

METHODS FOR NETWORK THROUGHPUT ENHANCEMENT

[0001] The present application claims the benefit of the United States provisional application 61/053,335 (filed on 15 May 2008), the entire contents of which are incorporated herein by reference for all purposes.

Technical Field

[0002] Embodiments relate to the field of communication systems, such as ad-hoc radio communication systems, for example. By way of example, embodiments relate to a method of transmitting data, such as OFDM symbols.

Background

[0003] Technical specifications for both UWB Physical layer (PHY) and Medium Access Control layer (MAC) have been developed in the ECMA standards (ECMA 368/369) and ISO/IEC standard (ISO IEC 26907/26908) [1] [2] [3]. Moreover, Wireless Personal Area Networks (WPAN) Working Group of China's National Information Technology Standardization (NITS) Technical Committee is aiming to define China's high rate UWB standard using ECMA [1] specification as a baseline. In the present invention, we will

refer to the latter effort in standardization activity in China as the C-WPAN standardization activity.

[0004] Now, schemes for achieving higher throughput in a network of ECMA [1] specified devices were proposed in [4]. The schemes in [4] relied on the use of slotted offset Time Frequency Codes (TFCs) for enhancing the throughput of a network of ECMA specified devices. Currently, China's Wireless Personal Area Network (C-WPAN) working group within NITS is looking at a Dual Carrier Time Frequency Codes (DC-TFCs) based scheme [5] pertaining to standardization. The DC-TFCs scheme in [5] uses two smaller non-adjacent bands with 264MHz bandwidth each to transmit Orthogonal Frequency Division Multiplexing (OFDM) symbols simultaneously with specific frequency hopping patterns. Considering China's spectrum availability for UWB technology, a band plan that divides the entire available band into 10 smaller bands with bandwidth of 264MHz each was proposed as part of the standardization activities in China.

[0005] FIG. 1 shows the details of Chinese available spectrum from 3-10 GHz for usage related to UWB technology. It is seen from FIG. 1 that there is about 600 MHz bandwidth in the low frequency band from 4.2 GHz to 4.8 GHz and about 2.55 GHz bandwidth in the high frequency band from 6 GHz to 8.55 GHz. Given China's spectrum availability, the new band plan alluded to in the above divides the entire available frequency band into

10 smaller frequency bands in the spectrum of 4.2-4.8 GHz and 6.0-8.55 GHz. Each frequency band has a bandwidth of 264 MHz. There are two frequency bands 1 (101) and 2 (102) in the range from 4.2 to 4.8 GHz and 8 frequency bands 3-10 (103-110) in the range from 6.0 to 8.55 GHz.

[0006] FIG. 2 shows a table illustrating the logical channels with hopping patterns associated with DC-TFCs that are being considered for inclusion as part of a standard being developed by the C-WPAN. It is seen in FIG. 2 that in channel 1 wherein the low frequency bands 1 and 2 (bands 101 and 102 in FIG. 1) are used, there is no hopping. While in channels 2-13, all 8 high frequency bands 3-10 (frequency bands 103 to 110 in FIG. 1) are used for different logical channels with different hopping patterns. For example, for logical channel 2, 8 frequency bands 3-10 (103-110 in FIG. 1) are used, and the frequency hopping pattern is frequency bands (3 and 5) to frequency bands (4 and 6) to frequency bands (8 and 10) to frequency bands (7 and 9).

[0007] FIG. 3 illustrates the frequency hopping pattern of channel 2 (FIG. 2) pertaining to DC-TFCs that is being considered for inclusion as part of a standard being developed by the C-WPAN. For channel 2, the center frequencies of the dual carrier frequency bands 3 (103) and 5 (105) to transmit the first two OFDM symbols are respectively 6.336 GHz and 6.864 GHz, namely frequency bands 3 and 5 (103 and 105 as in FIG. 1) are

used. Subsequently, the center frequencies are 6.6 GHz and 7.128 GHz for the second two OFDM symbols (namely frequency bands 4 and 6 (104 and 106 as in FIG. 1) are used), 7.392 GHz and 7.920 GHz for the third two OFDM symbols (frequency bands 7 (107) and 9 (109) are used) and 7.656 GHz and 8.184 GHz (frequency bands 8 (108) and 10 (110) are used) for the fourth two OFDM symbols. In other words, a device operating in channel 2 will transmit a first plurality of two OFDM symbols in frequency bands 103 and 105 during a first OFDM symbol time 301, transmit a second plurality of two OFDM symbols in frequency bands 104 and 106 during a second OFDM symbol time 302, transmit a third plurality of two OFDM symbols in frequency bands 107 and 109 during a third OFDM symbol time 303, and transmit a fourth plurality of two OFDM symbols in frequency bands 108 and 110 during a fourth OFDM symbol time. After this, the device will send a fifth plurality of two OFDM symbols restarting from the frequency bands 103 and 105 during a fifth OFDM symbol time 305, and follow the frequency hopping pattern of frequency bands 103 and 105 to frequency bands 104 and 106 to frequency bands 107 and 109 to frequency bands 108 and 110 in the subsequent OFDM symbol transmission.

[0008] In general, in the current version of ECMA standard for OFDM transmission system, when an ad-hoc radio communication group operates in a particular frequency channel, a frequency

band in a frequency band group is utilized only up to a maximum of a certain portion of the time. For example, if a device is transmitting in a particular frequency band during an OFDM symbol duration, the other bands in the band group (and possibly other band groups) are unutilized during that OFDM symbol transmission time. The standard pertaining to DC-TFCs being developed by the C-WPAN is based on the ECMA standard, and thus is in line with the ECMA standard: when a device is transmitting in two particular frequency bands during an OFDM symbol duration, such as 301, the other frequency bands are unutilized during that OFDM symbol transmission time.

[0009] Thus according to a proposal put forward to the C-WPAN related group, two frequency bands of the eight utilized frequency bands are only used up to one-fourth of the time (if devices operate in respective time-frequency-codes, such as frequency hopping pattern of channels 2-13 in FIG. 2), when the ad-hoc radio communication devices within an ad-hoc radio communication devices' group using DC-TFCs in a particular beacon group under normal equilibrium operation are tuned to a particular frequency channel. The above translates to low spectral usage and unutilized bands of frequencies.

[0010] Thus it can be seen that there is still a need to improve the proposal pertaining to DC-TFCs being looked into by the C-

WPAN related group to increase the point to point data rate as well as the overall network throughput.

[0011] In various embodiments, modifications to the slotted offset TFCs based scheme given in [4] are provided to cater to its use with DC-TFCs, an OFDM based transmission system and the Chinese available spectrum for achieving higher throughput in network of UWB devices that incorporate DC-TFCs as the usually used transmission scheme. The proposed modification to [4] allows UWB devices that incorporate DC-TFCs to enhance their overall network throughput by up to four times.

[0012] In addition, a new Information Element (IE) is provided and modifications to a few existing IEs as given in ECMA specification are suggested in order to cater to slotted offset TFCs and DC-TFCs. In various embodiments, also few new logical channels are proposed catering to DC-TFCs. Further, a synchronization algorithm is outlined that would aid UWB based devices in a network to maintain clock-period level synchronization and thus allowing for the use of slotted offset TFCs.

Summary

[0013] A method for transmitting OFDM symbols by a plurality of ad-hoc radio communication devices in an ad-hoc radio communication devices' group is provided, the method comprising:

a first ad-hoc radio communication device of the ad-hoc radio communication devices' group transmitting a first plurality of two OFDM symbols in a first plurality of two frequency sub-ranges of a frequency range selected for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges; in the same transmission time period, a second ad-hoc radio communication device of the ad-hoc radio communication devices' group transmitting a second plurality of two OFDM symbols in a second plurality of two frequency sub-ranges of the frequency range, wherein the second plurality of frequency sub-ranges has no overlap with the first plurality of frequency sub-ranges.

Brief Description of the Drawings

[0014] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of various embodiments. In the following description, various embodiments are described with reference to the following drawings, in which:

FIG. 1 shows the Chinese Available Spectrum for UWB Application;

FIG. 2 shows a table illustrating the hopping pattern for DC-TFCs;

FIG. 3 shows an illustration of Dual Carrier Time Frequency Codes (DC-TFCs);

FIG. 4 shows an illustration of ad-hoc radio communications among ad-hoc communication devices within an ad-hoc radio communication devices' group;

FIG. 5 shows a method to transmit OFDM symbols according to ref. [4];

FIG. 6 shows a method to transmit OFDM symbols according to one embodiment of the invention;

FIG. 7 shows the structure of a superframe and a method to transmit OFDM symbols;

FIG. 8 shows an illustration of an ad-hoc radio communication device according to one embodiment of the invention;

FIG. 9 shows an illustration of the details of Distributed Reservation Protocol (DRP) IE according to one embodiment of the invention;

FIG. 10 shows an illustration of the Prioritized Channel Access (PCA) Availability IE according to one embodiment of the invention;

FIG. 11 shows an illustration of the Relinquish Request IE according to one embodiment of the invention;

FIG. 12 shows an illustration of the MAC Capabilities IE according to one embodiment of the invention;

FIG. 13 shows an illustration of the PHY Capabilities IE according to one embodiment of the invention;

FIG. 14 shows an illustration of the proposed Enhanced DRP Availability IE according to one embodiment of the invention;

FIG. 15 shows an illustration that two of the reserved bits of PHY Control register are used for TFC Offset Control;

FIG. 16 shows an illustration of a synchronization method;

FIG. 17 shows a flow diagram of the synchronization scheme as illustrated in FIG. 16;

FIG. 18 shows a table illustrating the proposed logical channel according to one embodiment;

FIG. 19 shows a table illustrating the proposed logical channel pertaining to backward compatibility with WiMedia/ECMA devices.

