(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 September 2010 (30.09.2010)

PCT

(10) International Publication Number
WO 2010/111037 A1

(51) International Patent Classification:
H04W 72/00 (2009.01)

(21) International Application Number:
PCT/US2010/026808

(22) International Filing Date:
10 March 2010 (10.03.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/163,782 26 March 2009 (26.03.2009) US
61/164,192 27 March 2009 (27.03.2009) US
12/620,422 17 November 2009 (17.11.2009) US

(71) **Applicant** *(for all designated States except US)*: **NTT DOCOMO, INC.** [JP/JP]; Sanno Park Tower, 11-1, Nagata-cho, 2-chome, Chiyuda-ku, Tokyo, Tokyo 100-6150 (JP).

(72) **Inventors; and**
(75) **Inventors/Applicants** *(for US only)*: **CHONG, Chia-Chin** [MY/US]; 4048 Fitzpatrick Way, Santa Clara, California 95054 (US). **MINN, Hlaing** [MM/US]; 1007 Estes Park Drive, Allen, Texas 75013 (US). **WATANABE, Fujio** [JP/US]; 34908 Limestone Court, Union City, California 94587 (US).

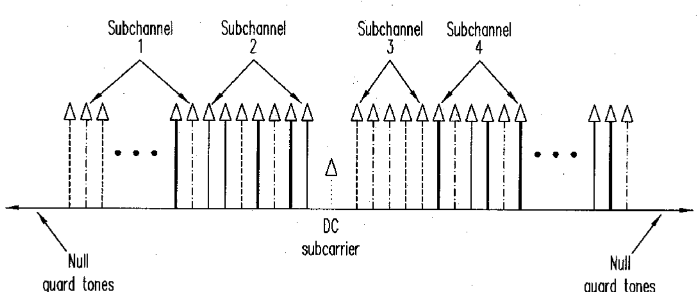
(74) **Agent**: **KWOK, Edward C.**; Haynes and Boone, LLP, 2033 Gateway Place, Suite 400, San Jose, California 95110 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title**: A NON-CYCLIC EVOLVING-TYPE USER RESOURCE STRUCTURE FOR OFDMA BASED SYSTEM WITH NULL GUARD TONES



An illustration of an OFDMA system with large null guard tones.

FIG. 1

(57) **Abstract**: A non-cyclic evolving-type user resource structure applicable for use in the uplink and the downlink of an OFDMA system with large null guard tones (e.g., a 3GPP LTE system) is provided. In one example, the user resource structure combines the benefits of localized and distributed types of resource structures available in the current baseline 3GPP LTE (Release 8) specifications, and is especially suitable for operating in a fast time-varying channel. In another example, the non-cyclic evolving-type resource structure may be simplified to have no more than three stages: a band-type first stage, a partially evolved-type second stage and an interleaved-type third stage. Depending upon the target or average mobile speed and packet length, the resource structure may even have less than three stages.

WO 2010/111037 A1

A Non-Cyclic Evolving-Type User Resource Structure for OFDMA Based System with Null Guard Tones

Chia-Chin Chong
Hlaing Minn
Fujio Watanabe

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is related to and claims priority of (i) U.S. provisional patent application, entitled “A Non-Cyclic Evolving-Type User Resource Structure for OFDMA Based System with Null Guard Tones,” serial no. 61/163,782, filed on March 26, 2009, (ii) U.S. provisional patent application, entitled “A Simplified Evolving-Type User Resource Structure for OFDMA Based System,” serial no., 61/164,192, filed on March 27, 2009, and (iii) U.S. non provisional patent application, entitled “A Non-Cyclic Evolving-Type User Resource Structure for OFDMA Based System with Null Guard Tones,” serial no. 12/620,422, filed on November 17, 2009. The disclosures of these U.S. provisional and non-provisional patent applications are hereby incorporated by reference in their entireties.

The present invention is also related to co-pending U.S. patent application (“Copending Application”), entitled “An Evolving-Type User Resource Structure/Channelization with Enhanced Diversity for OFDMA Based Time-Varying Channels,” naming inventors C.-C. Chong, H. Minn, and F. Watanabe, serial no. 12/455,268, filed on May 28, 2009. The disclosure of the Copending Application is hereby incorporated by reference in its entirety.

For the U.S. designation, the present application is a continuation of the aforementioned U.S. patent application no. 12/620,422.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to wireless communication, such as cellular networks. In particular, the present invention relates to the structure and allocation of resources in wireless communication systems, such as cellular communication systems using orthogonal frequency division multiple-access (OFDMA) signaling protocols.

2. Discussion of the Related Art

Because of its better resource resolution in the time-frequency grid, OFDMA has attracted significant attention and has been adopted in many wireless systems. The better resource resolution also provides better exploitable diversity when proper resource allocation and resource structuring schemes are adopted. Resource allocation or sub-carrier and power allocation for OFDMA systems are discussed, for example, in (i) U.S. Patent Application Publication 2005/0265223, entitled "Method and apparatus for scheduling downlink channels in an orthogonal frequency division multiple access system and a system using the same," by J. –H. Song, filed on May 13, 2005 and published on Dec 1, 2005; (ii) U. S. Patent Application Publication 2006/0109865, entitled "Method for allocating resources in a multicarrier system and transmission apparatus using the same," by S. –Y. Park, Y. –W. Lee, S. –B. Yun, Y. –S. Kim, filed on November 25, 2005 and published on May 25 2006; (iii) U.S. Patent 6,917,812, entitled "Air interface scheduler for wireless communication networks," by A. Damnjanovic, filed on December 3, 2001, and issued on July 12, 2005; (iv) U.S. Patent 6,987,738, entitled "Method for packet scheduling and radio resource allocation in a wireless communication system," by V. G. Subramanian, R. Agarwal, R. J. La, filed on January 12, 2001 and issued on January 17, 2006; (v) U.S. Patent Application Publication 2006/0149620, entitled "Scheduling apparatus and method in a multicarrier communication system," by C. –H. Suh, S. –H. Park, S. –H. Yoon, S. –K. Hong, Y. –K. Cho, filed on December 30, 2001 and published on July 6, 2006; (vi) U.S. Patent Application Publication 2008/0076438, entitled "Method for dynamic resource allocation of uplink and downlink in OFDMA/TDD cellular system," by K. H. Chang, S. J. Ko, T. H. Sun, J. H. Kim, filed on September 21, 2007 and published on March 27, 2008; and (vii) U.S. Patent Application Publication 2008/0043610 ("Liu"), entitled "Multi-carrier communications with group-based subcarrier allocation," by X. Li, H. Liu, H. Yin, G. Xing, F. Mu, filed on October 26, 2007 and published on February 21, 2008. For example, Liu discloses a method for subcarrier selection in an OFDMA system, which partitions subcarriers into groups of one or more clusters of subcarriers for use in communication with the subscriber[1]. These resource allocation schemes in the prior art neither exploit multiuser diversity benefits nor take into account a time-varying channel.

Some prior art schemes exploit multiuser diversity using complete or partial knowledge of the channel to guide resource allocation or scheduling. Such schemes includes (i) the article, entitled "Opportunistic beamforming and scheduling for OFDMA systems," by P. Svedman, S. K. Wilson, L. J. Cimini, and B. Ottersten, published in *IEEE Trans. Commun.*, vol. 55, no. 5,

[1] Subscriber is also known as mobile station (MS) or user equipment (UE).

May 2007, pp. 941-952; (ii) the article ("Chemaly"), entitled "Adaptive resource allocation for multiuser MIMO/OFDM networks based on partial channel state information," by R. Chemaly, K. Letaief, and D. Zeghlache, *Proc. IEEE GLOBECOM 2005*, St. Louis, MO, Nov. 2005, pp. 3922-3926; (iii) U.S. Patent Application Publication 2007/0110003 ("Tujkovic I"), entitled "Subcarrier allocation in OFDMA with imperfect channel state information at the transmitter," by D. Tujkovic, A. Paulraj, filed on June 16, 2006 and published on May 17, 2007; and (iv) U.S. Patent Application Publication ("Tujovic II"), entitled "Time domain interference averaging with multiuser diversity in OFDMA systems," by D. Tujkovic, A. Paulraj, filed on June 16, 2006 and published on January 3, 2008.

Such channel knowledge-based schemes are mostly applicable only to quasi-static or slow-varying channels. For example, Tujovic I fails to consider the impact of time-varying channels which deteriorate multiuser diversity gain. Tujovic I discloses a method that combines features of multiuser diversity and frequency diversity allocation schemes. The method of Tujovic I retains advantages of multiuser diversity allocation whenever possible by assigning a fraction of the available bandwidth to users in high signal-to-noise ratio (SNR) channels. Recognizing that channel state information (CSI) at the transmitter is not perfect, the system and method allocate the remaining bandwidth pseudo-randomly according to frequency diversity. Similarly, Tujovic II reduces interference between multiple users operating under multiuser diversity within a coherence bandwidth in an OFDMA system by spreading out the users' transmission symbols randomly in time within the coherence bandwidth. When transmission symbols are randomly dispersed, the variance of interference between users in the same sub-band is reduced.

Other schemes that incorporate time-variation or Doppler spread in their resource allocation include Chemaly (above) and the articles (i) "Sub-band rate and power control for wireless OFDM systems," by J. Oh and J. M. Cioffi, published in *Proc. IEEE Vehicular Technology Conference (VTC 2004-Fall),* Los Angeles, CA, Vol. 3, 26-29 Sept. 2004, pp. 2011–2014; and (ii) "Fair adaptive radio resource allocation of mobile OFDMA," by F.-S. Chu and K.-C. Chen, published in *Proc. IEEE Personal, Indoor and Mobile Radio Communications (PIMRC 2006)*, Helsinki, Finland, Sept. 2006, pp. 1–5. These time-variation or Doppler spread resource allocation schemes, however, require knowledge of the Doppler spread. Even with knowledge of Doppler spread, these methods still suffer from performance degradation at high mobile speeds. The mismatches between the models used in these methods and the actual channel time-correlation and the maximum Doppler shift may introduce additional degradation.

In the prior art, several resource structures or user channelization exploit diversity, such as (i) band division multiple access (BDMA) in the article "BDMA testbed-configuration and performance results," by T. Kunihiro, T. Yamaura, M. Suzuki, E. Fujita, published in *Proc. IEEE Vehicular Technology Conference, VTC Spring*, Vol. 3, 16-20 May 1999, pp. 1836–1840; (ii) interleaved frequency division multiple access (IFDMA), adaptive FDMA (AFDMA), and adaptive block division multiple access (ABDMA) in the article "Resource allocation and power control in a TDD OFDM-based system for 4G cellular networks," by P. Bisaglia, S. Pupolin, D. Veronesi, M. Gobbi, published in *Proc. IEEE Vehicular Technology Conference, VTC Spring*, Vol. 4, 7-10 May 2006, pp.1595–1599; and (iii) non frequency scattering and hopping (NFSH), frequency scattering (FS), and frequency scattering and hopping (FSH) in the article "Performances of multicarrier system with time and frequency domain spreading for wireless communications," by Y. Teng, K. Naito, K. Mori, H. Kobayashi, published in *Proc. International Conference on Wireless Networks, Communications and Mobile Computing*, Vol. 1,13-16 June 2005, pp. 558–563.

Other examples of resource structures include (i) in WiMAX and IEEE 802.16e, distributed permutation and contiguous/adjacent permutation (see, Broadband Wireless Access: IEEE MAN standard, IEEE LAN/MAN Standards Committee IEEE 802.16e, 2005.); and (ii) in 3GPP LTE, localized and distributed type resource blocks (see, 3rd Generation Partnership Project (3GPP); Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 8), Doc. 3GPP TR 36.211, Version 8.4.0, September 2008).

All of the above user resource structures may be classified into two main categories: *band-type* (also known as localized-structure) and *interleaved-type* (also known as distributed-structure). In a band-type resource structure, a user is allocated a band of adjacently located subcarriers. In an interleaved-type resource structure, a user is allocated subcarriers that are (i) spread out across the entire band in use, (ii) interleaved with those of the other users, or (iii) both. In such a user resource structure, the subcarriers may be non-contiguous, or may be provided in several non-adjacent groups of contiguous subcarriers. The assigned subcarriers may also change from symbol to symbol in a systematic way across all users. Each of these user resource structures have their own advantages as well as disadvantages, depending upon application, usage, channel condition, mobility and other factors.

In an OFDMA system, *multiuser diversity* may be exploited by assigning to each user contiguous subcarriers (i.e., a band-type user resource structure). If a channel varies substantially within a transmission frame, a centralized OFDMA resource allocation scheme may lose most of its multiuser diversity gains as a result of the outdated or mismatched channel information used in the resource allocation at the beginning of the frame. In fact, the channel allocated to a user may well be in deep fade at a later part of the frame. In order to alleviate the effect of such an adverse deep fade, one may provide a shorter frame length, or a more frequent update (feedback) of channel information, at the cost of substantial throughput loss due to large overhead (e.g., preamble and control information, such as DL-MAP and UL-MAP). A very short frame length is therefore overhead inefficient. Alternatively, the time-varying channel effect may also be alleviated by keeping the subcarriers assigned to a user spread out over the entire band (i.e., interleaved-type). One example of an interleaved-type resource structure is provided in the article "A new ranging method for OFDMA systems," by X. Fu, Y. Li, and H. Minn, published in *IEEE Trans. on Wireless Commun.*, vol. 6, no. 2, Feb. 2007, pp. 659-669. While an interleaved-type resource structure addresses the deep fade problem through frequency diversity, multiuser diversity gain is lost. Thus, existing user resource structures (i.e., both band-type and interleaved-type) have limited diversity exploitation capability in time-varying channels.

SUMMARY

The present invention provides a non-cyclic evolving-type user resource structure applicable for use in the uplink and the downlink of an OFDMA system with large null guard tones (e.g., a 3GPP Long Term Evolution (LTE) system). In one embodiment, the user resource structure combines the benefits of localized and distributed types of resource structures such as the one available in the current baseline 3GPP LTE (Release 8) specifications, and is especially suitable for operating in a fast time-varying channel i.e., high mobility environment.

According to another embodiment of the present invention, the non-cyclic evolving-type resource structure for an OFDMA system may be simplified to have no more than three stages: a band-type first stage, a partially evolved-type second stage and an interleaved-type third stage. Depending upon the target mobile speed (or average mobile speed in a cell) and packet length, the resource structure may even have less than three stages. Such an evolving resource structure may be implemented in a simple manner, with flexible system parameters.

The present simplification methodology proposed in this invention is applicable to both (a) evolving resource structures with cyclic expansion (e.g., a resource structure for an OFDMA system without null guard tones or with a small null guard tone (e.g., Mobile WiMAX), and (b) evolving resource structures with non-cyclic expansion (e.g., a resource structure for an OFDMA systems with large null guard tones (e.g., 3GPP LTE).

