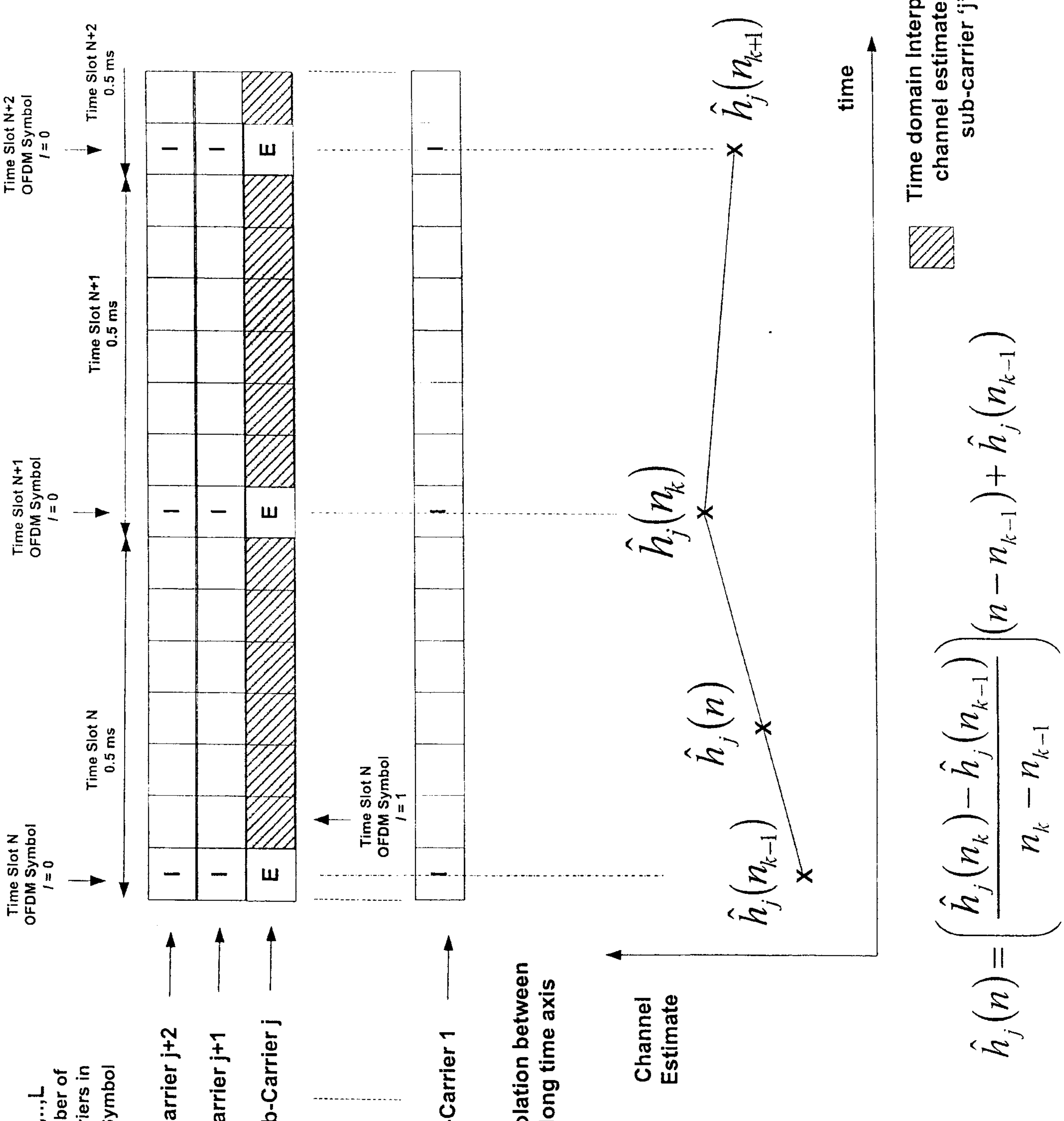

Interpolation of Channel Estimates: Method-1 continued
Interleaved Channel Estimates
Frequency Domain Interpolated Channel Estimates
Time Domain Interpolated Channel Estimates
Interpolation in time to obtain channel estimate
Interpolation in time to obtain channel estimate
Sub-Carriers
Time
801
810
812
804
l = 0
l = 6
Time Slot N 0.5 ms
Time Slot N+1 0.5 ms