Description

[0015] As used herein, the term frequency band or band may refer to a predefined continuous frequency range, which may be used for signal transmission. In the context of this description, a frequency band or band may often be referred to using a (frequency) band number associated with it.

[0016] Further, the term frequency channel or a logical channel may refer to a combination of one or more frequency bands, and such a combination may be used for signal transmission as well. In this context, a frequency channel or a logical channel may or may not have a continuous frequency range. In the context of this description, a frequency channel or a logical channel is often referred to using a frequency channel number associated with it.

[0017] Additionally, the term band group may refer to a group of frequency bands. A band group may or may not be used for signal transmission. It should be noted that it is possible that a frequency channel may have the same frequency bands as a band group.

[0018] Still further, the term Time-Frequency Code (TFC) may include a frequency hopping pattern, wherein some patterns hop among frequency bands and some stay fixed in a single frequency band. For example, the ECMA standard specifies 3 types of TFCs: one is referred to as Time-Frequency Interleaving (TFI) where the coded information is interleaved over three frequency bands; one is referred to as two-band TFI or TFI2, where the coded information is interleaved over two frequency bands; one is referred to as Fixed Frequency Interleaving (FFI), where the coded information is transmitted on a single band. Under the ECMA standard and as used hereinafter, the terms "Time-Frequency

Codes (TFC)" and "frequency hopping pattern" are synonymous with the term "frequency channel" or "logical channel".

[0019] An ad-hoc radio communication group generally consists of a plurality of ad-hoc radio communication devices, wherein the communication among these devices is self-organized. The plurality of devices are able to discover each other within a range to form the communication group, and within the communication group, they can communicate with each other without the need of a central control.

[0020] Orthogonal Frequency Division Multiplexing (OFDM) is a widely used technique in ad-hoc radio communication systems. OFDM is a multi-carrier transmission technique, which divides the available frequency spectrum into many subcarriers, each one being modulated by a low data rate stream. OFDM can achieve high-speed data transmission and high spectral efficiency. So far, several of OFDM based standards have been put forward, such as the ECMA standard.

[0021] FIG. 4 shows an illustration of an ad-hoc radio communication group 400 including devices A to H (411 -418), wherein all the devices A to H (411-418) work in a particular frequency channel. For illustration, circle line 401 represents the transmission range of device B 412, meaning that device B 412 is able to transmit OFDM symbols to other devices that are located within the circle line 401. In this illustration, device

B 412 is able to transmit OFDM symbols to devices A 411, C 413, D 414, E 415, and H 418. Similarly, circle line 402 represents the transmission range of device C 413, meaning that device C is able to transmit OFDM symbols to other devices that are located within the circle line 402, and circle line 403 represents the transmission range of device D 414, meaning that device D 414 is able to transmit OFDM symbols to other devices that are located within the circle line 403. According to the current ECMA standard, for example, when device A 411 sends OFDM symbols to device B 412, no other data transmission among the ad-hoc radio communication devices C to H (413-418) in the radio communication devices' group 400 can be carried out at the same time.

[0022] Assume channel 2 as illustrated in FIG. 2 is used.

Transmission of OFDM symbols from device A 411 to device B 412 is illustrated in FIG. 3, wherein device A 411 transmits OFDM symbols to device B 412 in a frequency band group with 8 bands 103-110. When frequency channel 2 is used, transmitted OFDM symbols is interleaved over eight frequency bands 103-110 according to a frequency hopping pattern of frequency bands 103 and 105 to frequency bands 104 and 106 to frequency bands 107 and 109, and to frequency bands 108 and 110. Accordingly, a frequency band is used only up to a maximum of one-fourth of the time during the transmission. Further, when device A 411 is

transmitting data to device B 412 in a particular plurality of two frequency bands during an OFDM symbol duration time, the other bands in the band group are unutilized during that OFDM symbol transmission time. Thus, the spectral usage is low due to the unutilized bands of frequencies.

[0023] Reference [4] proposes the use of slotted offset Time Frequency Codes (TFCs) to utilize the available spectrum (say, entire band group) effectively at a given time by a particular beacon group. The scheme proposed in [4] is summarized as below.

[0024] According to the version 1.0 of the ECMA standard, if a device is transmitting in a particular band during an OFDM symbol duration, the other bands in the band group are unutilized during that OFDM symbol. Using offset TFCs proposed in [4], the entire band group may be utilized at the same time. As an illustration of offset TFCs, in Fig. 5, if the grey colored boxes 541-546 constitute TFC offset 0, then the black colored boxes 561-566 constitute first offset, namely TFC offset 1, of TFC offset 0, and the white colored boxes 551-556 constitute the second offset, namely TFC offset 2, of TFC offset 0. Note that for a frequency channel with 3 frequency bands, there can only be up to two offsets of a TFC. Now, refer to Fig. 4. If device A 411 sends data to device B 412 using TFC offset 0, then using the scheme proposed in [4], device C 413 would be able to send data to device D 414 simultaneously using TFC

offset 1. Similarly, device E 415 would be able to send data to device F 416 at the same time using TFC offset 2. Hence up to three simultaneous transmissions can go on utilizing offset TFCs thereby increasing the network throughput up to three times of what is achievable by version 1.0 of ECMA specification. In addition to the benefit of offset TFCs mentioned above, another benefit is that a device with three separate RF chains while transmitting data to another device would be able to receive data from up to two other devices using two offsets of TFC offset 0.

[0025] In the slotted offset TFCs implementation proposed in [4], all the devices that are synchronized assume that their first OFDM symbol starts at the Beacon Period Start Time (BPST) of the slowest neighbor or the average of the BPSTs of all the nodes in a beacon group. In this regard, Beacon Period (BP) may be defined as a period of time declared by a device during which it sends or listens for beacons according to the ECMA standard, and the term beacon may refer to information regarding such as the reservation of time slots in the further data period. Each superframe starts with a BP, which extends over one or more contiguous Medium Access Slots (MASs). The start of the first MAS in the BP, and the superframe, is called the Beacon Period Start Time (BPST). As background information, under the ECMA standard, frame is defined as unit of data transmitted by a

device, and a superframe is the basic timing structure for frame transmissions. A superframe is composed of 256 MASs, and a superframe includes a BP followed by a data period. A BP comprises a number of beacon slots, and a beacon can be transmitted within a beacon slot. In one embodiment, an ad-hoc radio communication device may start its OFDM transmission in a MAS in the data period at the start of that MAS. FIG. 7 illustrates the basic structure of superframe 710 according to the ECMA standard. According to the ECMA standard, a superframe is defined as periodic time interval used to coordinate frame transmissions between devices, which contains a beacon period 701 followed by a data period 702, wherein frame is defined as unit of data transmitted by a device. A superframe is composed of 256 MASs 703.

[0026] An OFDM in-band time (in a band) including band switching time is $312.5\text{ns} + 9.47\text{ns} = 321.97\text{ns}$ according to ECMA standard. With the slotted offset TFCs, each OFDM symbol is transmitted only during an OFDM Symbol Transmission Duration (OSTD) of period 321.97ns . Refer to FIG. 5. It was proposed in [4] that all the OSTDs be aligned contiguously from the beginning of a MAS. Thus, since a MAS duration is 256 microseconds, we have 795 OSTDs and some small time left over at the end of the MAS (considering in band time of an OFDM symbol as given in ECMA specification). The first OSTD of the next MAS is scheduled to

begin at the beginning of the next MAS. In order to facilitate transmission of OFDM symbol at exactly each OSTD, [6] proposed a synchronization method using virtual clock concept to achieve finer synchronization between devices at clock period level so that OSTDs of devices are synchronized and do not overlap much to cause interference.

[0027] In the following, modifications to the schemes proposed in [4] are proposed to cater to their usage with DC-TFCs. The modifications proposed enable UWB devices that implement DC-TFCs to enhance their network throughput by up to four times. The schemes proposed herein apply to both Prioritized Channel Assess (PCA) and Distributed Reservation Protocol (DRP) periods of the MAC superframe structure. The DRP is used in the ECMA standard, and is a protocol implemented in each device to support negotiation and maintenance of channel time reservation binding on all neighbor devices of the reservation participants. The DRP enables devices to reserve one or more MASSs that the device can use to communicate with one or more neighbours. PCA is used in the ECMA standard to provide differentiated distributed contention access to the medium for a device for transmission.

[0028] In one embodiment, a method for transmitting OFDM symbols by a plurality of ad-hoc radio communication devices in an ad-hoc radio communication devices' group is provided, the method comprising: a first ad-hoc radio communication device of the ad-

hoc radio communication devices' group transmitting a first plurality of two OFDM symbols in a first plurality of two frequency sub-ranges of a frequency range selected for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges; in the same transmission time period, a second ad-hoc radio communication device of the ad-hoc radio communication devices' group transmitting a second plurality of two OFDM symbols in a second plurality of two frequency sub-ranges of the frequency range, wherein the second plurality of frequency sub-ranges has no overlap with the first plurality of frequency sub-ranges.

[0029] FIG. 6 shows an illustration of the method to transmit OFDM symbols catering to the usage of DC-TFCs according to one embodiment of the invention.