The present invention is better understood upon consideration of the detailed description below in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates an OFDMA frame structure with a large number of null guard tones.

Figure 2 shows, under 3GPP LTE, an LTE frame structure Type 1 for an FDD system.

Figure 3 shows, under 3GPP LTE, an LTE frame structure Type 2 for a TDD system.

Figure 4 shows, under 3GPP LTE, an LTE downlink resource grid.

Figure 5 illustrates the parameters definition for a non-cyclic evolving-type OFDMA resource structure, according to one embodiment of the present invention.

Figure 6 shows a basic E-PRB template for a 2.5 MHz channel bandwidth supporting up to 4 users simultaneously, according to one embodiment of the present invention.

Figure 7 shows a basic E-PRB template for a 2.5 MHz channel bandwidth supporting up to 6 users simultaneously, according to one embodiment of the present invention.

Figure 8 shows a basic E-PRB template for 2.5 MHz and 5 MHz channel bandwidths supporting up to 8 users simultaneously, according to one embodiment of the present invention.

Figure 9 shows a basic E-PRB template for 5 MHz and 10 MHz channel bandwidths supporting up to 12 users simultaneously, according to one embodiment of the present invention.

Figure 10 shows a basic E-PRB template for a 10 MHz channel bandwidth supporting up to 16 users simultaneously, according to one embodiment of the present invention.

Figure 11 shows a basic E-PRB template for 10 MHz and 20 MHz channel bandwidths supporting up to 24 users simultaneously, according to one embodiment of the present invention.

Figure 12 is flowchart that summarizes the steps for designing a non-cyclic E-PRB structure, in accordance with one embodiment of the present invention.

Figure 13 is a flowchart that summarizes the designing of a 3-stage simplified E-PRB structure that can be used in a system with a large number of null guard tones, in accordance with one embodiment of the present invention.

Figure 14 shows, in the shaded areas of all three stages, the k-th E-PRB, $2 \leq k \leq U-1$, according to one embodiment of the present invention.

Figure 15 shows, in the shaded areas of all three stages, the first E-PRBs, i.e., $k=1$, according to one embodiment of the present invention.

Figure 16 shows, in the shaded areas of all three stages, the last E-PRBs, i.e., $k=U$, according to one embodiment of the present invention.

Figure 17 illustrates an example in which E-VRBs are provided in a system with parameters $N = 128$, $N_{\text{used}} = 72$, $M = 28$, $W = 6$, $N_{\text{SPRB}} = 4$, $U = 3$, $\mu = 2$ and $v = 80$ km/h (i.e., $\alpha_1 = 8$, $\alpha_2 = 8$, $\alpha 3 = 12$), in accordance with one embodiment of the present invention.

Figure 18 illustrates an example in which E-VRBs are provided in a system with parameters $N = 256$, $N_{\text{used}} = 144$, $M = 28$, $W = 6$, $N_{\text{SPRB}} = 4$, $U = 6$, $\mu = 2$ and $v = 80$ km/h (i.e., $\alpha_1 = 8$, $\alpha_2 = 8$, $\alpha 3 = 12$), according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The Copending Application, incorporated herein by reference above, discloses an efficient diversity-exploiting user resource structure, referred to as an "*evolving-type resource structure*," suitable for use in fast time-varying, frequency-selective fading channel environments. Such a resource structure enjoys the advantages of both band-type and interleaved-type structures because it takes advantage of both multiuser diversity and frequency diversity in the fast time-varying channel. While this resource structure in the Copending Application is applicable to centralized, semi-distributed and distributed access schemes, and may be applied to both downlink (DL) and uplink (UL) cellular systems, such a resource structure is not applicable to an OFDMA frame structure with large null guard tones (e.g., in a 3GPP LTE system). Accordingly, the present invention provides a non-cyclic evolving-type user resource structure, which is applicable for both the UL and the DL of an OFDMA system with a large number of null guard tones.

Figure 1 illustrates an OFDMA frame structure with null guard tones. In this detailed description, 3GPP LTE (Release 8) system parameters are used to illustrate an evolving-type resource structure of the present invention. These system parameters are summarized in Table 1:

Table 1: 3GPP LTE Rel. 8 system parameters for OFDMA DL transmission scheme.

Parameters	**Value**

Carrier frequency	1.92 GHz
Subcarrier spacing, Δf	15 kHz
Number of subcarriers per resource block, N_{sc}^{RB}	12
Number of resource blocks, N_{RB}	$N_{RB\text{-}min} = 6$ $N_{RB\text{-}max} = 110$
Transmission bandwidth (MHz)	1.25, 2.5, 5, 10, 15, 20
Number of FFT size, N	128, 256, 512, 1024, 1536, 2048
Number of occupied subcarriers (including DC-subcarrier), N_{occup}	76, 151, 301, 601, 901, 1201
Number of cyclic prefix samples (short)	$N \times 9/128$
Number of OFDM symbols per time slot, N_{symb}	7 (for normal CP) 6 (for extended CP)
Number of OFDM symbols per subframe	14 (for normal CP) 12 (for extended CP)
Frame duration, T_{frame}	10 ms
Subframe duration, $T_{subframe}$	1 ms
Slot duration, T_{slot}	0.5 ms

Figures 2-4 show, in a 3GPP LTE system, an LTE frame structure Type 1 for a FDD system, an LTE frame structure Type 2 for a TDD system, and an LTE downlink resource grid, respectively. Figure 4 also shows a mapping of physical channels to resource elements using resource blocks. In LTE, there are two types of resource blocks, which are referred to as "physical resource block (PRB)" and "virtual resource block (VRB)." A PRB has N_{symb} consecutive OFDM symbols in the time domain and N_{sc}^{RB} consecutive subcarriers in the frequency domain, where N_{symb} and $N_{\text{sc}}^{\text{RB}}$ are given in Table 1 above. A PRB thus includes $N_{\text{symb}} \times N_{\text{sc}}^{\text{RB}}$ resource elements, corresponding to one slot in the time domain and 180 kHz (i.e., 12 subcarriers × 15 kHz) in the frequency domain.

In the current LTE specifications, which provide that a VRB has the same size as a PRB, two types of VRBs are defined: *localized-type* and *distributed-type*. VRBs are introduced to provide distributed resource-block allocation. One embodiment of the present invention provides, in an LTE system, a third type of VRB (referred to as an *evolving-type* VRB or E-VRB) and an evolving-PRB or E-PRB. E-VRB and VRB differ in size and E-PRB and PRB differ in both size and structure (e.g., subcarrier locations).

In this detailed description, the present invention is illustrated by a DL OFDMA system having M OFDM symbols per radio subframe and U E-VRBs over M OFDM symbols. The FFT size is N and the number of usable subcarriers is N_{used} per OFDM symbol, while other subcarriers are used as null guard tones. There are n_{B} sub-PRBs (SPRBs) per OFDM symbol, with each SPRB spanning over one OFDM symbol only, unlike the PRB in the current LTE specifications, which spans over M OFDM symbols. An SPRB plays a similar role as a PRB, however. Therefore, there are $N_{\text{SPRB}} = N_{\text{used}}/n_{\text{B}}$ consecutive subcarriers per SPRB (i.e., over one OFDM symbols) and $W = n_{\text{B}}/U$ SPRBs per symbol for each E-VRB, which spans over M symbols. This non-cyclic evolving-type OFDMA resource structure is illustrated in Figure 5.

A E-VRB of the present invention is designed to have the following characteristics: (a) a total number of used subcarriers that is divisible by the number of subcarriers in an E-VRB, (b) the evolving resource structure spreads out in *sub-block* units (i.e., groups of consecutive subcarriers) or equivalently SPRBs, rather than single subcarrier; and (c) the E-VRB has reasonably large number of SPRBs. Spreading out the SPRB achieves robustness to inter-carrier interference (ICI), such as that caused by frequency offset. Accordingly, each E-VRB consists of a number SPRBs that are adjacent at the beginning of the subframe, and spreads out gradually towards the end of the subframe. Channel knowledge is assumed available at the beginning of the subframe, so that multiuser diversity can be exploited at the beginning of the subframe.

After the E-VRB is defined, the SPRB indices are associated with the E-VRB in each of the different stages. In one embodiment, five different stages are used. In the first stage, the SPRB indices are assigned according to a localized-type structure. Because of the null guard tones at the localized edges, the SPRBs of the two E-PRBs at these localized edges can each spread out only in one direction (i.e., towards the opposite edge of the applicable bandwidth), while the other SPRBs can spread out in both directions. At the last stage, the SPRBs of different E-PRBs have evolved to become distributed-type E-PRBs. The SPRB indices in each stage are preferably disjoint (i.e., no two SPRBs being assigned to the same E-VRB). Figures 6-11 show the basic templates of E-PRB structure for various channel bandwidths, according to the various embodiments of the present invention.

Case 1 – Structure for 2.5 MHz Channel Bandwidth

Figure 6 shows a non-cyclic E-PRB template for a 2.5 MHz channel bandwidth, according to one embodiment of the present invention. The E-VRB resulting from this case is much larger in size than the original PRB. Under the current LTE system parameters, a 2.5 MHz channel bandwidth provides 151 occupied subcarriers (including DC subcarrier which contains no data) with an FFT size $N = 256$. Under the existing LTE, each PRB has 12 subcarriers (see, Figure 4), and there are 12 PRBs (each spanning over 6 or 7 symbols), so that there a total of $N_{\text{used}} = 144$ used subcarriers. According to this embodiment, $N_{\text{SPRB}} = 6$ subcarriers per SPRB, and $n_{\text{B}} = 6$ SPRBs per E-VRB are selected, thereby resulting in 36 subcarriers per E-VRB (i.e., 6 subcarriers per SPRB × 6 SPRBs per E-VRB), which is much larger in size than the original PRB. Accordingly, 4 E-VRBs can be obtained (i.e., $144/(6\times6) = 4$). With 4-EVRBs, 4 simultaneous users may be supported.

Case 2 – Design Structure for 2.5 MHz Channel Bandwidth

Figure 7 shows a non-cyclic E-PRB template for a 2.5 MHz channel bandwidth, in accordance with one embodiment of the present invention. In this example, $N_{\text{SPRB}} = 4$ subcarriers per SPRB (i.e., support lower data rate than the SPRB of Case 1) and $n_{\text{B}} = 6$ SPRBs per E-VRB are selected, thus providing 24 subcarriers per E-VRB (i.e., 4 subcarriers per SPRB × 6 SPRBs per E-VRB). In this example, 6 E-VRBs results (i.e., $144/(4\times6) = 6$), thus supporting up to 6 simultaneous users.

Case 3 – Structure for 2.5 MHz and 5 MHz Channel Bandwidths

Figure 8 shows an E-PRB template for 2.5 MHz and 5 MHz channel bandwidths, in accordance with one embodiment of the present invention. For a 2.5 MHz channel bandwidth, $N_{\text{SPRB}} = 3$ subcarriers per SPRB (i.e., supporting a lower data rate than both Case 1 and Case 2) and $n_{\text{B}} = 6$ SPRBs per E-VRB may be selected, to result in 24 subcarriers per E-VRB (i.e., 3 subcarriers per SPRB × 6 SPRBs per E-VRB).

Under the current LTE specifications, in a 5 MHz channel bandwidth, which has 301 occupied subcarriers (including DC subcarrier which contains no data) with an FFT size $N = 512$.

Since each resource block consists of 12 subcarriers, there are 24 PRBs (each with 12 subcarriers per symbol over 6 or 7 symbols) with a total of $N_{\text{used}} = 288$ used subcarriers. In this example, $N_{\text{SPRB}} = 6$ subcarriers per SPRB and $n_{\text{B}} = 6$ SPRBs per E-VRB may be selected, so as to provide 36 subcarriers per E-VRB (i.e., 6 subcarriers per SPRB × 6 SPRBs per E-VRB).

Therefore, in either 2.5 MHz bandwidth or 5.0 MHz bandwidth, 8 E-VRBs may be obtained (i.e., $144/(3\times 6)=8$ and $288/(6\times 6)=8$) to support up to 8 simultaneous users.

<u>Case 4 – Structure for 5 MHz and 10 MHz Channel Bandwidths</u>

Figure 9 shows an E-PRB template for 5 MHz and 10 MHz channel bandwidths, in accordance with one embodiment of the present invention. For a 5 MHz channel bandwidth, $N_{\text{SPRB}} = 4$ subcarriers per SPRB (thus support lower data rate than Case 3) and $n_{\text{B}} = 6$ SPRBs per E-VRB may be selected, to result in 24 subcarriers per E-VRB (i.e., 4 subcarriers per SPRB × 6 SPRBs per E-VRB).

Under the current LTE specifications, for a 10 MHz channel bandwidth, there are 601 occupied subcarriers (including DC subcarrier which contains no data) with an FFT size $N =$ 1024. As each resource block consists of 12 subcarriers, there are 48 PRBs (each with 12 subcarriers per symbol over 6 or 7 symbols) with a total of $N_{\text{used}} = 576$ used subcarriers. In this example, $N_{\text{SPRB}} = 8$ subcarriers per SPRB and $n_{\text{B}} = 6$ SPRBs per E-VRB are selected, to result in 48 subcarriers per E-VRB (i.e., 8 subcarriers per SPRB × 6 SPRBs per E-VRB).

Therefore, under either 5 MHz or 10 MHz channel bandwidth, 12 E-VRBs may be obtained (i.e., $288/(4\times 6)=12$ and $576/(8\times 6)=12$), supporting up to 12 simultaneous users.

<u>Case 5 – Structure for 10 MHz Channel Bandwidth</u>

Figure 10 shows an E-PRB template for a 10 MHz channel bandwidth, in accordance with one embodiment of the present invention. In this example, an extension to increase the available resources by using a larger FFT size can be achieved by splitting each SPRB. In this example, each SPRB may be split into two SPRBs. Figure 10 shows, for example, SPRB "1a" and SPRB "1b" being assigned to two different E-VRBs. In this example, $n_{\text{B}} = 6$ SPRBs per E-VRB and $N_{\text{SPRB}} = 12$ subcarriers per SPRB are selected, with each SPRB having two sub-SPRB of $N_{\text{S-SPRB}} = 6$ subcarriers. Accordingly, 36 subcarriers per E-VRB (i.e., 6 subcarriers per sub-SPRB × 6 SPRBs per E-VRB) result. As a result, 16 E-VRBs are obtained (i.e., $576/(6\times 6)=16$), supporting up to 16 simultaneous users.

Case 6 – Structure for 10 MHz and 20 MHz Channel Bandwidths

Figure 11 shows an E-PRB template for 10 MHz and 20 MHz channel bandwidths, in accordance with one embodiment of the present invention. As in Case 5, this example also supports splitting a SPRB into sub-SPRBs. For a 10 MHz channel bandwidth, $N_{\text{S-SPRB}} = 4$ subcarriers per sub-SPRB and and $n_B = 6$ SPRBs per E-VRB are selected, to result in 24 subcarriers per E-VRB (i.e., 4 subcarriers per SPRB × 6 SPRBs per E-VRB).