FIG. 11



j = 1,..,L
L: Number of Subcarriers in OFDM Symbol
Sub-Carrier j+2
Sub-Carrier j+1
Sub-Carrier j
Sub-Carrier 1
Time Slot N OFDM Symbol l = 0
Time Slot N 0.5 ms
Time Slot N OFDM Symbol l = 1
Time Slot N+1 OFDM Symbol l = 0
Time Slot N+1 0.5 ms
Time Slot N+2 OFDM Symbol l = 0
Time Slot N+2 0.5 ms
I
E
Linear Interpolation between estimates along time axis
Channel Estimate
time
$\hat{h}_j(n_{k-1})$
$\hat{h}_j(n)$
$\hat{h}_j(n_k)$
$\hat{h}_j(n_{k+1})$
Time domain Interpolated channel estimates for sub-carrier 'j'
$\hat{h}_j(n) = \left(\frac{\hat{h}_j(n_k) - \hat{h}_j(n_{k-1})}{n_k - n_{k-1}}\right)(n - n_{k-1}) + \hat{h}_j(n_{k-1})$

FIG. 12

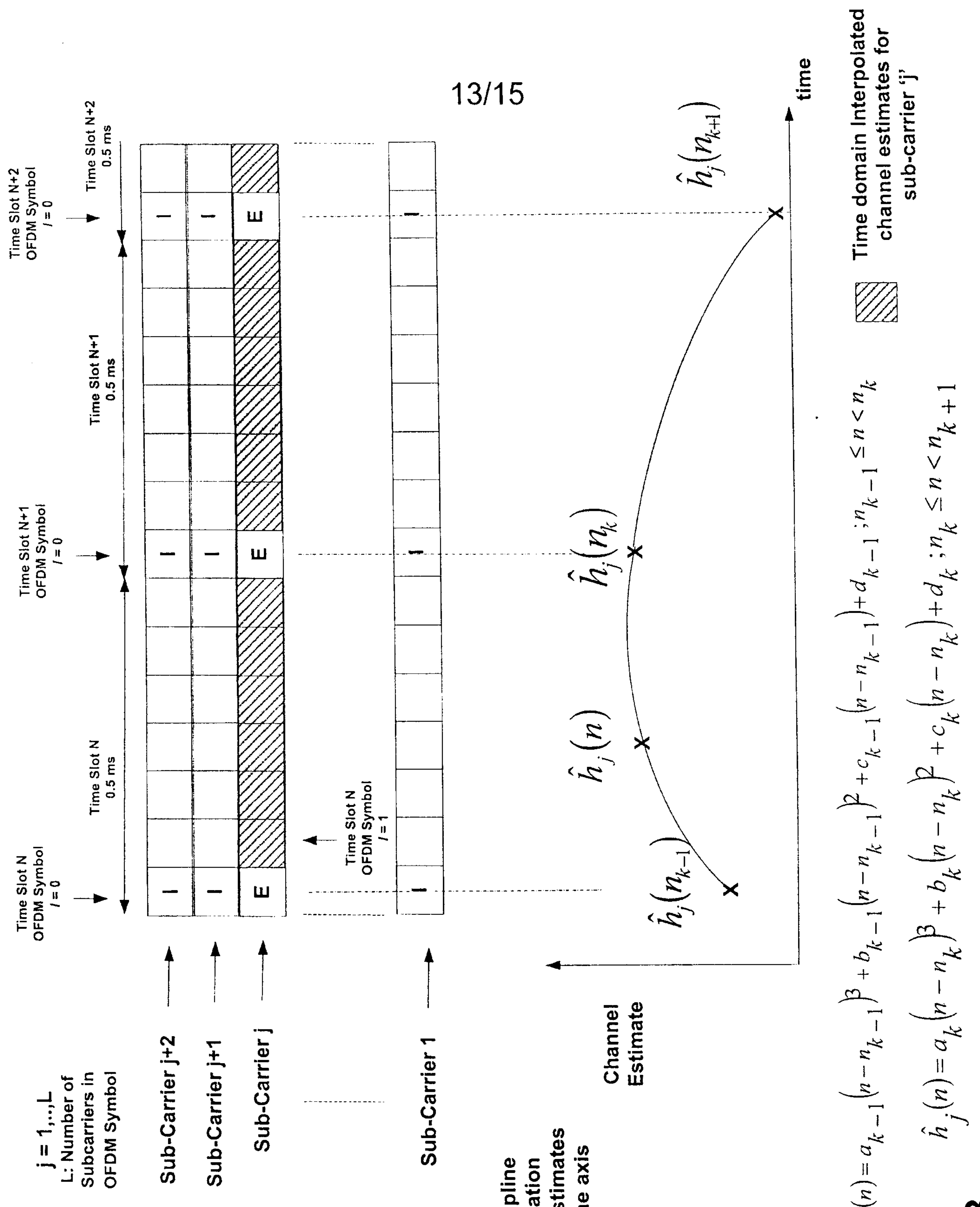

Time Slot N OFDM Symbol l = 0
Time Slot N 0.5 ms
Time Slot N+1 OFDM Symbol l = 0
Time Slot N+1 0.5 ms
Time Slot N+2 OFDM Symbol l = 0
Time Slot N+2 0.5 ms
Time Slot N OFDM Symbol l = 1
j = 1,..,L
L: Number of Subcarriers in OFDM Symbol
Sub-Carrier j+2
Sub-Carrier j+1
Sub-Carrier j
Sub-Carrier 1
I
E
Cubic Spline Interpolation between estimates along time axis
Channel Estimate
time
$\hat{h}_j(n_{k-1})$
$\hat{h}_j(n)$
$\hat{h}_j(n_k)$
$\hat{h}_j(n_{k+1})$
Time domain Interpolated channel estimates for sub-carrier 'j'
$\hat{h}_j(n) = a_{k-1}(n-n_{k-1})^3 + b_{k-1}(n-n_{k-1})^2 + c_{k-1}(n-n_{k-1}) + d_{k-1}; n_{k-1} \le n < n_k$
$\hat{h}_j(n) = a_k(n-n_k)^3 + b_k(n-n_k)^2 + c_k(n-n_k) + d_k; n_k \le n < n_{k+1}$