[0030] Refer to FIGs. 4 and 6. Assume that OFDM symbols are transmitted within a band group 680 having 8 frequency bands 103-110 as shown in FIG. 6. Also assume that OFDM symbols are transmitted with a frequency hopping pattern of channel 2 as listed in FIG. 2, namely (bands 103 and 105) to (bands 104 and 106) to (bands 107 and 109) to (bands 108 and 110) as shown in the grey colored boxes (601, 601'-608, 608') in FIG. 6. For example, a device will transmit a first plurality of two OFDM symbols in the frequency bands 103 and 105 during a first OFDM symbol time 301, transmit a second plurality of two OFDM symbols

in the frequency bands 104 and 106 during a second OFDM symbol time 302, transmit a third plurality of two OFDM symbols in the frequency bands 107 and 109 during a third OFDM symbol time 303, and transmit a fourth plurality of two OFDM symbols in the frequency bands 108 and 110 during a fourth OFDM symbol time 304. After this, the device will send a fifth plurality of two OFDM symbols restarting from the frequency bands 103 and 105 during a fifth OFDM symbol time 305, and follow the frequency hopping pattern of (bands 103 and 105) to (bands 104 and 106) to (bands 107 and 109) to (bands 108 and 110) in the subsequent OFDM symbol transmission.

[0031] Also referring to FIG. 6, it can be seen that the black colored boxes 625, 625'-632, 632', the white colored boxes 617, 617'-624, 624' as well as the light grey colored boxes 609, 609'-616, 616' represent the same frequency hopping pattern as the grey colored boxes 601, 601'-608, 608', with the only exception of the starting frequency bands for transmission of the first plurality of OFDM symbols. Such a difference can be also interpreted in another way: the black colored boxes 625, 625'-632, 632', the white colored boxes 617, 617'-624, 624' as well as the light grey colored boxes 609, 609'-616, 616' respectively represent an offset of the frequency hopping pattern, or a time shifted version of the frequency hopping pattern represented by the grey colored boxes 601, 601'-608,

608'. For example, the black colored boxes 625, 625'-632, 632' represent a time shifted version of the frequency hopping pattern relative to the frequency hopping pattern represented by the grey colored boxes 601, 601'-608, 608'. Similarly, the white colored boxes 617, 617'-624, 624' represent a still larger time shifted version of the frequency hopping pattern relative to the frequency hopping pattern represented by the grey colored boxes 601, 601'-608, 608'. Similarly, the light grey colored boxes represent an even still larger time shifted version of the frequency hopping pattern relative to the frequency hopping pattern represented by the grey colored boxes 601, 601'-608, 608'. A first ad-hoc radio communication device of the ad-hoc radio communication devices' group (not shown) may transmit a first plurality of two OFDM symbols within a first plurality of two frequency bands 103 and 105 during a first OFDM symbol transmission time 301 (see grey colored boxes 601 and 601' in FIG. 6). In the same transmission time period 301, a second ad-hoc radio communication device may transmit a second plurality of two OFDM symbols in a second plurality of two frequency bands 104 and 106 (see light grey colored boxes 609 and 609' in FIG. 6), wherein the second plurality of two frequency bands 104 and 106 is different from the first plurality of two frequency bands 103 and 105.

[0032] In a further embodiment, in the same transmission time period, a third ad-hoc radio communication device of the ad-hoc radio communication device's group transmits a third plurality of two OFDM symbols in a third plurality of two frequency sub-ranges, wherein the third plurality of two frequency sub-ranges has no overlap with the first and the second pluralities of two frequency sub-ranges.

[0033] This embodiment is also illustrated in FIG. 6. In the same transmission time period 301 of the first and second pluralities of two OFDM symbols transmitted by two separate devices, a third ad-hoc radio communication device (not shown) may transmit a third plurality of two OFDM symbols in a third plurality of two frequency bands 107 and 109 (see white colored boxes 617 and 617' in FIG. 6), wherein the third plurality of two frequency bands 107 and 109 is different from the first plurality of two frequency bands 103 and 105 and the second plurality of two frequency bands 104 and 106.

[0034] Similarly, in the same transmission time period 301 of the first, second and third pluralities of two OFDM symbols transmitted by three separate devices, a fourth ad-hoc radio communication device (not shown) may transmit a fourth plurality of two OFDM symbols in a fourth plurality of two frequency bands 108 and 110 (see black colored boxes 625 and 625' in FIG. 6), wherein the fourth plurality of two frequency bands 108 and 110

is different from the first plurality of two frequency bands 103, and 105, the second plurality of two frequency bands 104 and 106, and the third plurality of two frequency bands 107 and 109.

[0035] It thus can be seen that the entire band group may be utilized at the same time. For example, in FIG. 6, the grey colored boxes 601, 601'-608, 608' constitute TFC offset 0 (671), the black colored boxes 625, 625'-632, 632' constitute TFC offset 1 (672), the white colored boxes 617, 617'-624, 624' constitute TFC offset 2 (673), and the light grey colored boxes 609, 609'-616, 616' constitute TFC offset 3 (674). Here, TFC offset 0 (671), TFC offset 1 (672), TFC offset 2 (673) and TFC offset 3 (674) are within a same frequency channel (channel 2 as given in FIG. 2 with same frequency hopping pattern) and are four offsets of the frequency channel that can be used for transmission of OFDM symbols. TFC offset 1 (672), TFC offset 2 (673) and TFC offset 3 (674) have a frequency shifting with respect to TFC offset 0 (671) within the same hopping pattern. TFC offset 1 (672) has a time shifted version of the frequency hopping pattern relative to TFC offset 0 (671), TFC offset 2 (673) has a still larger time shifted version of the frequency hopping pattern relative to TFC offset 0 (671), and TFC offset 3 (674) has an even still larger time shifted version of the frequency hopping pattern relative to TFC offset 0 (671). Now,

refer to FIG. 4. Assume devices A 411-H 418 work in frequency channel 2 as give in FIG. 2 with the frequency hopping pattern of (bands 103 and 105) to (bands 104 and 106) to (bands 107 and 109) to (bands 108 and 110). If device A 411 sends OFDM symbols to device B 412 using TFC offset 0 (671), device C 413 would be able to send OFDM symbols to device G 417 simultaneously using TFC offset 1 (672) (an offset of channel 2 using the same MAS slot). Similarly, device E 415 would be able to send OFDM symbols to device H 418 at the same time using TFC offset 2 (673). Similarly, device D 414 would be able to send OFDM symbols to device F 416 at the same time using TFC offset 3 (674). Hence up to four transmissions can go on simultaneously, thereby increasing the network throughput up to four times using a single band group compared with the case where DC-TFCs are used without slotted offsets.

[0036] In one embodiment, a first ad-hoc radio communication device of an ad-hoc radio communication devices' group transmits a first plurality of two OFDM symbols in a first plurality of two frequency sub-ranges of a frequency range selected for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges. In the same transmission time period, a second ad-hoc radio communication device of the ad-hoc radio communication devices' group transmits a second plurality of two OFDM symbols in a

second plurality of two frequency sub-ranges of the frequency range in accordance with a time shifted version of the above same frequency hopping pattern, wherein the second plurality of two frequency sub-ranges is different from the first plurality of two frequency sub-ranges. In one embodiment, the frequency hopping pattern is with reference to a fixed point in time such as the start of a beacon slot or the start of a MAS. In a further embodiment, in the same transmission time period, a third ad-hoc radio communication device of the ad-hoc radio communication devices' group transmits a third plurality of two OFDM symbols in a third plurality of two frequency sub-ranges of the frequency range in accordance with a still larger time shifted version of the above same frequency hopping pattern, wherein the third plurality of frequency sub-ranges is different from the first and second pluralities of two frequency sub-ranges. In one embodiment, the frequency range is a frequency band group, the frequency sub-range is a frequency band within the frequency band group. In one embodiment, the frequency band group comprises eight frequency bands. In one embodiment, the frequency hopping pattern is a Time-Frequency Code (TFC).

[0037] It should be noted that the hopping pattern is not limited to the pattern as shown in FIG. 6, but can be, such as, frequency hopping patterns of channels 2-13 as shown in FIG. 2. The hopping pattern can also be any of the other possible

hopping patterns not listed here. It should also be noted that the number of OFDM symbols that can be transmitted by the plurality of ad-hoc radio communication devices in the ad-hoc radio communication devices' group is limited to the number of bands within the band group 680 show in FIG. 6.

[0038] In one embodiment, all the ad-hoc radio communication devices in the ad-hoc radio communication group are synchronized. In one embodiment, ad-hoc radio communication devices may start their OFDM symbol transmission at a same time. For example, for the ECMA standard based system, all the ad-hoc radio communication devices may start their OFDM symbol transmission at the BPST of the slowest neighbor device or the average of the BPSTs of all the devices in an ad-hoc radio communication devices' group. In one embodiment, an ad-hoc radio communication device may start its OFDM symbol transmission during the Beacon Period at the start of the device's beacon slot. In one embodiment, an ad-hoc radio communication device may start its OFDM transmission in a MAS in the data period at the start of that MAS.

[0039] In one embodiment, in the frequency range, an OSTD of a first OFDM symbol transmission is followed by an OSTD of a second OFDM symbol transmission with no time interval between them, and all the OSTDs within a fixed time period are contiguously aligned starting from a fixed reference point in

the fixed time period. In one embodiment, the fixed time period is a beacon slot or a MAS, and the fixed reference point is the start of the beacon slot or the start of the MAS. In one embodiment, an OSTD includes OFDM symbol transmission time and OFDM frequency sub-range switching time.

[0040] For the DC-TFCs based scheme[5] that is being considered by C-WPAN working group, an OSTD may be $625\text{ns} + 18.94\text{ns} = 643.94\text{ns}$, wherein an OFDM symbol transmission time of 625ns and a band switching time of 18.94 ns is included. In one embodiment, an OFDM symbol is transmitted only during an OSTD. In one embodiment, all the OSTDs may be aligned continuously without time gap within a MAS.