Under the current LTE specifications, a 20 MHz channel bandwidth provides 1201 occupied subcarriers (including DC subcarrier which contains no data) with an FFT size N = 2048. Since each resource block consists of 12 subcarriers, there are 96 PRBs (each with 12 subcarriers per symbol over 6 or 7 symbols) with a total of $N_{\text{used}} = 1152$ used subcarriers. In this example, $N_{\text{S-SPRB}} = 8$ subcarriers per sub-SPRB and $n_B = 6$ SPRBs per E-VRB are selected, resulting in 48 subcarriers per E-VRB (i.e., 8 subcarriers per sub-SPRB × 6 SPRBs per E-VRB).

Therefore, for either the 10 MHz or the 20 MHz channel bandwidth, 24 E-VRBs are obtained (i.e., $576/(4\times 6) = 24$ and $1152/(8\times 6) = 24$), thereby supporting up to 24 simultaneous users.

After obtaining the SPRB indices of the E-PRB template of a given transmission bandwidth, the SPRB indices are mapped over M OFDM symbols. Table 2 may be used to provide the duration of each stage for each of the examples of Figures 6-11. The design criterion is based on the channel temporal correlation as a function of the target mobile speed. When the exact target mobile speed is not available, an estimate of average mobile speed may be obtained from the Doppler spectrum of the estimated channel.

Let μ represents the delay in OFDM symbols of CSI knowledge at the transmitter, T_x be the time interval for which the channel temporal normalized correlation ρ changes from 1 to x/100, and T_{sym} be the OFDM symbol duration including a cyclic prefix or a null guard interval. Let the duration of the first stage to be T_A and the combined duration of all stages before the last one to be T_B, where A and B are design parameters. As switching from one stage to another can only occur at the symbol boundary, the durations of the stages are rounded to integer symbol units (i.e., α_i OFDM symbols in the i^{th} stage). Let $N_1 = \text{round}\left(T_A/T_{\text{sym}}\right)$ and $N_2 = \text{round}\left(T_B/T_{\text{sym}}\right)$ (e.g., $T_A = T_{90}$ and $T_B = T_{50}$), then Table 2 provides the duration of the i-th stage of the E-PRB structure, in OFDM symbols. Note that N_1 and N_2 and hence α_i depend on the mobile speed -- either a target mobile speed or an average mobile speed -- and the system parameters (e.g., carrier frequency, symbol duration).

Table 2: Parameters for mapping SPRB indices over M OFDM symbols based on the target mobile speed.

Stage	Number of OFDM symbols
1	$\alpha_1 = \min(M, N_1 - \mu)$
2	$\alpha_2 = \begin{cases} 0, & \alpha_1 = M \\ \min(round((N_2 - N_1)/3), M - \alpha_1), & \alpha_1 < M \end{cases}$
3	$\alpha_3 = \begin{cases} 0, & \alpha_2 = 0 \\ \min(round((N_2 - N_1)/3), M - \alpha_1 - \alpha_2), & \alpha_2 > 0 \end{cases}$
4	$\alpha_4 = \begin{cases} 0, & \alpha_3 = 0 \\ \min(round((N_2 - N_1)/3), M - \alpha_1 - \alpha_2 - \alpha_3), & \alpha_3 > 0 \end{cases}$
5	$\alpha_5 = \begin{cases} 0, & \alpha_4 = 0 \\ M - \alpha_1 - \alpha_2 - \alpha_3 - \alpha_4, & \alpha_4 > 0 \end{cases}$

Using Table 2, all the examples of Figure 6-11 may be achieved in 5 stages or less. Typically, a slow mobile speed results in an evolving E-PRB structure that has less than 5 stages.

In this invention, Jakes' Doppler spectrum may be used to derived the parameters of Table 2. However, other Doppler spectra may also be used. Using Jakes's Doppler spectrum, the normalized temporal correlation function is given by $J_0(2\pi f_m \tau)$, where $J_0(\cdot)$ is the zero-th order Bessel function, f_m is the maximum Doppler frequency, and τ is the correlation lag (time interval). Selecting T_{90} for N_1 and T_{50} for N_2, Table 3 shows the values of N_1 and N_2 for several mobile speeds can be obtained:

Table 3: Values of N_1 and N_2 based on T_{90} and T_{50} for different target mobile speeds.

Mobile speed	N_1	N_2

(km/h)	(based on T_{90})	(based on T_{50})
3	268	636
20	40	95
50	16	38
80	10	24
120	7	16
200	4	10
350	2	5

Table 4 shows the number of OFDM symbols in each of the evolving stages for a sub-frame length of M=14 symbols and CSI delays of μ=1 and μ=2 symbols.

Table 4: The number of OFDM symbols used in each of the evolving stages under different target mobile speeds for M = 14, μ = 1 and μ = 2.

M = 14										
	μ=1					μ=2				
Mobile speed (km/h)	α_1	α_2	α_3	α_4	α_5	α_1	α_2	α_3	α_4	α_5
3	14	0	0	0	0	14	0	0	0	0
20	14	0	0	0	0	14	0	0	0	0
50	14	0	0	0	0	14	0	0	0	0
80	9	5	0	0	0	8	5	1	0	0
120	6	3	3	2	0	5	3	3	3	0

200	3	2	2	2	5	2	2	2	2	6
350	1	1	1	1	10	0	1	1	1	11

Figure 12 is flowchart that summarizes the steps for designing a non-cyclic E-PRB structure, in accordance with one embodiment of the present invention. As shown in Figure 12, at step 1201, the following system parameters are determined: (a) transmission bandwidth, (b) an FFT size (N), (c) the number of subcarriers per SPRB (N_{SPRB}), (d) the number of SPRB per E-VRB (n_B), (e) the number of OFDM symbols (M) in a DL or UL subframe, and (f) the target or average mobile speed (v). At step 1202, using the parameters determined at step 1201, the total usable subcarriers (N_{used}) is tested for divisibility of the number of subcarriers in each E-VPRB (i.e., the product of N_{SPRB} and n_B). Steps 1201 and 1202 are repeated until N_{used} is divisible by the number of subcarriers in each E-VPRB. At step 1203, the number of E-VRB is calculated. The non-cyclic E-PRB structure is then determined using the SPRB indices in step 1204. In step 1205, the SPRB indices for each of the M OFDM symbols in each subframe are mapped based on the target or average mobile speed and the system parameters using, for example, Tables 2 and 3.

The E-PRB structure of the present invention provides better diversities and hence better performance over non-evolving resource structures (e.g., localized-type and distributed-type of the current LTE specifications). In addition, the present invention offers efficient exploitation of various diversities in different mobile speeds and hence different service areas. The E-PRB structure of the present invention is applicable to OFDMA systems with null guard tones, which are used in most OFDMA systems.

According to another embodiment of the present invention, an E-PRB structure simpler than the structures in the examples above is provided. Such a simpler E-PRB may be applicable for both OFDMA-based systems without null guard tones, or with a small number of null guard tones (e.g., Mobile WiMAX), and OFDMA-based systems with large null guard tones (e.g., 3GPP LTE). In the example below, the simpler E-PRB structure is illustrated by an E-PRB structure having 3 stages or less. In the first stage, the E-PRB has a band-type structure. As the transmitter acquires knowledge about channel, the band-type structure can achieve more multiuser diversity, as the resource allocation spreads out from band-type structure of the first stage. In the third (i.e., last) stage, an interleaved-type structure is achieved. Since the channel correlation is decreasing in a frame, the channel can be modeled as unknown after some symbol periods, so that an interleaved-type is suitable because of its robustness against frequency-selective deep fading. As the interleaved-type structure cannot exploit multiuser diversity, the second stage is designed to be a partially-evolved stage from the band-type to interleaved-type structure, so as to exploit partial multiuser diversity and partial frequency diversity.

According to one embodiment of the present invention, in a null-guard tones case, the allocation evolves over a single-sided spreading scheme for selected subchannels that are located on the boundary (see, for example, the E-PRB structures of Figures 4 and 5, to be discussed below). For the case without null guard tones, the allocation may be evolved in a wrapped around double-sided spread (i.e., cyclic manner) for all subchannels. In some case, the frame length is not long enough or the channel correlation decreases too slowly, so that the E-PRB structure does not evolve into the last stage (i.e., the evolution stops in the second stage).

Figure 13 is a flowchart that summarizes the design steps for a 3-stage simplified E-PRB structure that can be used in a system with a large number of null guard tones, in accordance with one embodiment of the present invention. As shown in Figure 13, at step 1301, the number of SPRB per E-VRB (n_B) in an OFDM symbol, the total number of SPRBs, and the number of subcarriers per SPRB (N_{SPRB}) are determined. At step 1302, a band-type VRB structure is selected. At step 1303, each E-PRB (i.e., from $k=1$ to $k=U$, where k is the index for each E-PRB) is tested if it is a middle E-PRB (i.e., $2 \le k \le U-1$). For a middle E-PRB, a double-sided spreading scheme is used (step 1304). Otherwise, i.e., $k=1$ or $k=U$, a single-sided spreading in one direction (step 1305). At step 1306, if the different E-PRBs in the E-PRB structure resulting from steps 1303-1305 has disjoint SPRBs, the E-PRB structure is adopted for the second stage. Otherwise, steps 1301-1306 are repeated. At step 1307, an interleaved-type VRB structure is adopted for the final stage.

Table 5 shows, for $W = 6$ SPRBs per E-PRB, the SPRB indices of the 3-stage E-PRB template for the k-th E-PRB, $2 \le k \le U-1$, in a system with null guard tones.

Table 5: SPRB indices of the k-th E-PRB, $2 \le k \le U-1$, for a system with null guard tones.

	SPRB indices for E-PRB # k					
Stage 1	$6(k-2)+7$	$6(k-2)+8$	$6(k-2)+9$	$6(k-2)+10$	$6(k-2)+11$	$6(k-2)+12$
Stage	$6(k-2)+4$	$6(k-2)+6$	$6(k-2)+8$	$6(k-2)+11$	$6(k-2)+13$	$6(k-2)+15$

2						
Stage 3	k	$k+U$	$k+2U$	$k+3U$	$k+4U$	$k+5U$

Figure 14 shows in the shaded areas of all three stages, the k-th E-PRB, $2 \leq k \leq U-1$, according to one embodiment of the present invention.

For the first E-PRB (i.e., $k = 1$) and the last E-PRB (i.e., $k = U$), the first and the third stages are defined in the same manner as the other E-PRBs (i.e., band-type and interleaved-type, respectively), but in order to maintain the same null guard tones throughout the packet, the second stage is changed through a single-sided expansion (not wrapped around at the band edge. Figures 15 and 16 show, in the shaded areas of all three stages, the first and the last E-PRBs, i.e., $k=1$ and $k=U$, respectively, according to one embodiment of the present invention.

Table 6 summarizes the SPRB indices of the band edge E-PRB in Stage 2 for the case of $W = 6$ SPRBs per E-PRB:

Table 6: SPRB indices of the band edge E-PRBs in Stage 2 for system with null guard tones.

	SPRB indices for the Stage 2					
E-PRB # 1	1	2	3	5	7	9
E-PRB # U	n_B-8	n_B-6	n_B-4	n_B-2	n_B-1	n_B

According to one embodiment of the present invention, switching from one stage to another occurs when the channel correlation falls below predefined threshold values (i.e., A and B). In this example, as in the previous examples, T_x is the time interval for which the channel temporal normalized correlation ρ changes from 1 to $x/100$. Based on this, the switching time according to T_A and T_B can be obtained. Figure 7 shows the resulting number of OFDM symbols in each stage:

Table 7: The number of OFDM symbols used in each stage.

Stage	Number of OFDM symbols
1	$\alpha_1 = \min(M, N_1 - \mu)$
2	$\alpha_2 = \begin{cases} 0, & \alpha_1 = M \\ \min(N_2 - N_1, M - \alpha_1), & \alpha_1 < M \end{cases}$
3	$\alpha_3 = \begin{cases} 0, & \alpha_1 + \alpha_2 = M \\ M - \alpha_1 - \alpha_2, & \alpha_1 + \alpha_2 < M \end{cases}$

where α_1, α_2, α_3 denote the number of OFDM symbols in the first, the second and the last stages, respectively, $N_1 = \text{round}\left(T_A/T_{\text{sym}}\right)$ and $N_2 = \text{round}\left(T_B/T_{\text{sym}}\right)$ with T_{sym} is the OFDM symbol duration including cyclic prefix guard intervals.

Table 8 shows, for $A = 90$ and $B = 70$ (i.e., $T_A = T_{90}$ and $T_B = T_{70}$), the values of N_1 and N_2 as a function of target or average mobile speed (v):

Table 8: Values of N_1 and N_2 based on T_{90} and T_{70} for different target or average mobile speeds.

Mobile speed, v (km/h)	N_1 (based on T_{90})	N_2 (based on T_{70})
3	268	477
20	40	72
50	16	29
80	10	18
120	7	12
200	4	7
350	2	4

Table 9 summarizes the numbers of SPRBs and E-PRBs for different transmission bandwidths of the 3GPP LTE OFDMA systems (see Table 1), according to one embodiment of the present invention.

Table 9: The simplified structure SPRB indices for different transmission bandwidths of the 3GPP LTE OFDMA systems.

Transmission Bandwidth (MHz)	Number of FFT size, N	Number of used subcarriers per OFDM symbol, N_{used}	Parameter Values of Simplified Evolving Structure
1.25	128	72	N_{SPRB}=4 subcarriers per SPRB → n_B=18 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=3 E-PRBs
			N_{SPRB}=6 subcarriers per SPRB → n_B=12 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=2 E-PRBs
2.5	256	144	N_{SPRB}=4 subcarriers per SPRB → n_B=36 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=6 E-PRBs
			N_{SPRB}=6 subcarriers per SPRB → n_B=24 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB →

			U=4 E-PRBs
5.0	512	288	N_{SPRB}=4 subcarriers per SPRB → n_B=72 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=12 E-PRBs
			N_{SPRB}=6 subcarriers per SPRB → n_B=48 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=8 E-PRBs
10	1024	600	N_{SPRB}=4 subcarriers per SPRB → n_B=150 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=25 E-PRBs
		612	N_{SPRB}=6 subcarriers per SPRB → n_B=102 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=17 E-PRBs
		576	N_{SPRB}=6 subcarriers per SPRB → n_B=96 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=16 E-PRBs
15	1536	888	N_{SPRB}=4 subcarriers per SPRB → n_B=222 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=37 E-PRBs
		900	N_{SPRB}=6 subcarriers per SPRB → n_B=150

			SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=25 E-PRBs
		864	N_{SPRB}=6 subcarriers per SPRB → n_B=144 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=24 E-PRBs
20	2058	1200	N_{SPRB}=4 subcarriers per SPRB → n_B=300 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=50 E-PRBs
		1224	N_{SPRB}=6 subcarriers per SPRB → n_B=204 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=34 E-PRBs
		1188	N_{SPRB}=6 subcarriers per SPRB → n_B=198 SPRBs per OFDM symbol; W=6 SPRBs per symbol for each E-PRB → U=33 E-PRBs

From Table 9, for instance, each DL or UL transmission may have 1, 2 or 4 sub-frames depending on the sub-frame assignment. With the system parameters of Table 9, the E-PRB structure may have M = 14, 28, or 56 OFDM symbols. Tables 10-12 provide the number of OFDM symbols in each of the 3 evolving stages, for various sub-frames lengths and for CSI delays $\mu = 1$ and $\mu = 2$.