FIG. 13

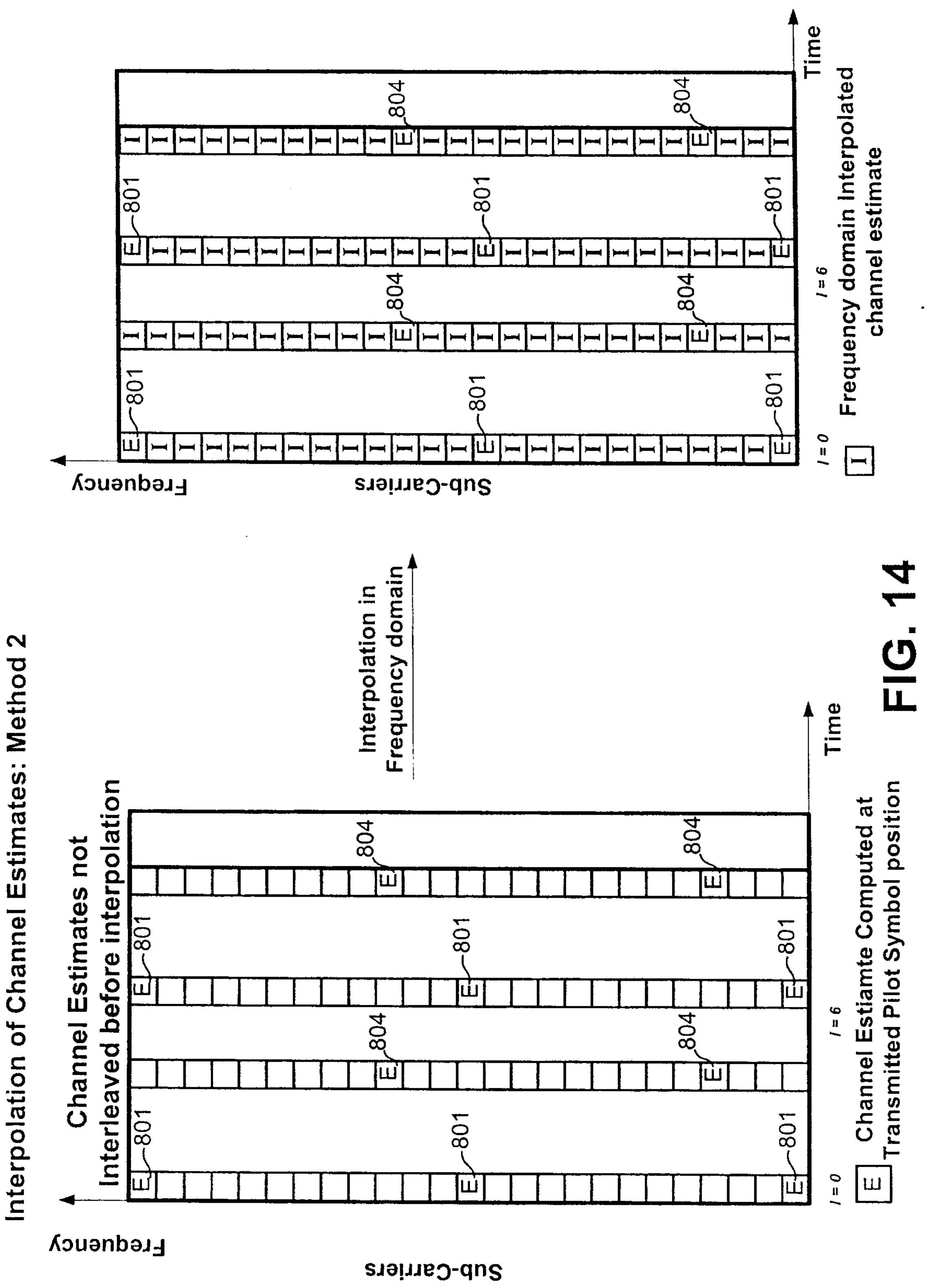

Interpolation of Channel Estimates: Method 2
Channel Estimates not Interleaved before interpolation
Frequency
Sub-Carriers
Time
l = 0
l = 6
801
804
E
Channel Estiamte Computed at Transmitted Pilot Symbol position
Interpolation in Frequency domain
I
Frequency domain Interpolated channel estimate