[0041] This embodiment is illustrated in FIG. 7 based on the ECMA standard. In this implementation, within each MAS 703, all the OSTDs 704 are aligned contiguously from the beginning of the MAS 705. One OSTD 704 follows right after its previous OSTD 704. 'S' represents an OSTD, and the second OSTD ($S=2$) follows right after the first OSTD ($S=1$). The third OSTD ($S=3$) follows right after the second OSTD ($S=2$), and the fourth OSTD ($S=4$) follows right after the third OSTD ($S=3$) and so on. Since a MAS length is 256 microseconds , a number of 795 OSTDs can be transmitted within each MAS, and some small time may be left over at the end of the MAS. In one embodiment, the first OSTD of the next MAS is scheduled to begin at the beginning of the next MAS. The above

applies to the DC-TFCs based scheme proposed in [5] and that is being considered by C-WPAN working group, wherein a number of 396 OSTDs can be transmitted within a MAS and some small time may be left over at the end of the MAS.

[0042] In one embodiment, in the frequency range, an OSTD of a first OFDM symbol transmission is followed by an OSTD of a second OFDM symbol transmission with a fixed guard interval between them, and all the OSTDs within the fixed time period are consecutively aligned (with guard intervals embedded between every two OSTDs) starting from the fixed reference point in the fixed time period. In one embodiment, all the OSTDs may be aligned consecutively with a fixed guard interval embedded between every two OSTDs within a MAS. In one embodiment, the first OSTD starts at the start of the MAS. Based on the ECMA standard, assuming the guard interval between every two OSTDs is 40 ns, then given an OSTD length of 321.97ns and MAS duration of 256 μ s, there can be 707 OSTDs with some small time unused at the end of the MAS. In one embodiment, the first OSTD of the next MAS is scheduled to begin at the beginning of the next MAS. This applies to the DC-TFCs based scheme in [5] that has been considered by C-WPAN working group. In such a case, given an OSTD length of 643.94ns, guard interval between every two OSTDs as 40ns and MAS duration of 256 μ s, there can be 372 OSTDs in a MAS with some small time unused at the end of the MAS. Note that

the above guard interval embedded between two OSTDs can be chosen as any other value that may be related to certain parameters, such as propagation delay.

[0043] According to one embodiment, the first plurality of two frequency bands of TFC offset 0 (671) may start at a MAS boundary and the TFC offset 1 (672), TFC offset 2 (673), and TFC offset 3 (674) may also start at the same MAS boundary. Any ad-hoc radio communication device hearing an ongoing transmission can easily identify the TFC offset by just finding the two frequency bands used in a particular OSTD in a particular MAS.

[0044] In one embodiment, any device in the ad-hoc radio communication devices' group reserves or uses a default plurality of two frequency sub-ranges of the frequency range for transmission during an OFDM symbol transmission time according to a frequency hopping pattern. For example, the device may always reserve or use a default plurality of two frequency bands 103 and 105 of the band group 680 (FIG. 6) for transmission of OFDM symbols during the first OFDM symbol transmission time or OSTD at the beginning of a MAS during the data period according to the frequency hopping pattern of channel 2 (FIG. 2). In other words, an ad-hoc radio communication device may reserve or select a default plurality of two frequency sub-ranges of a frequency range (in accordance to a frequency hopping pattern that has no offset of the default channel) for transmission or

reception in accordance with the frequency hopping pattern. For example, within an ad-hoc radio communication group, an ad-hoc radio communication device may always choose the default offset, such as TFC offset 0 (671 in FIG. 6)) for transmitting beacons, wherein at the beginning of the transmission, the default plurality of two frequency sub-ranges are frequency bands 103 and 105. For another example, the beacons transmitted by the ad-hoc radio communication device may reserve a MAS for transmission of OFDM symbols during the data period using a default offset, such as TFC offset 0 (671), wherein at the beginning of the data transmission (at the start of the MAS), the default plurality of two frequency sub-ranges are frequency bands 103 and 105.

[0045] In one embodiment, when a device in the ad-hoc radio communication devices' group senses that a default plurality of two frequency sub-ranges or a default TFC offset is not available for transmission of OFDM symbols, the device may select another plurality of two frequency sub-ranges or another TFC offset for transmission. For example, if a device senses that the default plurality of two frequency bands 103 and 105 is not available at time slot 301 according to a frequency hopping pattern or time shifted version of a frequency hopping pattern, the device may select another plurality of two frequency bands, such as band 108 and 110, for transmission of OFDM symbols.

[0046] In one embodiment, the device selects the other plurality of the two frequency sub-ranges for transmission in accordance with a time shifted version of the frequency hopping pattern. For example, the device may select the other plurality of the two frequency bands 108 and 110 for transmission in accordance with a time shifted version of the frequency hopping pattern, namely TFC offset 1 (672 as in FIG. 6).

[0047] In one embodiment, if times are reserved for the other plurality of the two frequency sub-ranges of the frequency range in accordance with the time shifted version of the frequency hopping pattern, then the device reserves a different plurality of two frequency sub-ranges of the frequency range in accordance with a still larger time shifted version of the frequency hopping pattern. For example, if times are reserved for the other plurality of the two frequency bands 108 and 110 of the frequency band group 680 in accordance with the time shifted version of the frequency hopping pattern, namely TFC offset 1, the device may reserve a different plurality of two frequency bands, such as bands 107 and 109 in accordance with a still larger time shifted version of the frequency hopping pattern, namely TFC offset 2 673 (FIG. 6).

[0048] Similarly, if times are reserved for the plurality of the two frequency bands 107 and 109 of the frequency band group 680 in accordance with the larger time shifted version of the

frequency hopping pattern, namely TFC offset 2, the device may reserve a different plurality of two frequency bands, such as bands 104 and 106 in accordance with an even still larger time shifted version of the frequency hopping pattern, namely TFC offset 3 674 (FIG. 6).

[0049] In the following, two options for selecting a plurality of two frequency sub-ranges for transmission in accordance with a frequency hopping pattern are proposed catering to the use of slotted offset TFCs with scheme proposed in [5].

[0050] In one embodiment, a device in the ad-hoc radio communication devices' group may select or reserve a plurality of two frequency sub-ranges of the frequency range for transmitting a plurality of two OFDM symbols. In one embodiment, the device selects or reserves the plurality of the two frequency sub-ranges in accordance with a random time shifted version of the frequency hopping pattern, or a prior fixed time shift of the frequency hopping pattern at every OFDM symbol transmission duration during a fixed time slot. In one embodiment, the fixed time slot is a beacon slot or a MAS. For example, a beacon may be transmitted by a device in a beacon slot using a default TFC offset, say TFC offset 0, or using a randomly chosen TFC offset. For another example, a beacon transmitted during a BP by a device may select or reserve a default TFC offset, such as TFC offset 0 (671 as in FIG. 6), to

transmit data during a data period. In another embodiment, a beacon transmitted during a BP by a device may select or reserve a random TFC offset, such as TFC offset 0 (671) or TFC offset 1 (672), or TFC offset 2 (673), or TFC offset 3 (674 as in FIG. 6), to transmit data during a data period.

[0051] The following embodiment is illustrated under the ECMA standard. The DRP is used in the ECMA standard. According to the embodiment, a device always tries to search or reserve MASSs where transmissions and receptions can happen using a default TFC offset (i.e. TFC offset 0 (671), FIG. 6) in accordance with a frequency hopping pattern such as the frequency hopping pattern of channel 2 (given in FIG. 2). If adequate bandwidth is not available (all the MASSs are reserved for the data period), then the device may try to reserve MASSs for transmissions and reception using the next higher TFC offset of the channel in accordance with a time shifted version of the frequency hopping pattern of the default TFC offset. For example, a device always reserves MASSs pertaining to TFC offset 0 (671) as shown in FIG. 6, when it requires bandwidth. If all the MASSs are reserved for TFC offset 0, then the device may try to reserve MASSs for higher TFC offsets of the channel such as TFC offset 1 (672) or TFC offset 2 (673) or TFC offset 3 (674) as shown in FIG. 6 in the same band group 680. The device should ensure that all the MASSs are occupied for the default TFC offset (i.e. TFC offset 0

(671)) before reserving MASs for another TFC offset such as TFC offset 1 (672) or TFC offset 2 (673) or TFC offset 3 (674). In one embodiment, if a device has only one RF chain, the device may ensure that the MASs reserved pertaining to a particular TFC offset be not the same as those reserved pertaining to any lower TFC offset. In one embodiment, the device should ensure that all the MASs are occupied for all lower offsets of TFC before reserving MASs for a particular TFC offset such as TFC offset 1 (672) or TFC offset 2 (673) or TFC offset 3 (674). In one embodiment, if the device has only one RF chain, when the device holds reservations for some MASs pertaining to a particular TFC offset and intends to reserve more MASs using any higher TFC offset(s) of the channel in the same band group 680, the device may ensure that the MASs to be reserved for the higher TFC offset(s) be not the same as the MASs reserved for that particular TFC offset.

[0052] In another embodiment, a device in the ad-hoc radio communication devices' group may select or reserve a plurality of two frequency sub-ranges in accordance with a time shifted version of the frequency hopping pattern, the plurality of two frequency sub-ranges being different from a plurality of two frequency sub-ranges that have been reserved or selected by another device in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern in

the ad-hoc radio communication devices' group. When a device in the ad-hoc radio communication devices' group senses that during a time period (i.e. MASs), a plurality of two frequency sub-ranges of the frequency range or a TFC offset for transmission in accordance with the frequency hopping pattern are reserved or occupied, the device may select or reserve a different plurality of two frequency sub-ranges from the frequency range or a higher TFC offset that has not been selected or occupied for transmission of OFDM symbols. This embodiment is also illustrated under the ECMA standard.