Table 10: The number of OFDM symbols used in each of the 3 evolving stages under different target mobile speeds for M = 14, μ = 1 and μ = 2.

M = 14						
	μ=1			M=2		
Mobile speed, v (km/h)	α_1	α_2	α_3	α_1	α_2	α_3
3	14	0	0	14	0	0
20	14	0	0	14	0	0
50	14	0	0	14	0	0
80	9	5	0	8	6	0
120	6	5	3	5	5	4
200	3	3	8	2	3	9
350	1	2	11	0	2	12

Table 11: The number of OFDM symbols used in each of the three evolving stages under different target mobile speeds for M = 28, μ = 1 and μ = 2.

M = 28						
	μ=1			μ=2		
Mobile speed, v (km/h)	α_1	α_2	α_3	α_1	A_2	α_3
3	28	0	0	28	0	0
20	28	0	0	28	0	0
50	15	13	0	14	13	1
80	9	8	11	8	8	12

120	6	5	17	5	5	18
200	3	3	22	2	3	23
350	1	2	25	0	2	26

Table 12: The number of OFDM symbols used in each of the three evolving stages under different target mobile speeds for $M = 56$, $\mu = 1$ and $\mu = 2$.

$M = 56$						
	μ=1			M=2		
Mobile speed, v (km/h)	α_1	α_2	α_3	α_1	α_2	α_3
3	56	0	0	56	0	0
20	39	17	0	38	18	0
50	15	13	28	14	13	29
80	9	8	39	8	8	40
120	6	5	45	5	5	46
200	3	3	50	2	3	51
350	1	2	53	0	2	54

Figure 17 illustrates an example in which E-VRBs are provided in a system with parameters $N = 128$, $N_{used} = 72$, $M = 28$, $W = 6$, $N_{SPRB} = 4$, $U = 3$, $\mu = 2$ and $v = 80$ km/h (i.e., $\alpha_1 = 8$, $\alpha_2 = 8$, $\alpha 3 = 12$), in accordance with one embodiment of the present invention.

Figure 18 illustrates an example in which E-VRBs are provided in a system with parameters $N = 256$, $N_{used} = 144$, $M = 28$, $W = 6$, $N_{SPRB} = 4$, $U = 6$, $\mu = 2$ and $v = 80$ km/h (i.e., $\alpha_1 = 8$, $\alpha_2 = 8$, $\alpha 3 = 12$), according to one embodiment of the present invention.

The simplified E-PRB structure for an OFDMA system, according to the present invention, provides enhanced diversities and hence improved performance over existing non-evolving resource structures. As a result, efficient diversity exploitation for various mobile speeds and hence different service areas are achieved. This simplified design offers a much easier implementation and better flexibility to system parameters, as compared to the E-PRB structure designs of Figures 6-11 above for an OFDMA system, with and without null guard tones.

The above detailed description is provided to illustrate the specific embodiments of the present invention and is not intended to be limiting. Numerous modifications and variations within the scope of the present invention are possible. The present invention is set forth in the accompanying claims.

CLAIMS

We claim:

1. A method for allocating resources in an OFDMA system having a selected bandwidth and an FFT size, comprising:

determining a number of usable subcarriers, excluding null guard tones, within the bandwidth of the OFDMA system for each symbol interval;

determining a size for a resource allocation block (SPRB), each SPRB representing a predetermined number of consecutive subcarriers within the bandwidth in each symbol interval;

based on the usable subcarriers, determining a number of SPRBs to be associated with an evolving virtual resource block (E-VRB);

based on the number of SPRBs to be associated with each E-VRB, determining a number of E-VRBs to be used in the OFDMA system for a predetermined number of symbol intervals;

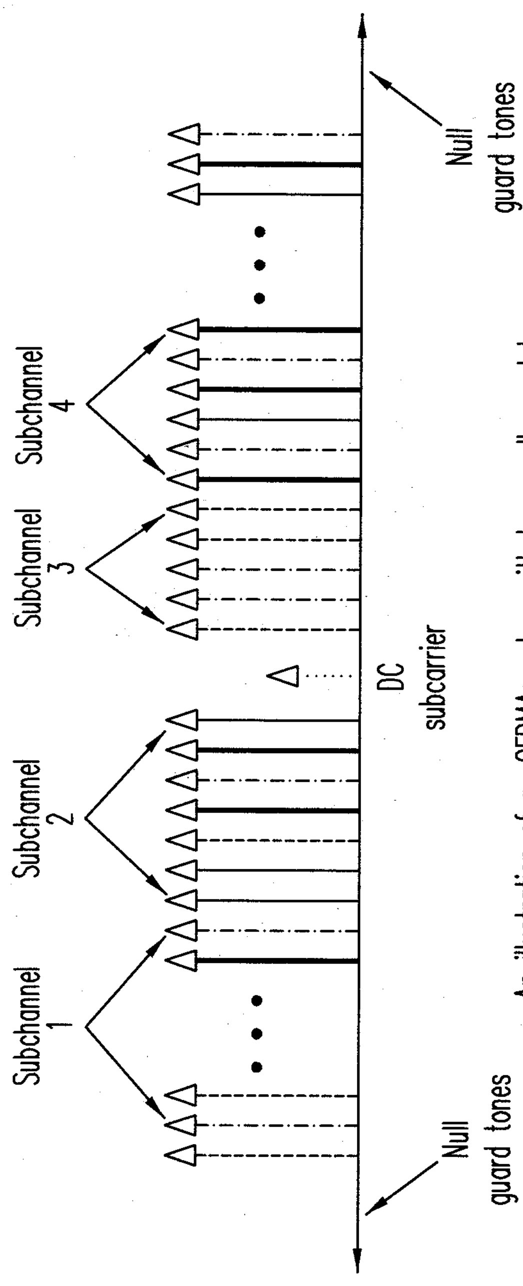
dividing the predetermined number of symbol intervals into a plurality of stages ordered successively in time; and

for each stage, allocating the SPRBs corresponding to the symbol intervals of the stage to the E-VRBs according to increasing frequency diversity.

2. An evolving virtual resource block (E-VRB) for an OFDMA system having a selected bandwidth and an FFT size, the selected bandwidth having, for each symbol interval, a number of usable subcarriers, excluding null guard tones within the bandwidth, comprising:

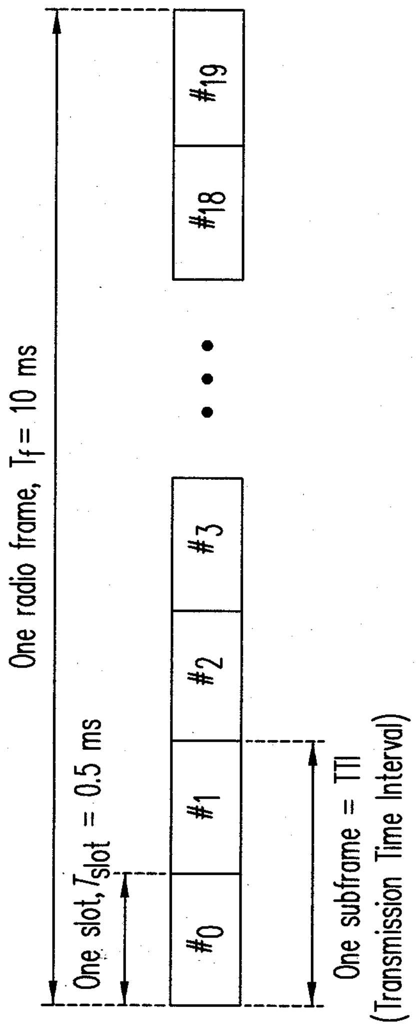
a plurality of resource allocation block (SPRB), each SPRB representing a predetermined number of consecutive subcarriers within the bandwidth in each symbol interval, the number of SPRB associated with the E-VRB being a function of the number of usable subcarriers, and a number of E-VRBs to be used in the OFDMA system for a predetermined number of symbol intervals, and

wherein the predetermined number of symbol intervals is divided into a plurality of stages ordered successively in time and, for each stage, the SPRBs corresponding to the symbol intervals of the stage are allocated to the E-VRB according to increasing frequency diversity.



An illustration of an OFDMA system with large null guard tones.

FIG. 1



LTE frame structure Type 1 for FDD systems (Prior art).

FIG. 2

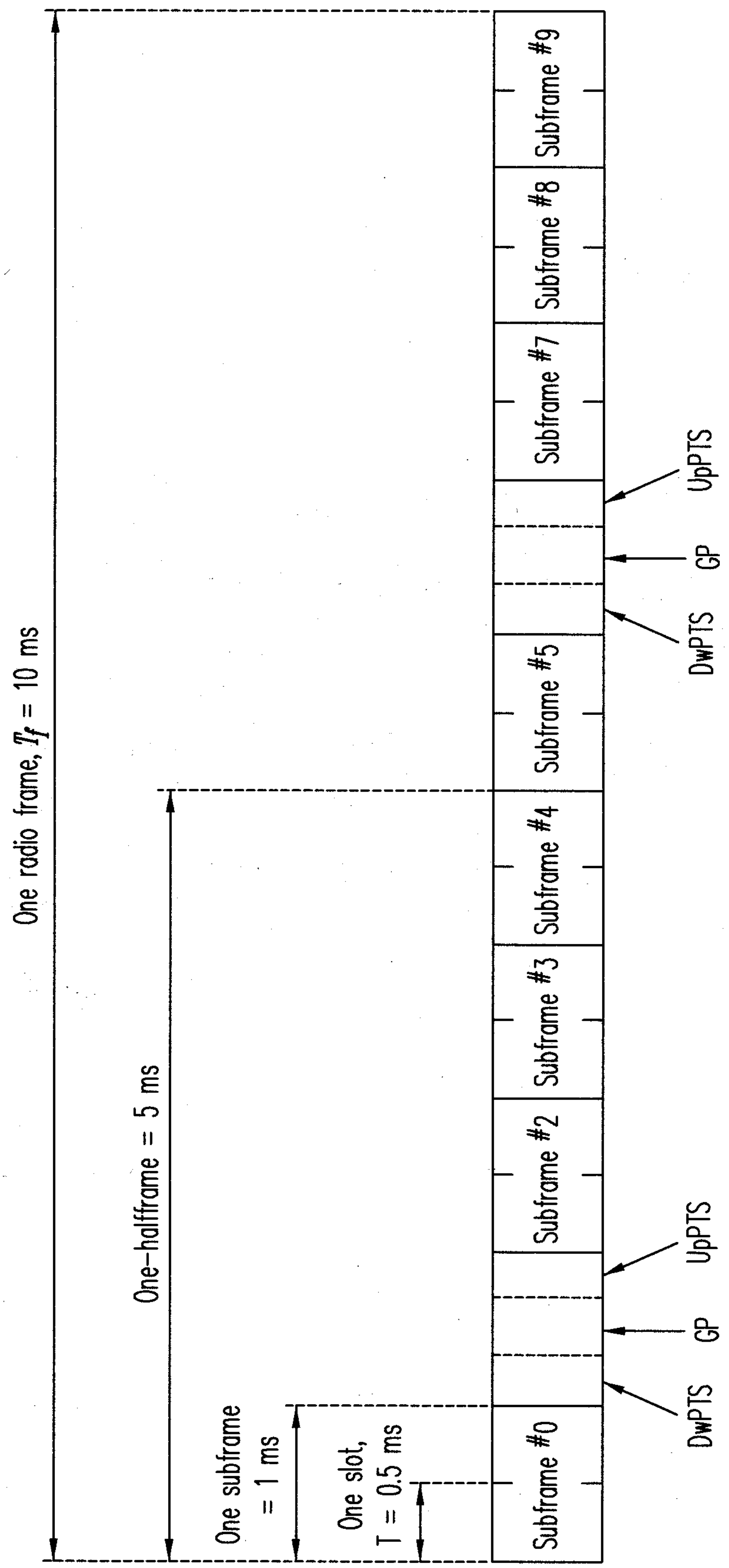


FIG. 3

LTE frame structure Type 1 for TDD systems (prior art).

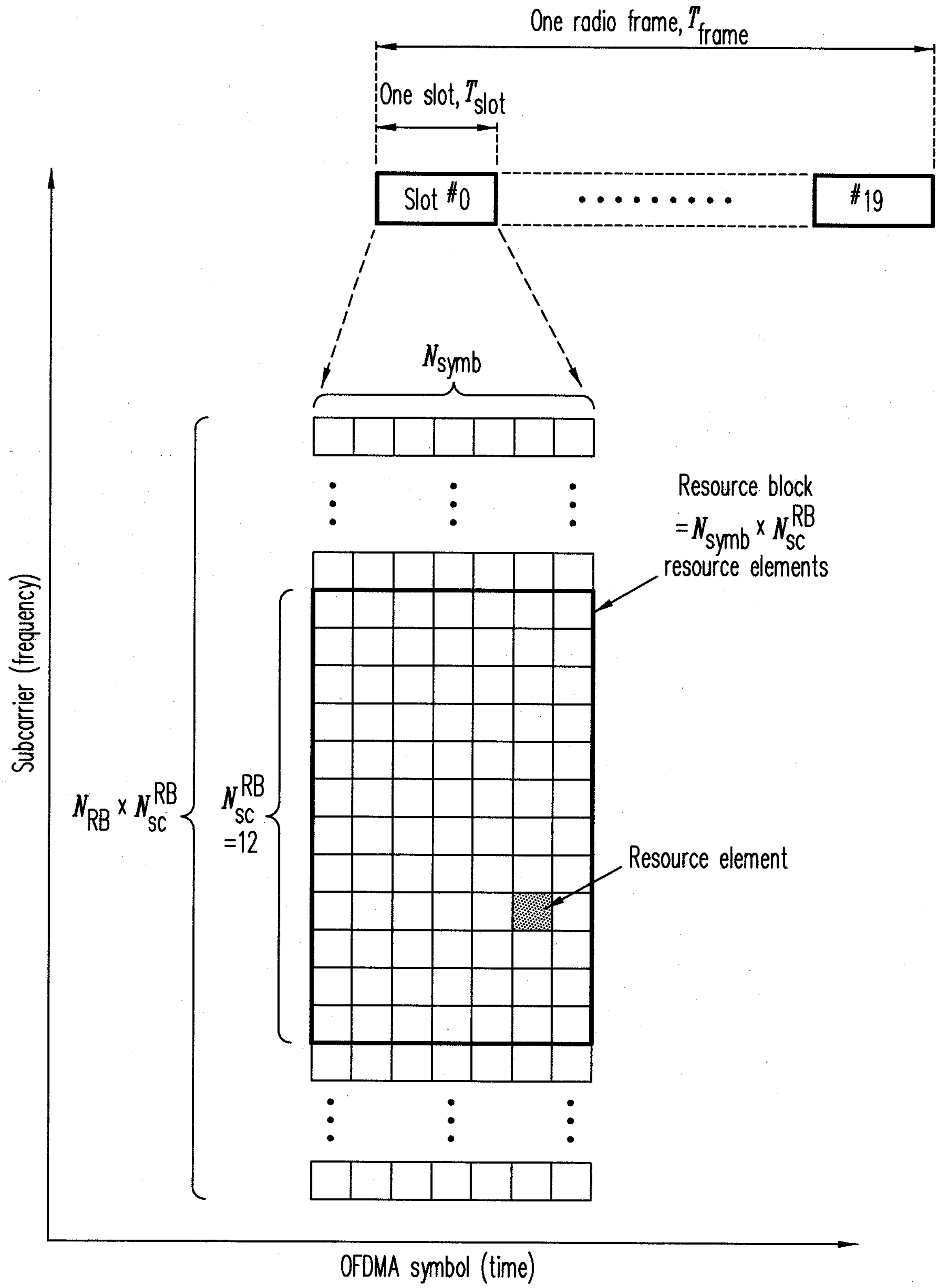


FIG. 4

LTE downlink resource grid (prior art).