FIG. 14

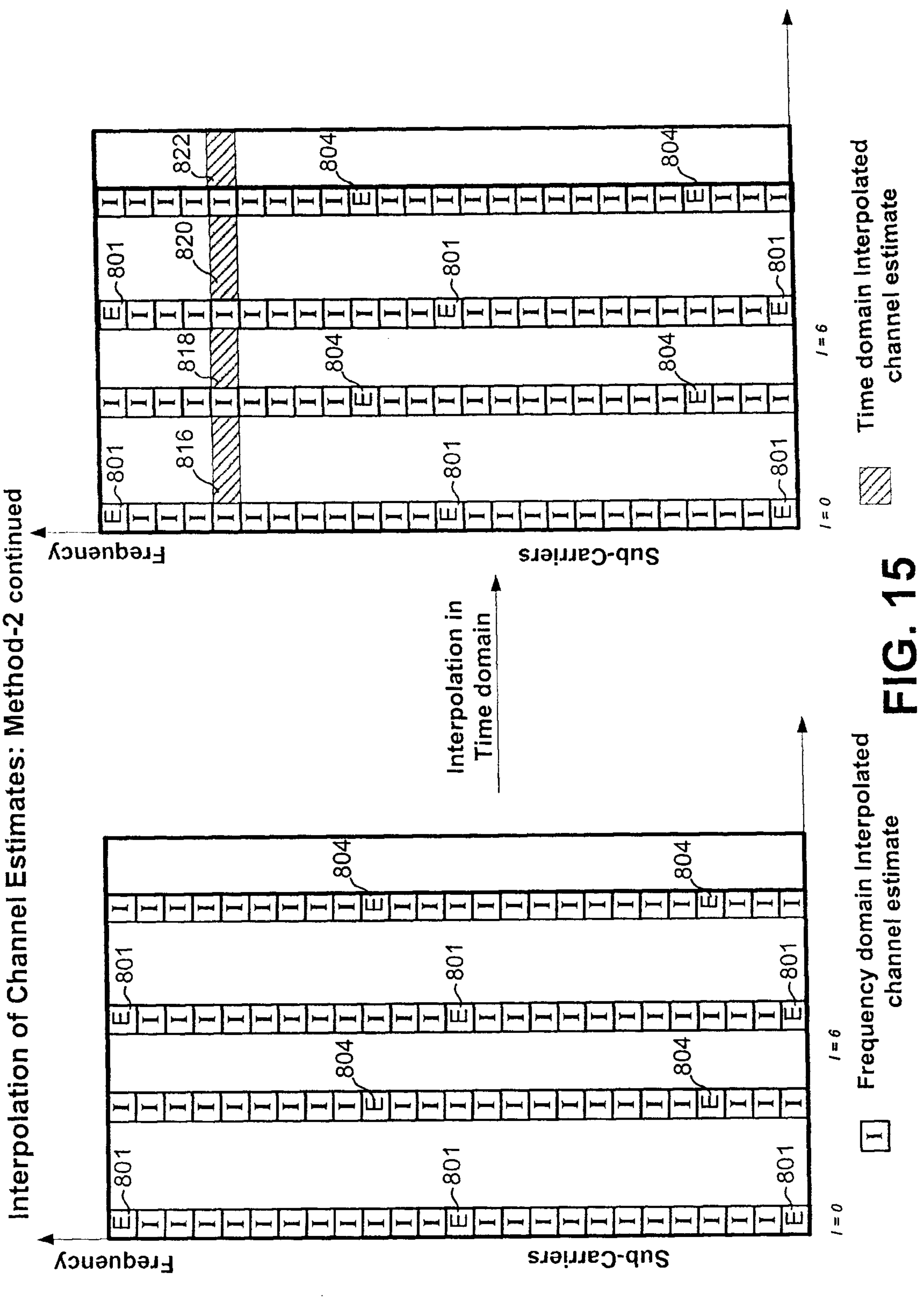

Interpolation of Channel Estimates: Method-2 continued
Frequency
Sub-Carriers
801
804
l = 0
l = 6
Interpolation in Time domain
Frequency domain Interpolated channel estimate
816
818
820
822
Time domain Interpolated channel estimate

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2010/000126

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***H04W 84/12*** (2009.01) , ***H04W 88/16*** (2009.01) , *H04W 72/08* (2009.01) , *H04N 7/015* (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W 84/12 (2009.01) , ***H04W 88/16*** (2009.01) , *H04W 72/08* (2009.01) , *H04N 7/015* (2006.01)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Epoque, QPat, IEEExplore, Google Patent
Keyword: LONG, TERM, EVOLUTION, NETWORK, WHITE, TV, PILOT, CONTROL, SPACE, WLAN, DOWNLINK, FRAMES

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US20080086749 (Goldberg et al.) 10 April 2008 (10-04-2008) ***para(s) [0043]***	1-6, 8-14, 16-18
Y	WO2008060203 (Wang et al.) 22 May 2008 (22-05-2008) ***page 5, lines 10-20; page 8, lines 18-30***	1-6, 8-14, 16-18
Y	"IEEE starts standard to tap open regions in the TV spectrum for wireless broadbad services" (IEEE) 12 October 2004 (12-10-2004) from: http://standards.ieee.org/announcements/pr_80222.html	1-6, 8-14, 16-18
A	US4750036 (Martinez) 7 June 1988 (07-06-1988) ***entire document***	1-20

[ ] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :
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"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
30 March 2010 (30-03-2010)

Date of mailing of the international search report
5 May 2010 (05-05-2010)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
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Gatineau, Quebec K1A 0C9
Facsimile No.: 001-819-953-2476

Authorized officer
Richin Choi (819) 934-4894

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
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		WO2008041229A3	07-05-2009
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