[0053] For example, a device seeking reservation of bandwidth always tries to reserve or use the already reserved time slots (MASs) by using an unused TFC offset of the channel. In case time slot 301 is reserved in accordance with TFC offset 0 (671), then the device may seek to reserve the reserved time slot 301 using an unused TFC offset such as TFC offset 1 (672), or TFC offset 2 (673), or TFC offset 3 (674). If the reserved MASs are unavailable for the device for any TFC offset of the channel, then the device seeks to reserve MASs other than the ones already reserved.

[0054] In one embodiment, every communication device may always reserve MASs pertaining to the least possible and available offset should it require bandwidth, and if all the MASs are

reserved for a given offset, then only should the device try to reserve MASSs for a higher offset in the same channel.

[0055] In one embodiment, when the times are reserved or selected within the default plurality of two frequency sub-ranges of the frequency range for transmission according to the frequency hopping pattern, the device selects another plurality of two frequency sub-ranges for transmission.

[0056] In one embodiment, if a device that wants to transmit a plurality of OFDM symbols in the ad-hoc radio communication devices' group senses that all the frequency sub-ranges are already reserved or used in accordance with the frequency hopping pattern and all the time shifts of the frequency hopping pattern, the device will select a plurality of two frequency sub-ranges in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern that will be first released from being used to transmit the plurality of OFDM symbols in accordance with the frequency hopping pattern or the time shifted version of the frequency hopping pattern. In one embodiment, a counter clock is applied to the frequency hopping pattern and to each time shifted version of the frequency hopping pattern, and upon the release of a plurality of two frequency sub-ranges from being used in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern, the counter clock corresponding to

the frequency hopping pattern or that time shifted version of the frequency hopping pattern starts being decremented from a predetermined value, wherein when the counter clock reaches zero, the device starts to transmit the OFDM symbols at the plurality of the two frequency sub-ranges in accordance with the frequency hopping pattern or the time shifted version of that frequency hopping pattern.

[0057] The embodiment is also illustrated in the ECMA standard. PCA is used in the ECMA standard to provide differentiated distributed contention access to the medium for a device for transmission. As an illustration of the embodiment, four independent and parallel implementations of the existing PCA back off module and protocol (as specified by the ECMA specification) are proposed to be used in parallel for use of the slotted offsets of a TFC with different starting frequency sub-ranges using PCA.

[0058] For example, when a device has a data packet to send using the PCA, the device tries to send the packet using the default TFC offset (TFC offset 0 (671)) as shown in FIG. 6 in a MAS. When a device senses the TFC offset 0 of the channel busy, the device invokes a back off mechanism similar to that used by the PCA in the ECMA specification. The back off counter is frozen as long as the TFC offset 0 remains in use or busy, and the back off counter is decremented when the TFC offset 0 of the

channel is sensed idle. In one embodiment, the use of one back off counter is provided for each TFC offset of the channel (four independent modules each similar to that used by PCA in the ECMA specification). When a device has packet to send and senses all the TFC offsets of the channel busy, the device invokes a back off counter for every TFC offset. The back off counter for a TFC offset is frozen as long as the TFC offset remains in use or busy, and the back off counter is decremented when the TFC offset of the channel is sensed idle. When any of the four back off counters reaches zero, the packet is transmitted using the TFC offset corresponding to the back off counter that reaches zero. Hence, the packet is transmitted as soon as one of the back off counters corresponding to the four TFC offsets of the channel reaches zero. It should be noted that the delay in accessing one of the TFC offsets by a packet is lower as compared to the case when only a default channel (with no TFC offsets) is used. It has to be noted that if two devices transmit Request To Send (RTS) frames in overlapping time interval, a third device with only one antenna and one RF chain may receive only one of the two RTS frames. However, if a device has already obtained a transmission opportunity (or TXOP) using PCA in one of the TFC offsets, then after the completion of transmission of the corresponding RTS from the corresponding owner of the above transmission opportunity any other device may

obtain another transmission opportunity (or TXOP) using PCA in another TFC offset that overlaps with the first (former) transmission opportunity. Hence, even if each device in a network uses only one RF chain, the proposed scheme is an improvement over the PCA scheme given in current ECMA specification as far as every device in the network is concerned. However, if a device has multiple RF chains, then the device may be able to receive multiple simultaneous RTS transmissions. In one embodiment a device maintains a Network Allocation Vector (NAV) (as given in ECMA specification) for every offset of TFC. In the event that a device chooses to send a RTS frame in an offset of TFC, the device shall ensure that the duration field included in the RTS frame is less than the least of its non zero NAVs or least of its non zero NAVs minus RTS frame transmission time. The above resolves a deafness related issue. In one embodiment, a device may not start the transmission of a RTS frame (for at least one RTS frame transmission duration) in a particular TFC offset even if it had obtained a TXOP in that offset if the device senses that in the immediately preceding past time interval of duration RTS frame transmission time plus SIFS, medium in another TFC offset had become busy after the medium in that other TFC offset having stayed idle for AIFS or longer.

[0059] In one embodiment, a method for transmitting OFDM symbols by a plurality of ad-hoc radio communication devices in an ad-hoc radio communication devices' group is provided, the method comprising: a first ad-hoc radio communication device of the ad-hoc radio communication devices' group reserving a transmission time period for the transmission of a first plurality of two OFDM symbols in a first plurality of two frequency sub-ranges of a frequency range selected for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges; in the same transmission time period, a second ad-hoc radio communication device of the ad-hoc radio communication devices' group reserving the transmission of a second plurality of two OFDM symbols in a second plurality of two frequency sub-ranges of the frequency range, wherein the second plurality of two frequency sub-ranges has no overlap with the first plurality of the two frequency sub-ranges. In one embodiment, the frequency hopping pattern is with reference to a fixed time. In one embodiment, the fixed time is the start of a beacon slot or the start of a MAS. In one embodiment, the second ad-hoc radio communication device reserves the same transmission time period for the transmission of the second plurality of the two OFDM symbols in accordance with a time shifted version of the frequency hopping pattern.

[0060] In one embodiment, two options for transmitting beacons can be carried out. Devices may always choose the default channel with no offset for transmitting beacons, such as TFC offset 0 (671) in FIG. 6. Alternatively, if devices carry multiple RF chains, any device may randomly pick an offset to send its beacon, such as TFC offset 0 (671) or TFC offset 1 (672), or TFC offset 2 (673), or TFC offset 4 (674). Note that in the first option mentioned above, the number of devices that can be supported is limited to the number of available beacon slots (as is the case in current ECMA specification). However, with latter option, the number of devices that can be supported can be up to a maximum of four times the number of available beacon slots. Moreover, with this latter option, beacon collisions may also be reduced since with lower probability will any two devices send beacons with the same offset in the same beacon slot compared to the case where only one default channel without offset is available to the device while transmitting beacons.

[0061] Also under this option, the usage of TFC offsets, such as TFC offset 0 (671), TFC offset 1 (672), TFC offset 2 (673) and TFC offset 3 (674) shown in FIG. 6, may require the OSTDs of devices to be aligned and synchronized to each other to clock period level. A device may be required to align the transmission of an OFDM symbol at only the beginning of any OSTD.

[0062] FIG. 8 illustrates an ad-hoc radio communication device 800 according to one embodiment of the invention. In one embodiment, the device 800 may comprise a selector 801, and a transmitter 802.

[0063] In one embodiment, the selector 801 is configured to select a first plurality of two frequency sub-ranges of a frequency range for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges.

[0064] In one embodiment, the transmitter 802 is configured to transmit a plurality of two OFDM symbols in the selected plurality of the two frequency sub-ranges in accordance with the frequency hopping pattern.

[0065] In one embodiment, the selector 801 is configured to select the first plurality of the two frequency sub-ranges of the frequency range for transmission such that the device transmits the plurality of the two OFDM symbols at a same transmission time period with another ad-hoc radio communication device that is within the same ad-hoc communication devices' group, wherein the other device uses a second plurality of two frequency sub-ranges of the frequency range for transmission, and wherein the first plurality of the two frequency sub-ranges has no overlap with the second plurality of the two frequency sub-ranges.

[0066] In one embodiment, the frequency hopping pattern is with reference to a fixed time. In one embodiment, the fixed time is the start of a beacon slot or the start of a MAS. In one embodiment, the other device uses the second plurality of the two frequency sub-ranges of the frequency range for transmission in accordance with a time shifted version of the frequency hopping pattern. In one embodiment, the device uses the first plurality of the two frequency sub-ranges of the frequency range for transmission in accordance with a time shifted version of the frequency hopping pattern. In one embodiment, the frequency range is a frequency band group, and the frequency sub-range is a frequency band within the frequency band group. In one embodiment, the frequency band group comprises eight frequency bands. In one embodiment, the frequency hopping pattern is a Time-Frequency Code (TFC).

[0067] In one embodiment, the ad-hoc radio communication device further comprises a synchronization circuit 803, wherein the synchronization circuit 803 is configured to synchronize the device with other devices within the ad-hoc radio communication devices' group.

[0068] In one embodiment, in each frequency sub-range, the transmitter 802 is configured to transmit an OFDM symbol such that the OSTD of an OFDM symbol transmission follows an OSTD of another OFDM symbol transmission with no time interval between

them. In one embodiment, an OSTD includes OFDM symbol transmission time and OFDM frequency sub-range switching time.