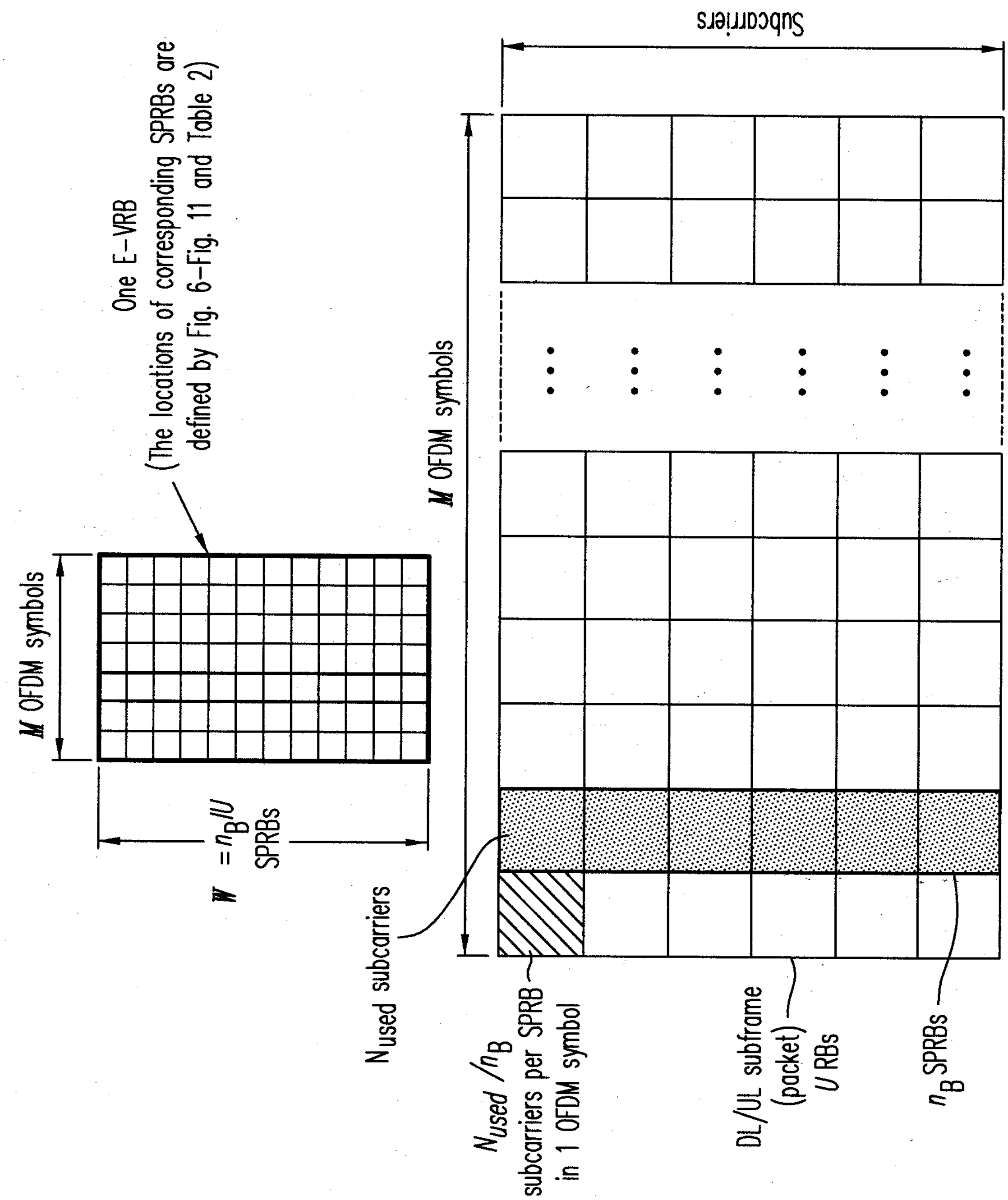


FIG. 5 Parameter definitions for the proposed non-cyclic evolving-type OFDMA resource structure.

	SPRB Index (Frequency)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Stage 1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4
Stage 2	1	1	1	2	1	2	1	2	1	2	3	2	3	2	3	4	3	4	3	4	3	4	4	4
Stage 3	1	2	1	2	1	2	1	3	2	1	3	1	4	2	4	3	2	4	3	4	3	4	3	4
Stage 4	1	2	3	1	2	3	1	2	4	1	3	4	1	2	4	1	3	4	2	3	4	2	3	4
Stage 5	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

FIG. 6

Proposed non-cyclic evolving-type resource structure for the case of 2.5 MHz channel bandwidth with up to 4 simultaneous users.

	SPRB Index (Frequency)																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Stage 1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4	5	5	5	5
Stage 2	1	1	1	2	1	2	1	2	1	2	3	2	3	2	3	4	3	4	3	4	3	4	5	4	5	4	5	6
Stage 3	1	2	1	2	1	2	1	3	2	3	1	4	2	1	3	4	2	3	4	5	3	4	6	5	3	6	4	5
Stage 4	1	2	3	1	2	4	3	1	2	4	5	1	3	2	6	4	5	1	6	2	3	1	5	4	6	2	3	5
Stage 5	1	2	3	4	5	2	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4

FIG. 7

Proposed non-cyclic evolving-type resource structure for the case of 2.5 MHz channel bandwidth with up to 6 simultaneous users.

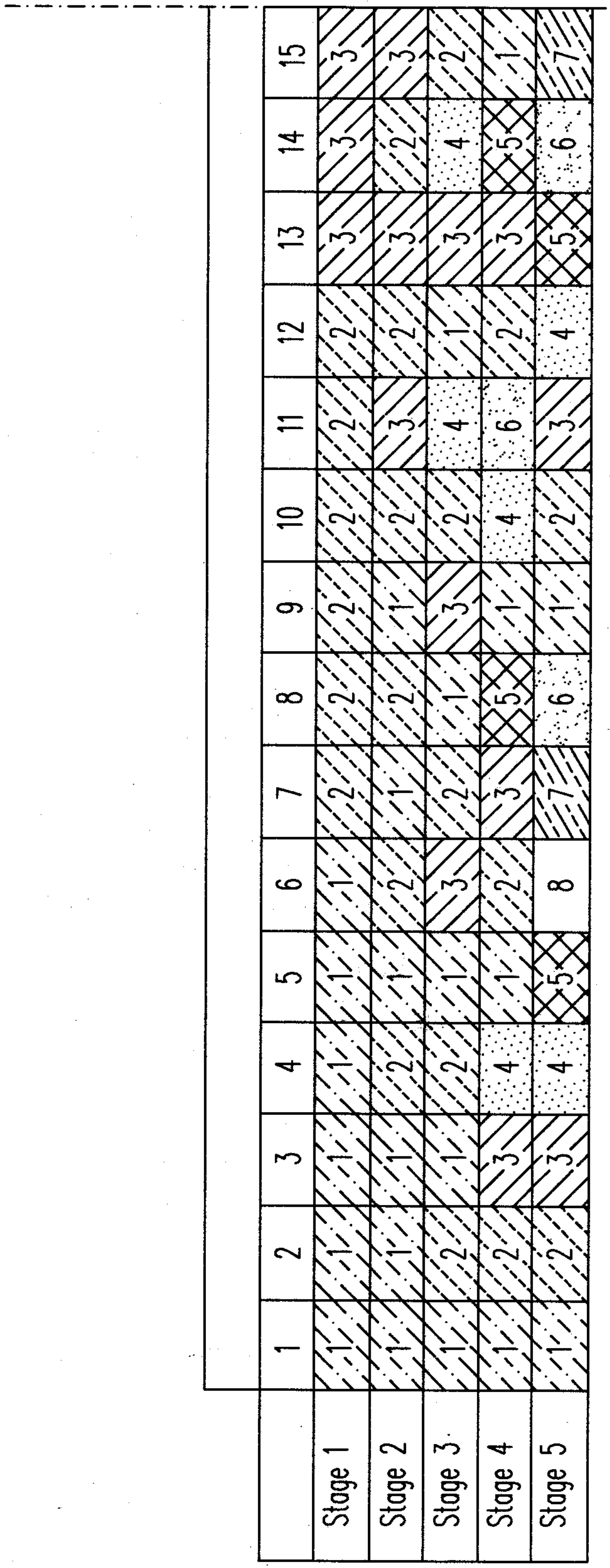
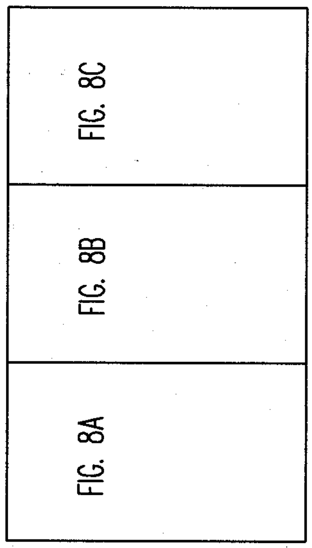


FIG. 8A



Key To
FIG. 8

SPRB Index (Frequency)

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
3	3	3	4	4	4	4	4	4	5	5	5	5	5	5	6	6
4	3	4	3	4	3	4	5	4	5	4	5	6	5	6	5	6
1	5	4	2	3	5	6	4	3	6	5	3	4	6	7	5	4
4	7	6	2	8	3	1	5	7	2	4	8	6	1	7	3	2
8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8

FIG. 8B

Proposed non-cyclic evolving-type resource structure for the case of 2.5 MHz and 5 MHz channel bandwith with up to 8 simultaneous users.

33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
6	6	6	6	7	7	7	7	7	7	8	8	8	8	8	8
5	6	7	6	7	6	7	8	7	8	7	8	7	8	8	8
8	7	5	6	8	5	7	6	8	7	6	8	7	8	7	8
5	8	4	6	7	3	5	8	4	6	7	8	5	6	7	8
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8

FIG. 8C

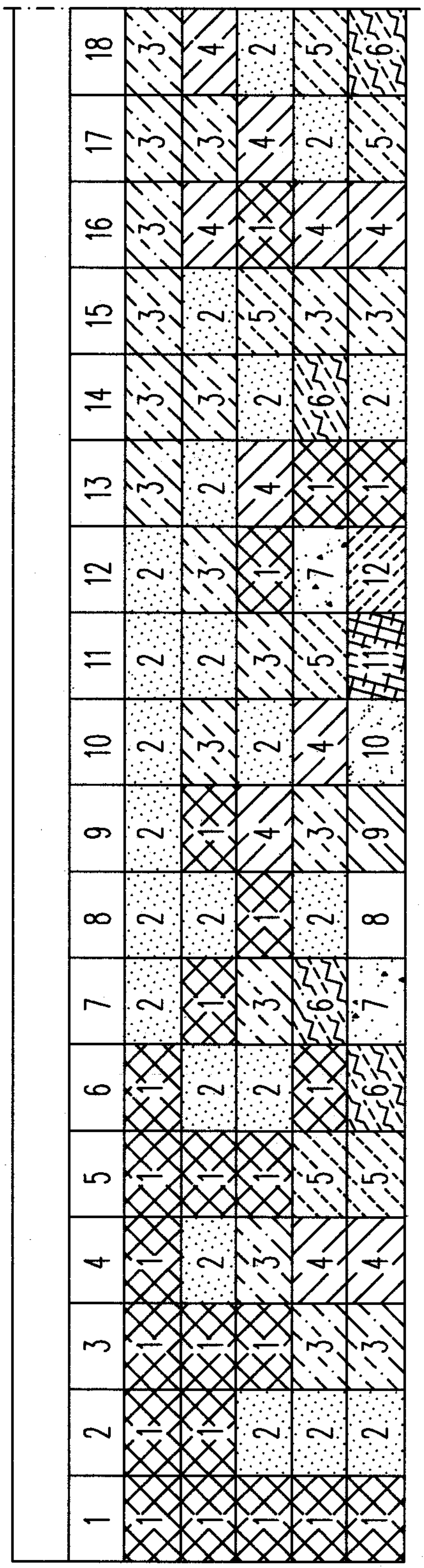
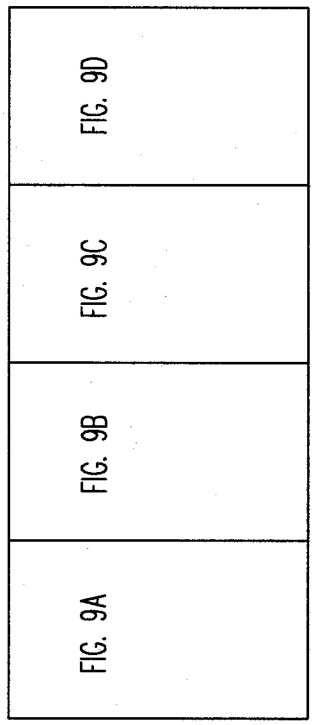


