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Additional inventors are being named on the 2nd page *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

Methods and Apparatus for Multi-carrier Communications with Variable Channel Bandwidth

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☑ Drawing(s) *Number of Sheets* 9 ☐ Other (specify) _____

☐ Application Data Sheet. See 37 CFR 1.76

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Methods and Apparatus for Multi-Carrier Communications with Variable Channel Bandwidth

Xiaodong Li, Titus Lo, Kemin Li, and Haiming Huang

1 Background of the Invention

A broadband wireless communication device should be able to roam from one geographic region to another over the world. However, wireless communication spectra are heavily regulated and controlled by individual countries or regional authorities. It is inevitable that each country or region will have its own spectral band for broadband wireless communications that is different in frequency and bandwidth from others. Furthermore, even within a country or region, a wireless operator may own and operate on a broadband spectrum that is different in frequency and bandwidth from other operators. The difference in bandwidth presents a unique challenge in designing a broadband wireless communication system with flexibility that works for different bandwidths.

One of the advantages of a multi-carrier communication system is that it can be designed with a certain degree of flexibility. In a multi-carrier communication system such as multi-carrier code division multiple access (MC-CDMA) and orthogonal frequency division multiple access (OFDMA), information data are multiplexed on subcarriers that are mutually orthogonal in the frequency domain. The design flexibility lies in the manipulablility of the parameters, such as the number of subcarriers and the sampling frequency. For example, by using a different sampling frequency a DVB-T device is capable of receiving signals broadcasted from a DVB-T station that is operating on a 6-, 7-, or 8-MHz bandwidth.

The present invention is intended to provide a practical and feasible solution for multi-carrier communication with variable channel bandwidth.

2 Summary of the Invention

This invention describes the methods and apparatus for multi-carrier communication with variable channel bandwidth. The multi-carrier system mentioned in this invention can be of any special formats such as Orthogonal Frequency Division Multiplexing (OFDM), Orthogonal Frequency Division Multiple Access (OFDMA), or Multi-Carrier Code Division Multiple Access (MC-CDMA). The invention can be applied to either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD). Without lost of generality, OFDMA is taken as an example to illustrate the present invention.

In accordance with aspects of certain embodiments of the variable bandwidth OFDMA (VB-OFDMA) system, the time frame structure and the OFDM symbol structure of the communication interface is maintained the same for different channel bandwidth. The variable channel bandwidth is realized by adjusting the number of usable subcarriers.

In accordance with yet other embodiments of the VB-OFDMA system, a core band (CB) is defined and reserved for the primary state of radio operation, where critical, essential, and important radio control signals, along with some data, are transmitted within the CB. The full-bandwidth is used for normal radio operation.

In accordance with aspects of the VB-OFDM system, automatic bandwidth recognition (ABR) enables a receiver to automatically recognize the operating bandwidth when it enters in to an operating environment or service area of a particular frequency and channel bandwidth.

In accordance with other embodiments of the VB-OFDMA system, preambles are constructed either using a direct sequence in the time domain or using an OFDM symbol which corresponds to a particular pattern in the frequency domain. The preambles occupy either the entire band or only the core band.

In accordance with yet other embodiments of the VB-OFDMA system, multi-modes are devised to handle an exceptionally wide range of variation in bandwidth.

3 Brief Description of the Drawings

The present invention will be thoroughly understood from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1: The radio resource is divided into small units in both the frequency and time domains: subchannels and time slots. Subchannels are formed by subcarriers. The basic structure of a multi-carrier signal in the time domain is made up of time slots.

Figure 2: The relationship is shown between the sampling frequency, the channel bandwidth, and the usable subcarriers. For a given bandwidth of a spectral band or channel (B_{ch}), the number of usable subcarriers is finite and limited, whose value depends on the size of the FFT and the sampling frequency (f_s).

Figure 3: The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Data subcarriers can be grouped into subchannels in a particular way. Each subchannel may be set at a different power level.

Figure 4: The basic structure of a multi-carrier signal in the time domain is generally made up of time frames, time slots, and OFDM symbols. A frame consists of a number of time slots, whereas each time slot is comprised of one or more OFDM symbols. The OFDM

time domain waveform is generated by applying the inverse-fast-Fourier-transform (IFFT) to the OFDM signals in the frequency domain. A copy of the last portion of the time waveform, known as the cyclic prefix (CP), is inserted at the beginning of the waveform itself to form the OFDM symbol.

Figure 5: A cellular wireless network is comprised of a plurality of cells, in each of which the coverage is provided by a base station (BS). Within each coverage area, there are distributed mobile stations. A base station is connected to the backbone of the network via a dedicated link and also provides radio links to the mobile stations within its coverage.

Figure 6: The variable channel bandwidth is realized by adjusting the number of usable subcarriers, whose spacing is set constant. In this realization, a particular number of usable subcarriers constitute a channel with a certain bandwidth. The width of the core band is less than the smallest channel bandwidth.

Figure 7: A time-domain windowing function can be applied to the OFDM symbols to shape the spectrum to conform to a given spectral mask. This process is independent of the operating bandwidth.

Figure 8: A preamble is designed to occupy either the entire operating bandwidth or only the core band.

Figure 9: The entire range (e.g., from 5 Mhz to 40 MHz) of bandwidth variation is divided into smaller trunks (e.g., 5-10 MHz, 10-20 MHz, 20-40 MHz, in sizes). Each trunk is handled in one particular mode. The mode for the lowest range of bandwidth is labeled as the fundamental mode and other modes are called higher modes (Mode 1, Mode 2, etc.).

4 Detailed Description

4.1 Multi-Carrier Signal Format

The physical media resource (e.g., radio or cable) in a multi-carrier communication system can be divided in both the frequency and time domains, as depicted in Figure 1. This canonical division provides a high flexibility and fine granularity for resource sharing.

The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. For a given bandwidth of a spectral band or channel (B_{ch}), the number of usable subcarriers is finite and limited, whose value depends on the size of the FFT and the sampling frequency (f_s) and the effective bandwidth (B_{eff}), as depicted in Figure 2. There are three types of subcarriers, as illustrated in Figure 3.

1. Data subcarriers, which carries information data;

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