[0069] In one embodiment, in each frequency sub-range, the transmitter 802 is configured to transmit an OFDM symbol such that the OSTD of an OFDM symbol transmission follows an OSTD of another OFDM symbol transmission with a fixed guard time interval between them.

[0070] In one embodiment, the selector 801 is configured to reserve or use a default plurality of two frequency sub-ranges of the frequency range for transmission in accordance with the frequency hopping pattern. In one embodiment, the frequency hopping pattern is with reference to a fixed time. In one embodiment, when the times are reserved or selected within the default plurality of the two frequency sub-ranges in accordance to the frequency hopping pattern, the selector 801 is configured to select another plurality of two frequency sub-ranges in accordance with a time shifted version of the frequency hopping pattern for transmission. In one embodiment, when the times are reserved or selected within the other plurality of the two frequency sub-ranges in accordance to the time shifted version of the frequency hopping pattern, the selector 801 is configured to select another plurality of two frequency sub-ranges in accordance with a still larger time shifted version of the frequency hopping pattern for transmission. In one embodiment,

the selector 801 is configured to select a plurality of two frequency sub-ranges of the frequency range in accordance with a random time shifted version of the frequency hopping pattern, or a prior fixed time shift of the frequency hopping pattern at every OFDM symbol transmission duration during a fixed time slot for transmitting OFDM symbol. In one embodiment, the fixed time slot is a beacon slot or a MAS. If the fixed time slot is a beacon slot, the selector 801 can be configured to select a plurality of two frequency sub-ranges of the frequency range in accordance with a random time shifted version of the frequency hopping pattern if all devices in the network have multiple RF chains. In one embodiment, the selector 801 is configured to select a plurality of two frequency sub-ranges in accordance with a time shifted version of the frequency hopping pattern, the plurality of the two frequency sub-ranges being different from a plurality of two frequency sub-ranges that has been reserved or selected by another device in the ad-hoc radio communication devices' group in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern. In one embodiment, if all the frequency sub-ranges are already reserved or used, the selector 801 is configured to select a plurality of two frequency sub-ranges in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern that will be first

released from being used in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern for transmitting two OFDM symbols.

[0071] In one embodiment, the ad-hoc radio communication device further comprises a counter clock 804 applied to the frequency hopping pattern and to each time shifted version of the frequency hopping pattern, wherein upon the release of a plurality of two frequency sub-ranges from being used in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern, the counter clock 804 corresponding to the frequency hopping pattern or that time shifted version of the frequency hopping pattern starts being decremented from a predetermined value, and when the counter clock reaches zero, the device starts to transmit the two OFDM symbols at the plurality of the two frequency sub-ranges in accordance with that frequency hopping pattern or that time shifted version of the frequency hopping pattern.

[0072] The method of transmitting OFDM symbols using Slotted Offset Dual Carrier Time Frequency Codes (SO-DC-TFCs) is developed based on the basic slotted offset concept given in [4] to cater to a system that employs DC-TFCs to transmit OFDM symbols over UWB channel.

[0073] The SO-DC-TFCs can result in increase of the network throughput by up to four times for a particular beacon group in

comparison with just using a default channel alone. Note that offsets for other channels (3rd channel and above as given in FIG. 2) can be derived in a similar manner as we have derived for channel 2.

[0074] To generalize, given different number of hopping bands with different hopping patterns, the above method for transmitting OFDM symbols using DC-TFCs can be generalized in such a way that the number of offsets be commensurate to the number of hopping bands and corresponding hopping pattern. In addition, the method for transmitting OFDM symbols using DC-TFCs is not limited to UWB system. It can be applied to other wireless communications systems as well.

[0075] To cater to the proposed SO-DC-TFCs scheme, some changes are required in a few information elements (IEs) as specified in the ECMA specification as follows:

[0076] DRP IE: Bits b13 and b14 that are currently reserved in the DRP Control field in the DRP IE are proposed to indicate the TFC offset of the channel as shown in FIG. 9. Table 901 illustrates the DRP IE. Table 902 shows the DRP control field of table 901. Table 903 shows bits b13 and b14 of the DRP Control field, which are used to indicate the TFC offset of the channel.

[0077] PCA Availability IE: The two reserved bits (b2-b1) of the Interpretation field of the PCA Availability IE are proposed to indicate the TFC offset of the channel. We propose that

additional PCA Availability IEs be sent if PCA availability for additional offsets of a TFC is required. Table 1001 shows the PCA Availability IE. Table 1002 shows the Interpretation field of table 1001. Table 1003 shows the use of two reserved bits b2-b1 of table 1002, which are used to indicate the TFC offset of channel. In one embodiment, additional PCA Availability IEs may be sent if PCA availability for additional offsets of a TFC is required.

[0078] Relinquish Request IE: Two reserved bits (b5-b4) of the Relinquish Request Control field are proposed to indicate the TFC offset of the channel. In FIG. 11, table 1101 shows the Relinquish Request IE. Table 1102 shows the Relinquish Request Control field of table 1101 in more detail. Table 1103 shows the reserved bits b5-b4 of table 1102, which are used to indicate the TFC offset of the channel.

[0079] MAC Capabilities IE: One of the reserved bits (b1) in octet 1 in the current MAC Capabilities IE as given in the ECMA standard is proposed to be used to indicate the capability of the device to transmit in TFC offsets of the channel. In FIG. 12, table 1201 shows the MAC Capabilities IE. Table 1202 shows the MAC Capability Bitmap of table 1201 in more detail, wherein b1 in Octet 1 is used to indicate the capability of the device to transmit in TFC offsets of the channel.

[0080] PHY Capabilities IE: One of the reserved octets are proposed to be used for TFC Offset Control. In this TFC Offset Control field, one of the bits is used to indicate the capability of a device to transmit in TFC offsets of the channel as shown in FIG. 13. Table 1301 shows PHY Capabilities IE. Table 1302 shows the TFC Offset Control field of table 1301 in more detail, wherein b1 is used to indicate the capability of a device to transmit in TFC offsets of the channel.

[0081] Enhanced DRP Availability IE: A new IE is proposed to be added to indicate a device's view of the current utilization of MASs in the current superframe (catering to the use of TFC offsets of the channel) as shown in FIG. 14. Table 1401 shows the newly proposed IE. Table 1402 shows the Interpretation field of table 1401 in more detail. Table 1403 shows b1-b0 of the Interpretation field of table 1402 in more detail.

[0082] It should be noted that the proposed Enhanced DRP Availability IE 1401 may be used in replacement of the existing DRP Availability IE (in current ECMA specification) catered for C-WPAN related specification(s). We propose that additional Enhanced DRP Availability IEs be sent if DRP availability for additional offsets of a TFC is required. Alternatively, the proposed Enhanced DRP Availability IE may be used as an add-on new IE in order to keep the backward compatibility with current ECMA specified devices. In such a case, the Enhanced DRP

Availability IE may be sent thrice or more contiguously immediately after the original DRP Availability IE is sent wherein the original DRP Availability IE may advertise the available MASSs for offset 0 and the following Enhanced DRP Availability IEs may advertise the available MASSs for the other offsets.

[0083] Dynamic Registers: Two of the reserved bits of PHY Control register as in current ECMA specification are proposed to be used for TFC Offset Control as shown in FIG. 15 to indicate the number of TFC offset.

[0084] In order to facilitate transmission of OFDM symbols at exactly each OSTD, a synchronization method may be used using virtual clock concept to achieve finer synchronization between devices at clock period level, so that OSTDs of devices are synchronized and do not overlap much to cause interference. The synchronization method proposed in [6] with a few suggested modifications will be described in more detail below.

[0085] Refer to FIG. 4. Assume devices A 411 and D 414 (slower than A 411) have entered or joined a same beacon group. Let P_{clk} be the hardware clock (current ECMA PHY clock is 528 MHz). As shown in Fig. 16, let B_A 1601 be the BPST of device A 411, B_D 1602 be the BPST of device D 414 from A 411's perspective, C_A 1603 be the clock period of A 411 (Assume A 411's clock period to be $1/P_{clk}$; assume A 411's clock to be of 528 MHz), and C_D be

the clock period of D 414 from A 411's perspective. Let the beacon slot of D 414 as seen by A 411 be n_1 , a known quantity. Let $m = T_{bp} \times P_{clk}$ be the number of clock cycles for a beacon slot duration, where T_{bp} is the time duration of each beacon slot. For current ECMA specified devices, $T_{bp} = 85 \mu s$ and $P_{clk} = 528 \text{ MHz}$. Hence $m = 85 \times 528$. In every beacon slot as seen by a device, the same device's physical clock counts m cycles. Let Y_{1610} be the actual reception time of the beacon of D 414 at A 411 (discounting propagation time), Z_{1611} be the estimated reception time of D 414's beacon at A 411.

[0086] Assume that no device moves its BPST at the end of the current (first) superframe (superframe N 1620). In the next superframe (superframe N+1 1621), the devices A 411 and D 414 do not move their BPST's. Let Y'_{1612} and Z'_{1613} be respectively the actual and estimated reception times of D 414's beacon at A 411 in superframe N+1 1621. Let n_2 be the Beacon Slot Number of beacon of D 414 in superframe N+1 1621. Let $p = T_{sf} \times P_{clk}$ be the number of clock cycles for a superframe duration, where T_{sf} is the time duration of one superframe. For current ECMA specified devices, $T_{sf} = 65536 \mu s$, hence $p = 65536 \times 528$. In every superframe the same device's physical clock counts p cycles. Note that P_{clk} can be selected differently depending on individual

implementations. For example, P_{clk} may also be selected based on 264 or 66 MHz clock. In such a case, $m=85 \times 264$ and $p=65536 \times 264$ or $m=85 \times 66$ and $p=65536 \times 66$ respectively and the proposed synchronization algorithm herein can be extended to such cases as well.