FIG. 9A



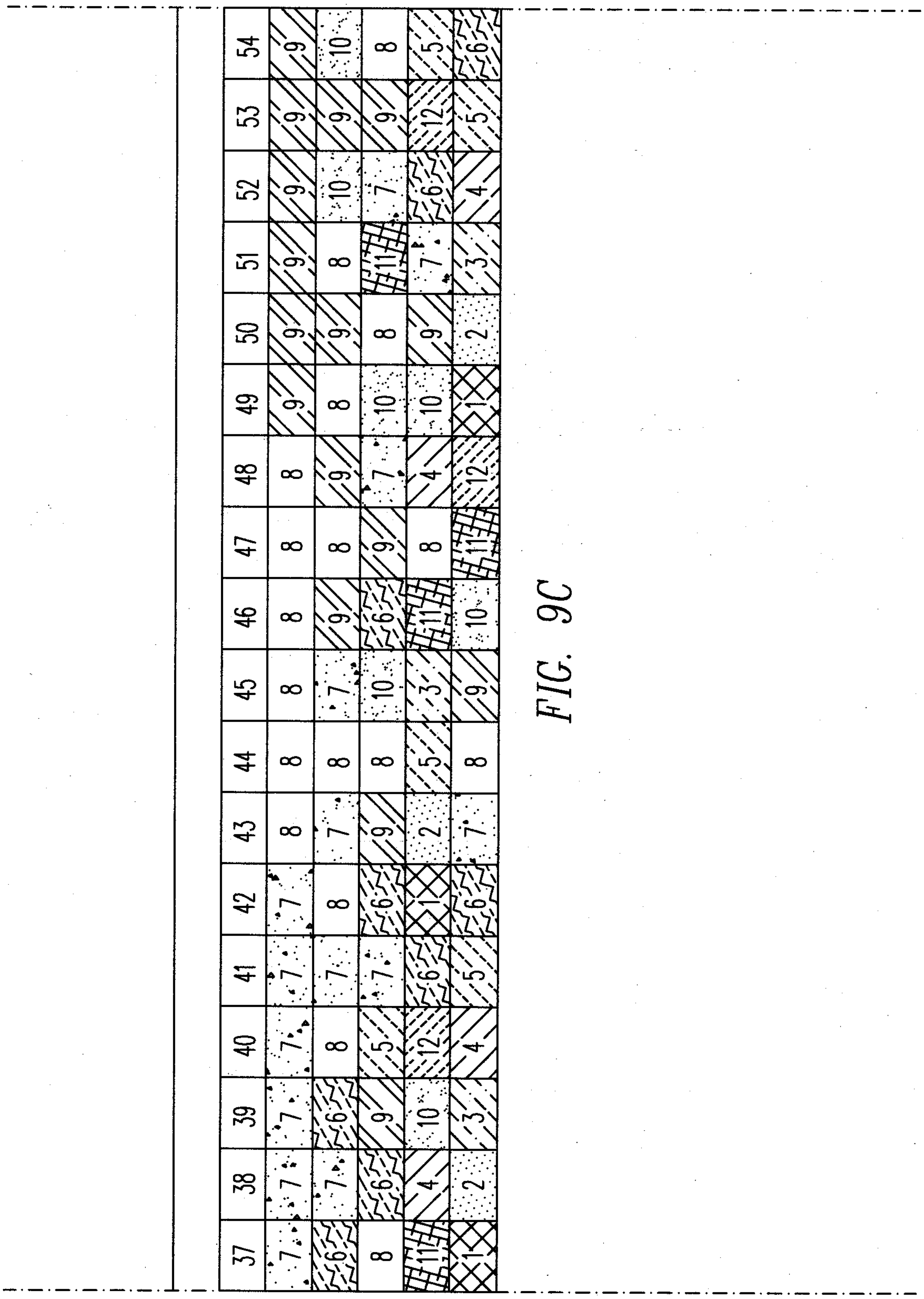
Key To
FIG. 9

SPRB Index (Frequency)

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6
3	4	3	5	4	5	4	5	4	6	5	6	5	6	5	7	6	7
5	3	6	2	5	3	6	4	7	3	5	4	7	6	8	4	7	5
8	7	1	6	4	3	9	5	2	10	1	11	12	8	7	3	9	2
7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12

FIG. 9B

Proposed non-cyclic evolving-type resource structure for the case of 5 MHz and 10 MHz channel bandwith with up to 12 simultaneous users.



37 7 6 8 11 1
38 7 7 6 4 2
39 7 6 9 10 3
40 7 8 5 12 4
41 7 7 7 6 5
42 7 8 6 1 6
43 8 7 9 2 7
44 8 8 8 5 8
45 8 7 10 3 9
46 8 9 6 11 10
47 8 8 9 8 11
48 8 9 7 4 12
49 9 8 10 10 1
50 9 9 8 9 2
51 9 8 11 7 3
52 9 10 7 6 4
53 9 9 9 12 5
54 9 10 8 5 6

FIG. 9C

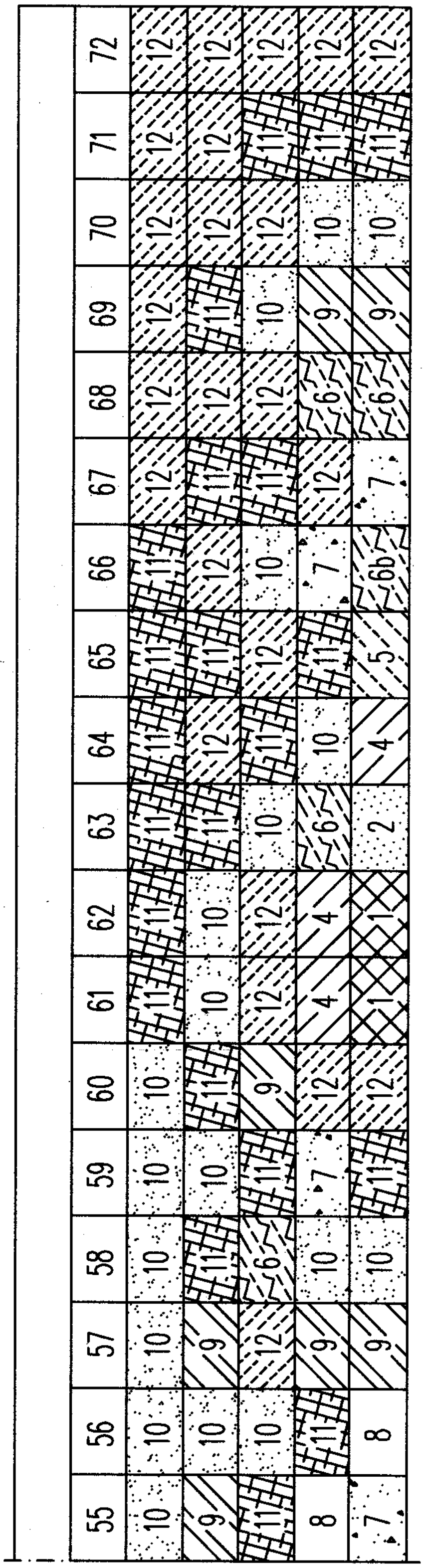

55 10 9 11 8 7
56 10 10 10 11 8
57 10 9 12 9 9
58 10 11 6 10 10
59 10 10 11 7 11
60 10 11 9 12 12
61 11 10 12 4 1
62 11 10 12 4 1
63 11 11 10 6 2
64 11 12 11 10 4
65 11 11 12 11 5
66 11 12 10 7 6b
67 12 11 11 12 7
68 12 12 12 6 6
69 12 11 10 9 9
70 12 12 12 10 10
71 12 12 11 11 11
72 12 12 12 12 12

FIG. 9D

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stage 1	1a	1a	1a	1b	1b	1b	2a	2a	2a	2b	2b	2b	3a	3a	3a
Stage 2	1a	1	1	2a	1	2	1	2	1b	2	3a	2	3	2b	3
Stage 3	1a	2a	1	2	1	3a	2	1	3	2	4a	1	3	4	2
Stage 4	1	2	3	4	1	2	3	5	1	4	6	2	3	5	1
Stage 5	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7

FIG. 10A

FIG. 10A	FIG. 10B	FIG. 10C

Key To
FIG. 10

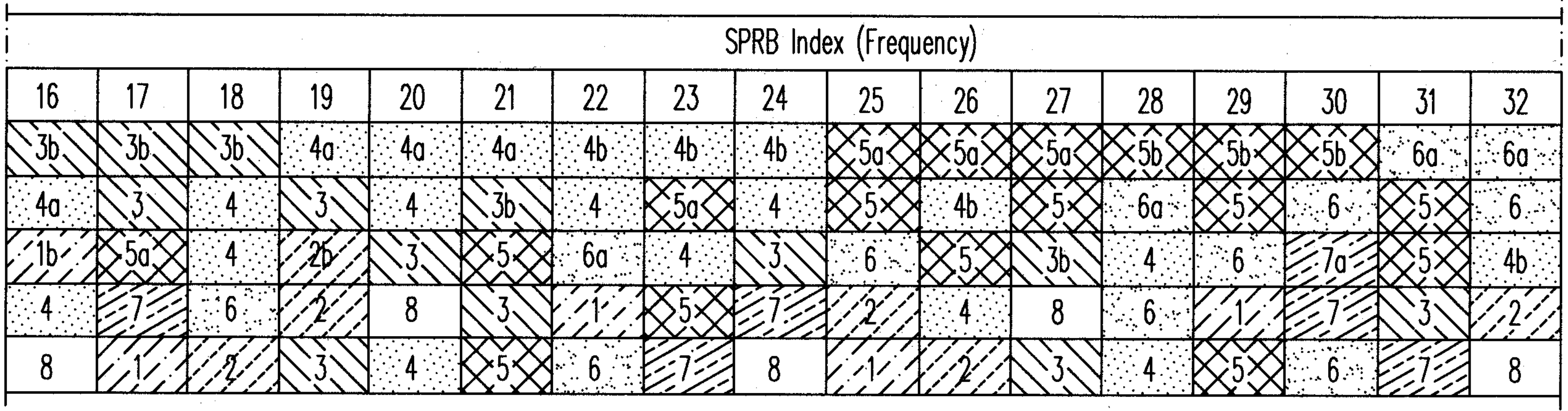


FIG. 10B

Proposed non-cyclic evolving-type resource structure for the case of 10 MHz channel bandwith with up to 16 simultaneous users.

33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
6a	6b	6b	6b	7a	7a	7a	7b	7b	7b	8a	8a	8a	8b	8b	8b
5b	6	7a	6	7	6	7	8a	7	8	7	8	7b	8	8	8b
8a	7	5	6	8	5a	7	6	8	7	6b	8	7	8	7b	8b
5	8	4	6	7	3	5	8	4	6	7	8	5	6	7	8
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8

FIG. 10C

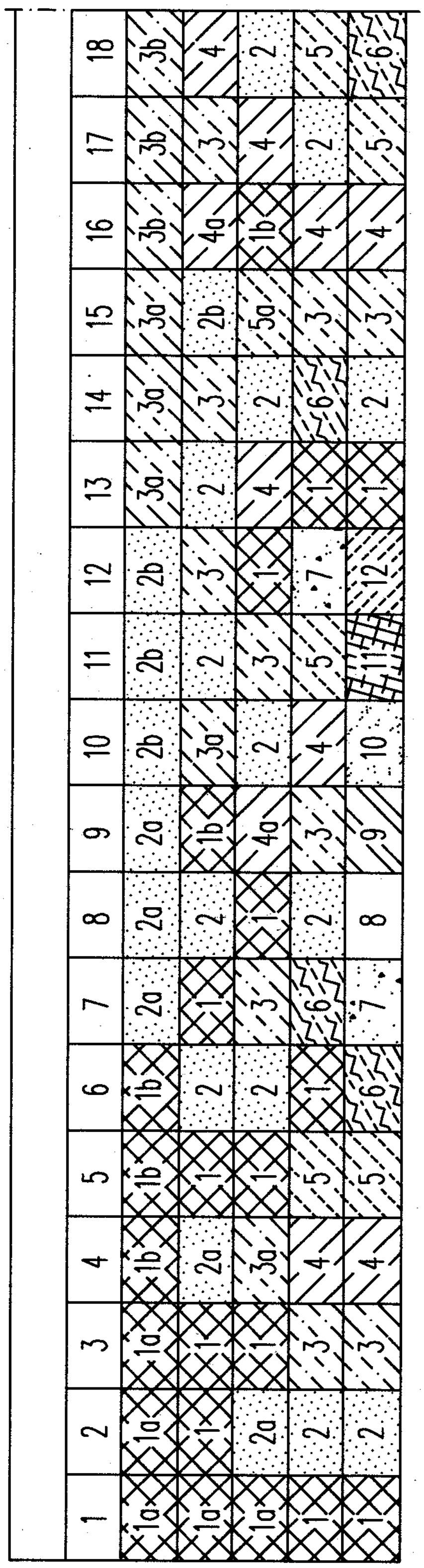
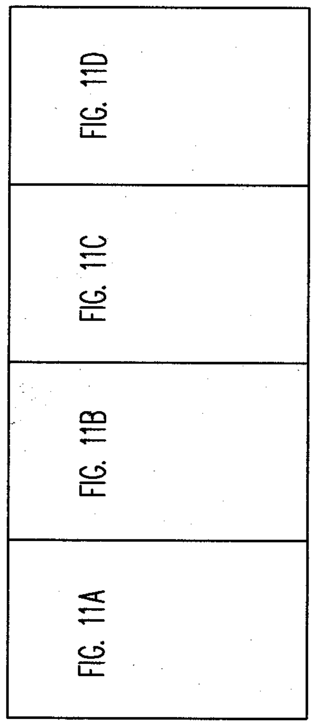


FIG. 11A



Key To
FIG. 11

SPRB Index (Frequency)

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
4a	4a	4a	4b	4b	4b	5a	5a	5a	5b	5b	5b	6a	6a	6a	6b	6b	6b
3	4	3b	5a	4	5	4	5	4b	6a	5	6	5	6	5b	7a	6	7
5	3	6a	2b	5	3	6	4	7a	3b	5	4	7	6	8a	4b	7	5
8	7	1	6	4	3	9	5	2	10	1	11	12	8	7	3	9	2
7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12

FIG. 11B

Proposed non-cyclic evolving-type resource structure for the case of 10 MHz and 20 MHz channel bandwith with up to 24 simultaneous users.