[0087] Now, Y 1610, Z 1611, Y' 1612, and Z' 1613 are known at device A 411 with respect to a fixed reference time (could be the BPST of A 411, B_A 1601). From the following four relations,

$$\textbf{[0088]} \quad Z = B_A + (n_1 - 1)C_A m \quad (1)$$

$$\textbf{[0089]} \quad Y = B_D + (n_1 - 1)C_D m \quad (2)$$

$$\textbf{[0090]} \quad Z' = B_A + pC_A + (n_2 - 1)C_A m \quad (3)$$

$$\textbf{[0091]} \quad Y' = B_D + pC_D + (n_2 - 1)C_D m \quad (4)$$

$$\textbf{[0092]} \quad \text{where } m = T_{bp} \times P_{clk} = 85 \times 528, \quad p = T_{sf} \times P_{clk} = 65536 \times 528$$

[0093] the estimates of B_D 1602 and C_D can be obtained in two superframes:

$$\textbf{[0094]} \quad C_D = (Y' - Y) / (p + m(n_2 - n_1)) \quad (5)$$

$$\textbf{[0095]} \quad B_D = Y - (n_1 - 1)C_D m = Y - (n_1 - 1)(Y' - Y)m / (p + m(n_2 - n_1)) \quad (6)$$

[0096] In the third superframe, the device A 411 may align its BPST to device D 414's BPST (which it knows through the knowledge of $B_D + 2pC_D$ and the fixed reference time) and reset its virtual clock count to zero. Let P_A be the number of physical clock cycles of A 411 during the superframe duration of D 414

(known to A 411) when P_D is the number of physical clock cycles of D 414 in that same superframe duration of D 414. It can be seen that $P_D = p = 65536 \times 528$.

[0097] If the device A 411 maintains a count of virtual clock cycles from the third superframe in such a way that its count of virtual clock cycles are obtained from the count of its physical clock cycles by subtracting one clock cycle from the count of its physical clock cycles every floor $\lfloor P_A / (P_A - P_D) \rfloor$ or Round $\lceil P_A / (P_A - P_D) \rceil$ of its physical clock cycles, the virtual clock of A 411 will be synchronized to the physical clock of D 414 to one clock period level.

[0098] In the above, the function floor $\lfloor x \rfloor$ denotes the largest integer value not greater than the value 'x', and Round $\lceil x \rceil$ denotes the nearest integer value to 'x'.

[0099] If $P_A - P_D = 0$, then the virtual clock is set to be the same as the physical clock. As seen above, only the first two superframes are needed for estimating clock periods and establishing the virtual clocks.

[00100] In one embodiment, device A 411 estimates the BPST and clock period of device D 414 at least once every fixed number of superframes which can be 16 or 32 superframes for example, and resynchronizes with device D 414.

[00101] Two examples are given to illustrate the above proposed schemes.

[00102] Example 1

[00103] Given $n_1=n_2=n=5$ and $P_{clk}=528$ MHz, $C_A=1/528$ μ s, Y is measured as 342.595 μ s and Y' is measured as 65882.595 μ s, then using equation (5), C_D can be estimated as 1.89405 ns and using equation (6), B_D can be estimated as 2.5752 μ s. In the superframe duration of D 414 ($=pC_D$), A 411's clock counts, $pC_D/C_A \sim 34605028$ cycles. However, D 414's clock still counts $p = 65536 \times 528 = 34603008$ cycles. A 411's virtual clock is got from subtracting 1 clock cycle from every 17131 (which is $=34605028/(34605028-34603008)$) physical clock cycles of A 411.

[00104] Example 2

[00105] Given $n_1=n_2=n=5$ and $P_{clk}=66$ MHz, $C_A=1/66$ μ s, Y is measured as 342.595 μ s and Y' is measured as 65882.595 μ s, then using equation (5), C_D can be estimated as 15.152 ns and using equation (6), B_D can be estimated as 2.584 μ s. In the superframe duration of D 414 ($=pC_D$), A 411's clock counts, $pC_D/C_A \sim 4325514$ cycles. However, D 414's clock still counts $p = 65536 \times 66 = 4325376$ cycles. A 411's virtual clock is got from subtracting 1 clock cycle from every 31344 (which is $\sim 4325514/(4325514-4325376)$) physical clock cycles of A 411.

[00106] The flow diagram of the synchronization scheme is given in FIG. 17.

[00107] In FIG. 17, P is the number of physical clock cycles of a device during the duration of a superframe of slowest device, Q ($Q = 65536 \times 528$) is the number of physical clock cycles of the slowest device in the same duration of the superframe of slowest device. Firstly in process 1701, a device joins a beacon group or the device's neighbor joins a beacon group. Then in process 1702, the device determines the start times of all neighbor devices' beacons for two consecutive superframes. The device would be faster than a neighbor if its physical clock counts more than Q ($= 65536 \times 528$) cycles in the superframe of its neighbor. If the device determines that it is the slowest device in the beacon group, in process 1704, the device sets the virtual clock to be same as the device's physical clock. If the device determines that it is not the slowest device in the beacon group, in process 1705, the device determines the variables P , Q , and floor $[P/(P-Q)]$ or round $[P/(P-Q)]$ with reference to the slowest device. Following process 1705, in process 1706, the device sets up a virtual clock from the third superframe and starts synchronizing to the slowest device at clock period level by updating the virtual clock.

[00108] As mentioned above, the introduced synchronization method may achieve finer synchronization between devices at clock period level, so that OSTDs of devices are synchronized and do not overlap much to cause interference.

[00109] In one embodiment, several additional new logical channels are proposed to be added based on DC-TFCs to the existing channels that have already been proposed to C-WPAN working group in order to allow for more orthogonal channels.

[00110] FIG. 18 shows a table illustrating proposed logical channels.

[00111] FIG. 19 shows a table illustrating proposed logical channels pertaining to backward compatibility with ECMA devices.

[00112] In one embodiment, all 2-combinations of bands in the available 8 higher bands (bands 3-10 (103-110) shown in FIG. 1) may be used without any hopping. An example of one 2-combination is the use of bands 3 (103) and 4 (104) consistently all the time without hopping as illustrated in channel 1 of FIG. 19 (equivalent to Fixed Frequency Interleaving in ECMA specification). An example of another 2-combination is the use of bands 3 (103) and 5 (105) consistently all the time without hopping (channel 1 of FIG. 18). Note that there can be ${}^8C_2$ (=28) channels possible that use just two bands. Out of the above 28 channels alluded to above, channels that use two bands with one and only one vacant band between them may be given priority, such as channels 1-4 in FIG. 18. A few of the channels that use just two bands are given in FIG. 18 (channels 1-9). A few of the remaining channels that we propose are also given in FIG. 19 (channels 12-23), which are of different kinds of frequency

hopping patterns. For example, channel 23 of FIG. 18 has the frequency hopping pattern of (bands 4 104 and 6 106) to (bands 8 108 and 10 110) to (bands 7 107 and 9 109).

[00113] In a further embodiment, an additional 11 logical channels based on DC-TFCs may be used in addition to the existing channels that have already been proposed to C-WPAN working group in order to allow for compatibility between DC-TFCs based devices (that may be specified by C-WPAN) and ECMA specified devices. These hopping pattern are listed in FIG. 19 (assuming that in actual implementations the carrier frequencies may be offset by a particular value to move the center frequencies of the OFDM transmissions to align with the bands as specified in ECMA standard whenever a device that uses DC-TFCs needs to communicate with a ECMA specified device). Pertaining to FIG. 19, in view of the above, the carrier frequency of each band will need to be changed accordingly in line with the corresponding carrier frequency specified in the ECMA specification. For example, when two DC-TFCs based devices communicate with each other using the proposed channel 1 in FIG. 19, there is no need to align the bands 3 and 4 in alignment with any band as specified by ECMA specified devices. However, if a DC-TFCs based device needs to communicate with a ECMA specified device, then it may use bands 3 and 4 (as given in FIG. 1) offset by a factor of say 264 MHz (i.e., both bands

moved by a fixed value by changing the carrier frequency/center frequency) to communicate.

[00114] In one embodiment, any device that incorporates a transmission system based on DC-TFCs may periodically scan all the 11 channels given in FIG. 19 (with appropriate carrier and center frequencies that allow alignment of bands with bands specified in ECMA specification) to discover ECMA specified devices or beacons from ECMA specified devices. When a beacon from an ECMA specified device is discovered, a DC-TFCs based device may then join the beacon group of the discovered ECMA specified device.

[00115] In the various embodiments, a modification of a scheme proposed in [4] is proposed to cater to its use with DC-TFC based transmission. A new information element pertaining to the use of DRP with slotted offset TFCs is also proposed. In addition, an algorithm proposed in [6] with a modification to allow for any clock frequency at the physical layer pertaining to synchronization is summarized. Finally, few logical channels are proposed catering to DC-TFCs.

[00116] In one embodiment, a slotted offset DC-TFCs based scheme is provided, wherein the scheme uses offsets of DC-TFCs hopping pattern for any two devices in the same beacon group to communicate signals during a MAS slot, the method comprising: two devices in a beacon group communicate signals using one of

the specified DC-TFCs during a MAS slot within a superframe; any other two devices in the same beacon group communicate signals using an offset of the selected DC-TFCs during the same MAS slot within the same superframe should they wish to do so; another two devices in the same beacon group communicate signals using another offset of the selected DC-TFCs during the same MAS slot within the same superframe should they wish to do so and any remaining offsets may as well also be used by other pair or pairs of devices to communicate.