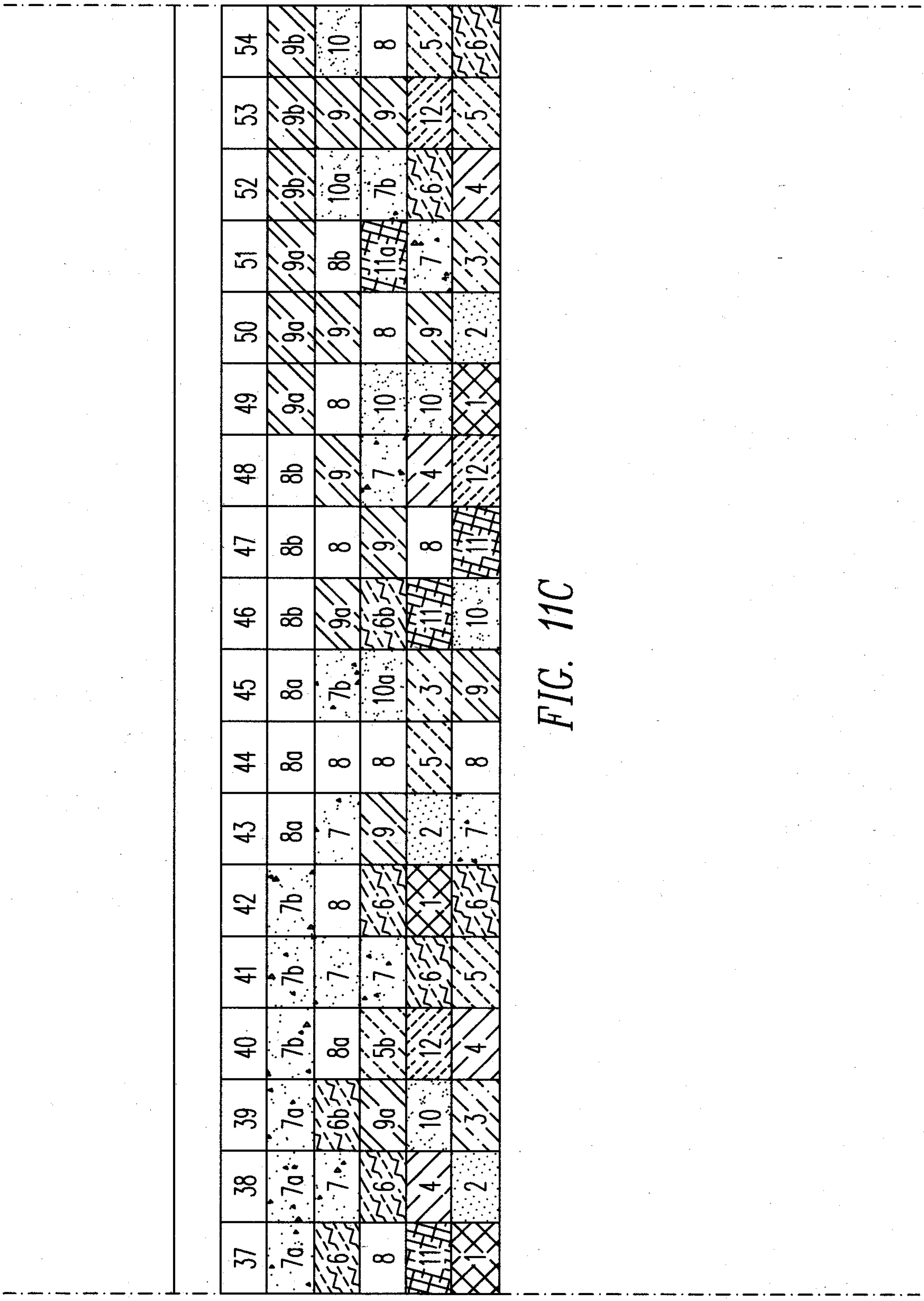

37 7a 6 8 11 1
38 7a 7 6 4 2
39 7a 6b 9a 10 3
40 7b 8a 5b 12 4
41 7b 7 7 6 5
42 7b 8 6 1 6
43 8a 7 9 2 7
44 8a 8 8 5 8
45 8a 7b 10a 3 9
46 8b 9a 6b 11 10
47 8b 8 9 8 11
48 8b 9 7 4 12
49 9a 8 10 10 1
50 9a 9 8 9 2
51 9a 8b 11a 7 3
52 9b 10a 7b 6 4
53 9b 9 9 12 5
54 9b 10 8 5 6

FIG. 11C

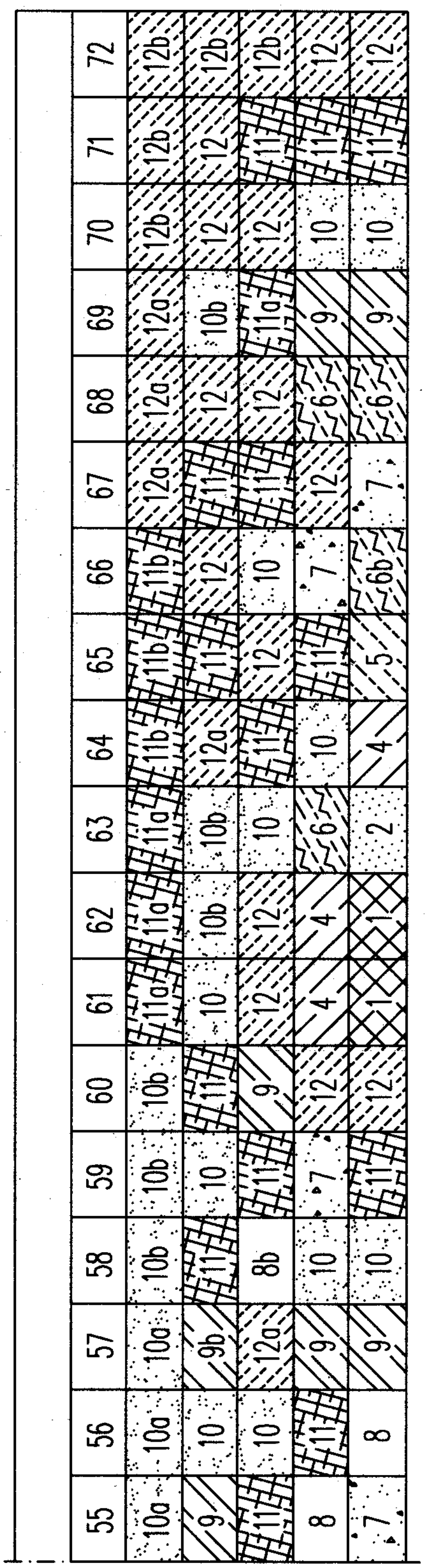

55 10a 9 11 8 7
56 10a 10 10 11 8
57 10a 9b 12a 9 9
58 10b 11 8b 10 10
59 10b 10 11 7 11
60 10b 11 9 12 12
61 11a 10 12 4 1
62 11a 10b 12 4 1
63 11a 10b 10 6 2
64 11b 12a 11 10 4
65 11b 11 12 11 5
66 11b 12 10 7 6b
67 12a 11 11 12 7
68 12a 12 12 6 6
69 12a 10b 11a 9 9
70 12b 12 12 10 10
71 12b 12 11 11 11
72 12b 12b 12b 12 12

FIG. 11D

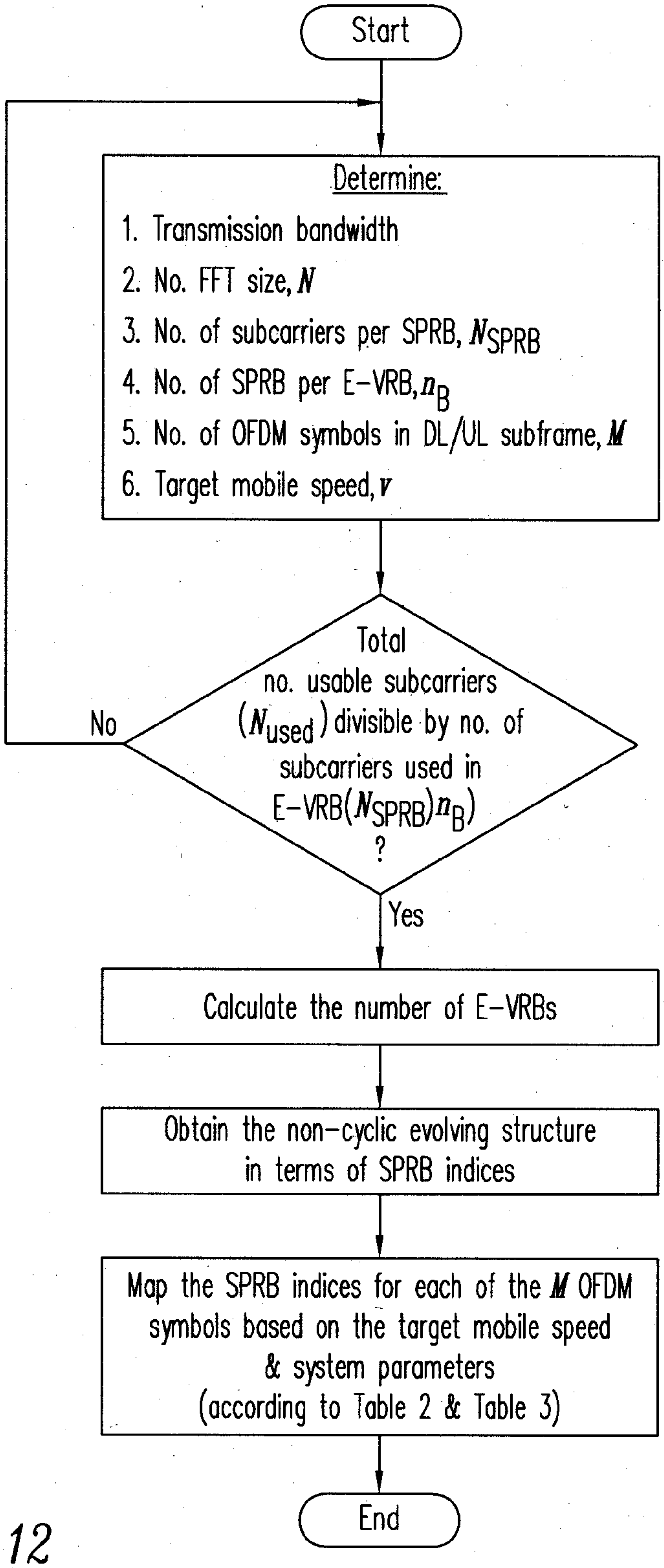


FIG. 12

Flowchart of the non-cyclic evolving-type user resource structure design.

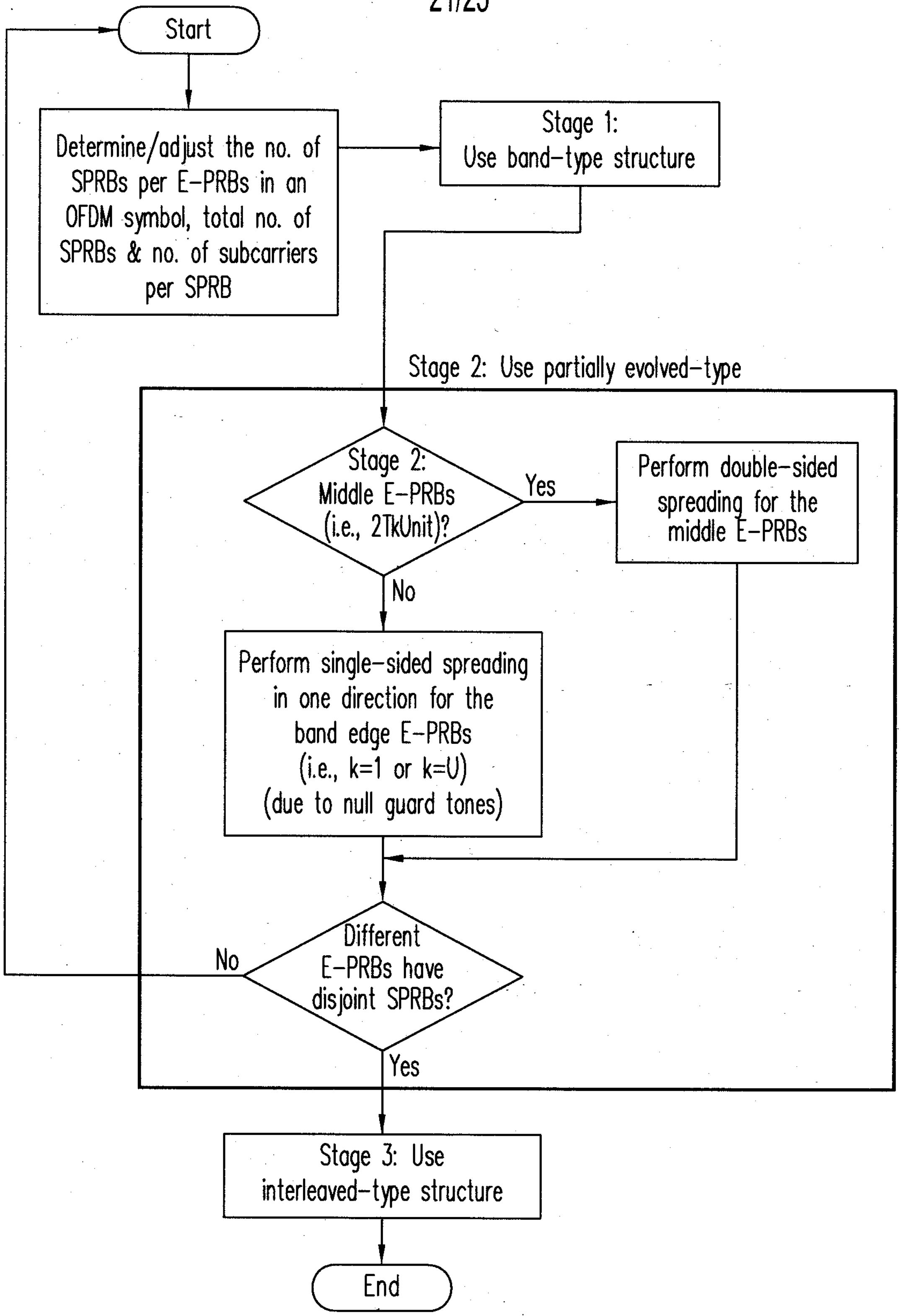


FIG. 13

Flowchart of the 3 stages simplified evolving structure design for systems with large number of null guard tones.

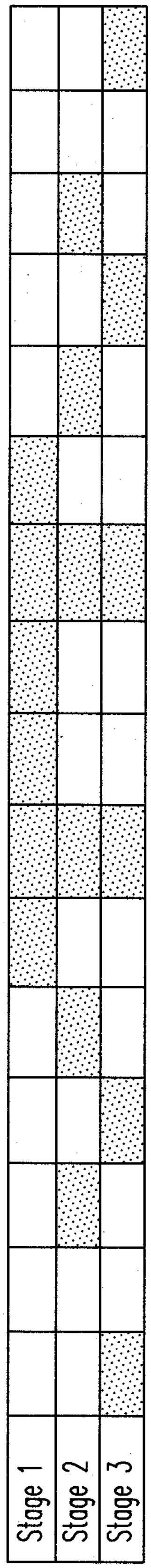


FIG. 14 Illustration of the resource shape of the k–th E–PRBs for all three stages where each block represents a SPRB.

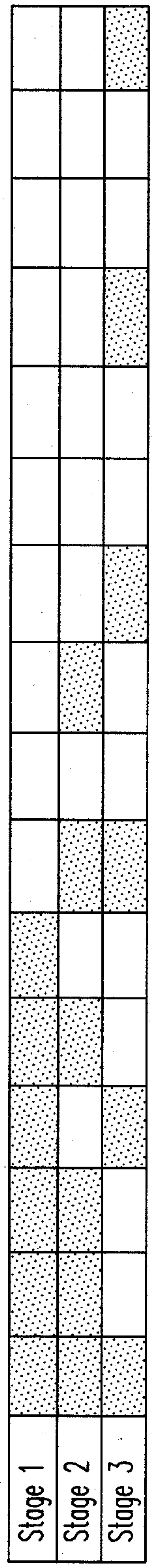


FIG. 15 Illustration of the resource shape of the 1st E–PRBs for all three stages where each block represents a SPRB.

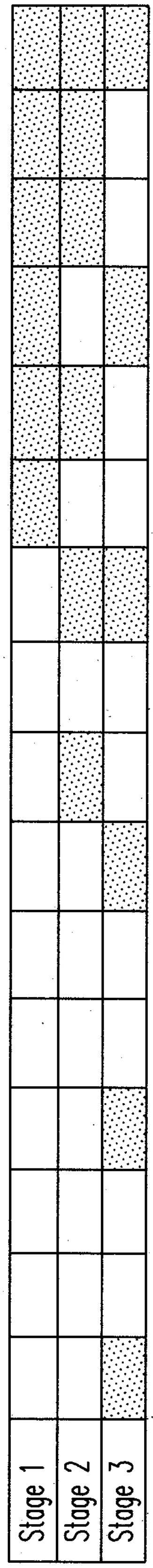


FIG. 16 Illustration of the resource shape of the U–th E–PRBs for all three stages where each block represents a SPRB.

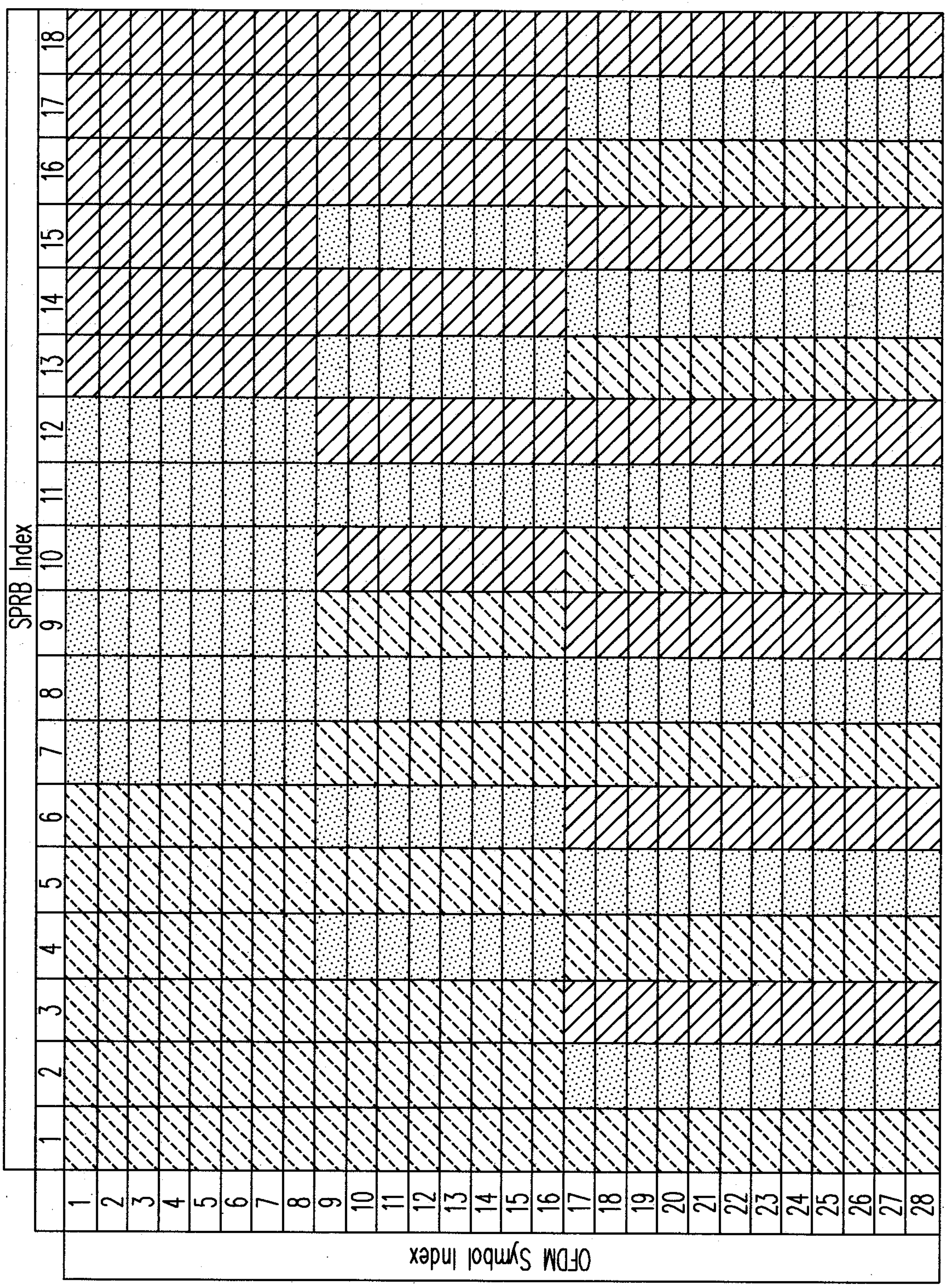


FIG. 17 Illustration of the E-PRBs for a system with parameters $N = 128$, $N_{used} = 72$, $M = 28$, $W = 6$, $N_{SPRB} = 4$, $U = 3$, $\mu = 2$ and $v = 80$ km/h. Different colors represent different E-PRBs.

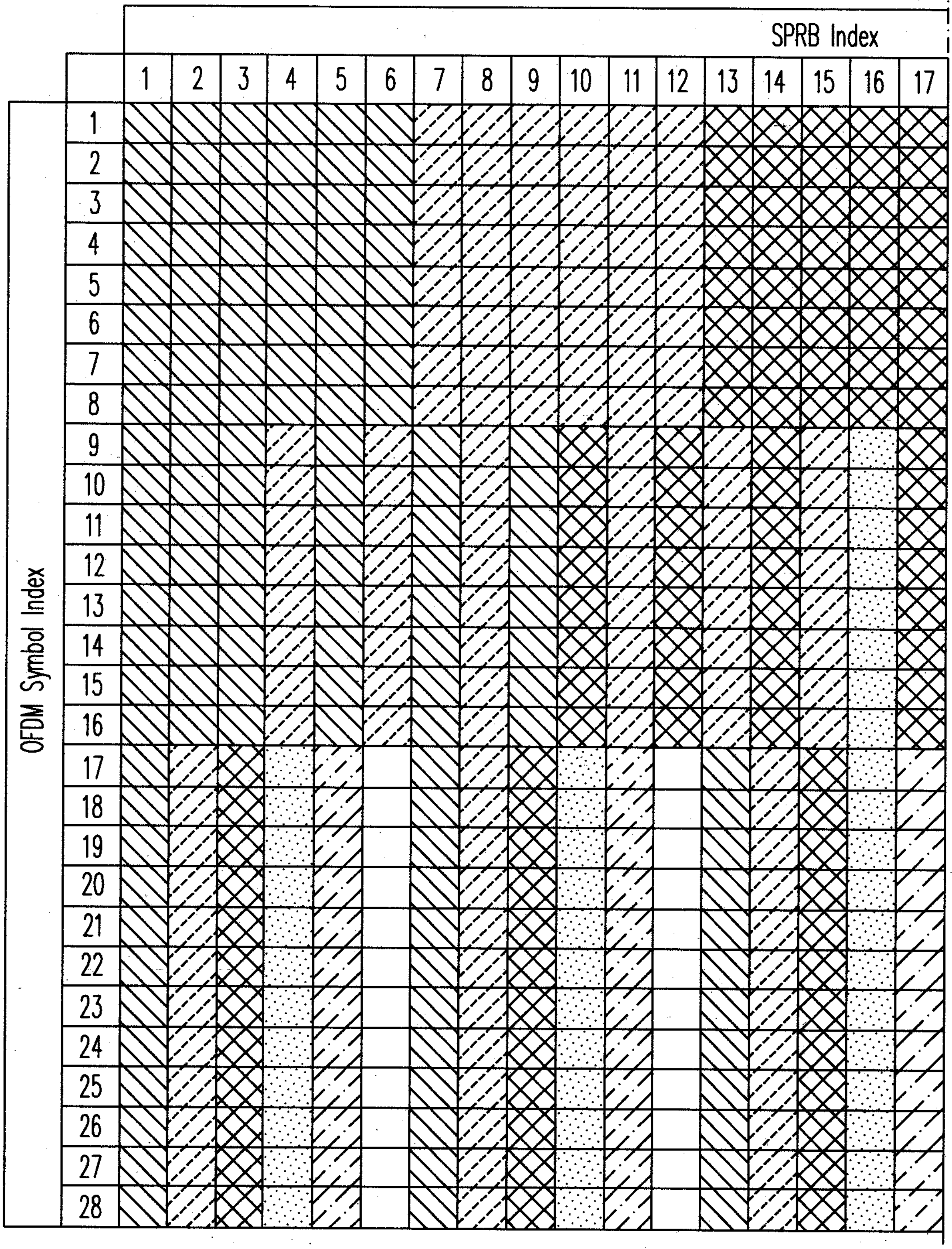


Illustration of the E-PRBs for a system with parameters
N = 128, N_{used} = 72, M = 28, W = 6, N_{SPRB} = 4, U = 3, μ = 2 and v = 80 km/h.
Different colors represent different E-PRBs.

FIG. 18A

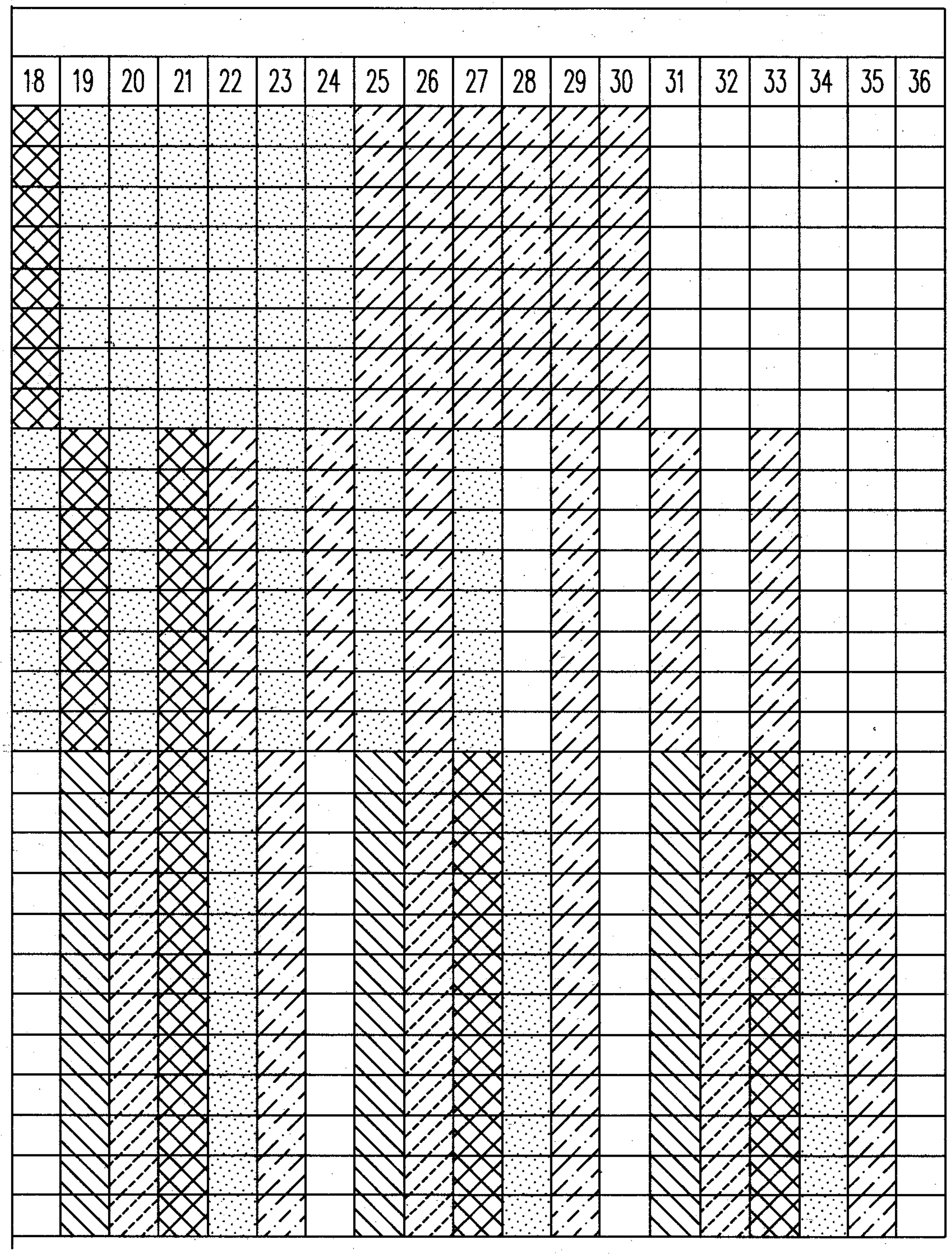
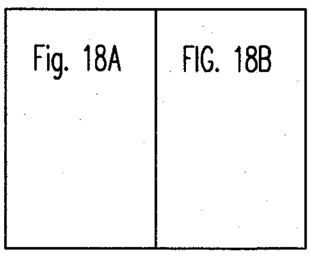


FIG. 18B

Key To
FIG. 18



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/026808

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04W 72/00 (2010.01)
USPC - 370/329
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)
IPC(8) - H04B 7/216; H04J 1/00; H04W 16/00, 16/02, 16/12, 36/00, 72/00 (2010.01)
USPC - 370/328, 329, 330, 331, 335; 375/260

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009/0073929 A1 (MALLADI et al) 19 March 2009 (19.03.2009) entire document	1-2
Y	WO 2007/119148 A2 (KASHIMA et al) 25 October 2007 (25.10.2007) entire document	1-2
Y	US 2007/0201398 A1 (YANG et al) 30 August 2007 (30.08.2007) entire document	1-2
A	US 2008/0248805 A1 (HAN et al) 09 October 2008 (09.10.2008) entire document	1-2

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of 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
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 April 2010	11 MAY 2010

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774