[00117] In one embodiment, possible changes to number of offsets can be incorporated to cater to any number of bands and any hopping pattern. In other words, given a hopping pattern over a number of bands, offsets can be derived pertaining to that hopping pattern.

[00118] In one embodiment, a synchronization scheme is provided, the scheme providing clock period level synchronization between devices, by use of a virtual clock (typically a register) in each device to maintain synchronization between devices. The virtual clock of every device is synchronized to the physical clock (crystal) of the slowest device. The beacon and data transmission by any device is based on its virtual clock and every device sends a beacon at the start of a beacon slot.

[00119] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

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4. Ananth Subramanian, Xiaoming Peng and Francois Chin, "Schemes for Achieving Higher Throughput in Network of ECMA Specified Devices, submitted for US provisional patent.
5. Bi Guo Guang et al, "Dual Carrier Orthogonal Frequency Division Multiplexing (DC-OFDM) for UWB Communication Systems," Chinese patent (patent no. 200510094890).
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Claims

What is claimed is:

1. A method for transmitting OFDM symbols by a plurality of ad-hoc radio communication devices in an ad-hoc radio communication devices' group, the method comprising:
 - a first ad-hoc radio communication device of the ad-hoc radio communication devices' group transmitting a first plurality of two OFDM symbols in a first plurality of two frequency sub-ranges of a frequency range selected for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges;
 - in the same transmission time period, a second ad-hoc radio communication device of the ad-hoc radio communication devices' group transmitting a second plurality of two OFDM symbols in a second plurality of two frequency sub-ranges of the frequency range, wherein the second plurality of frequency sub-ranges has no overlap with the first plurality of frequency sub-ranges.
2. The method of claim 1,
 - wherein the frequency hopping pattern is with reference to a fixed point in time.

3. The method of claim 2, wherein the fixed point in time is the start of a beacon slot or the start of a Medium Access Slot (MAS).
4. The method of claim 1, wherein the second ad-hoc radio communication device transmits the second plurality of two OFDM symbols in accordance with a time shifted version of the frequency hopping pattern.
5. The method of claim 1, further comprising:
in the same transmission time period, a third ad-hoc radio communication device of the ad-hoc radio communication devices' group transmitting a third plurality of two OFDM symbols in a third plurality of two frequency sub-ranges, wherein the third plurality of frequency sub-ranges has no overlap with the first and the second pluralities of frequency sub-ranges.
6. The method of claim 1, wherein the second ad-hoc radio communication device transmits the second plurality of two OFDM symbols in accordance with a time shifted version of the frequency hopping pattern, and in the same transmission time period, a third ad-hoc radio communication device of

the ad-hoc radio communication devices' group transmits a third plurality of two OFDM symbols in a third plurality of frequency sub-ranges of the frequency range, wherein the third plurality of frequency sub-ranges are different from the first and second pluralities of frequency sub-ranges, and wherein the third ad-hoc radio communication device transmits the third plurality of the two OFDM symbols in accordance with a still larger time shifted version of the frequency hopping pattern.

7. The method of claim 1,
wherein the frequency range is a frequency band group, and
the frequency sub-range is a frequency band within the
frequency band group.
8. The method according to claim 7,
wherein the frequency band group comprises at least eight
frequency bands.
9. The method according to claim 1,
wherein the frequency hopping pattern is a Time-Frequency
Code (TFC).
10. The method according to claim 1,

wherein the number of OFDM symbols that can be transmitted by the plurality of ad-hoc radio communication devices in the ad-hoc radio communication devices' group is limited to the number of frequency sub-ranges of the frequency range.

11. The method according to claim 1,
wherein the plurality of ad-hoc radio communication devices in the ad-hoc radio communication devices' group are synchronized.
12. The method according to claim 11, wherein in the frequency range, an OFDM Symbol Transmission Duration (OSTD) of a first OFDM symbol transmission is followed by an OSTD of a second OFDM symbol transmission with no time interval between them, and all the OSTDs within a fixed time period are contiguously aligned starting from a fixed reference point in the fixed time period.
13. The method according to claim 12, wherein the fixed time period is a beacon slot or a Medium Access Slot (MAS), and the fixed reference point is the start of the beacon slot or the start of the MAS.
14. The method according to claim 12,

wherein an OSTD includes OFDM symbol transmission time and OFDM frequency sub-range switching time.

15. The method according to claim 11, wherein in the frequency range, an OFDM Symbol Transmission Duration (OSTD) of a first OFDM symbol transmission is followed by an OSTD of a second OFDM symbol transmission with a fixed guard time interval between them, and all the OSTDs within a fixed time period are consecutively aligned with guard times embedded between every two OSTDs starting from a fixed reference point in the fixed time period.
16. The method according to claim 1,
wherein any device in the ad-hoc radio communication devices' group reserves or uses a default plurality of two frequency sub-ranges of the frequency range for transmission according to the frequency hopping pattern.
17. The method according to claim 16,
wherein when the times are reserved or selected within the default plurality of two frequency sub-ranges of the frequency range for transmission according to the frequency hopping pattern, the device selects another plurality of two frequency sub-ranges for transmission.

18. The method of claim 17, wherein the device selects the other plurality of the two frequency sub-ranges for transmission in accordance with a time shifted version of the frequency hopping pattern.
19. The method of claim 17,
wherein, if times are reserved for the other plurality of the two frequency sub-ranges of the frequency range in accordance with the time shifted version of the frequency hopping pattern, then the device reserves a different plurality of two frequency sub-ranges of the frequency range in accordance with a still larger time shifted version of the frequency hopping pattern.
20. The method of claim 1,
wherein a device in the ad-hoc radio communication devices' group selects or reserves a plurality of two frequency sub-ranges of the frequency range for transmitting a plurality of two OFDM symbols.
21. The method of claim 20, wherein the device selects or reserves the plurality of the two frequency sub-ranges in accordance with a random time shifted version of the

frequency hopping pattern, or a prior fixed time shift of the frequency hopping pattern at every OFDM symbol transmission duration during a fixed time slot.

22. The method of claim 21,
wherein the fixed time slot is a beacon slot or a Medium Access Slot.
23. The method of claim 1,
wherein a device in the ad-hoc radio communication devices' group selects or reserves a plurality of two frequency sub-ranges in accordance with a time shifted version of the frequency hopping pattern, the plurality of two frequency sub-ranges being different from a plurality of two frequency sub-ranges that has been selected or reserved by another device in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern in the ad-hoc radio communication devices' group.
24. The method of claim 1,
wherein if a device that wants to transmit a plurality of OFDM symbols in the ad-hoc radio communication devices' group senses that all the frequency sub-ranges are already reserved or used in accordance with the frequency hopping

pattern or all the time shifts of the frequency hopping pattern, the device will select a plurality of two frequency sub-ranges in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern that will be first released from being used to transmit the plurality of OFDM symbols in accordance with the frequency hopping pattern or the time shifted version of the frequency hopping pattern.

25. The method of claim 24, wherein a counter clock is applied to the frequency hopping pattern and to each time shifted version of the frequency hopping pattern, and wherein upon the release of a plurality of two frequency sub-ranges from being used in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern, the counter clock corresponding to the frequency hopping pattern or that time shifted version of the frequency hopping pattern starts being decremented from a predetermined value, and when the counter clock reaches zero, the device starts to transmit the OFDM symbols at the plurality of the two frequency sub-ranges in accordance with the frequency hopping pattern or the time shifted version of the frequency hopping pattern.

26. The method of any of claims 24-25, wherein the device maintains one Network Allocation Vector (NAV) for every time shifted version of the frequency hopping pattern and if the device should send a frame in a time shifted version of the frequency hopping pattern, the duration field in that frame is less than the least of its non zero NAVs or least of its non zero NAVs minus RTS frame transmission time.
27. A method for transmitting OFDM symbols by a plurality of ad-hoc radio communication devices in an ad-hoc radio communication devices' group, the method comprising:
a first ad-hoc radio communication device of the ad-hoc radio communication devices' group reserving a transmission time period for the transmission of a first plurality of two OFDM symbols in a first plurality of two frequency sub-ranges of a frequency range selected for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges;
in the same transmission time period, a second ad-hoc radio communication device of the ad-hoc radio communication devices' group reserving the transmission of a second plurality of two OFDM symbols in a second plurality of two

frequency sub-ranges of the frequency range, wherein the second plurality of two frequency sub-ranges has no overlap with the first plurality of the two frequency sub-ranges.

28. The method of claim 27, wherein the frequency hopping pattern is with reference to a fixed time.
29. The method of claim 28, wherein the fixed time is the start of a beacon slot or the start of a Medium Access Slot.
30. The method of claim 27, wherein the second ad-hoc radio communication device reserves the same transmission time period for the transmission of the second plurality of the two OFDM symbols in accordance with a time shifted version of the frequency hopping pattern.
31. The method of claim 27,
wherein the frequency range is a frequency band group and the frequency sub-range is a frequency band within the frequency band group.
32. The method according to claim 31,
wherein the frequency band group comprises at least eight frequency bands.

33. The method according to claim 27,
wherein the frequency hopping pattern is a Time-Frequency Code (TFC).
34. An ad-hoc radio communication device within an ad-hoc radio communication group for transmitting OFDM symbols,
comprising:
a selector configured to select a first plurality of two frequency sub-ranges of a frequency range for transmission in accordance with a frequency hopping pattern, the frequency range comprising a plurality of frequency sub-ranges;
a transmitter configured to transmit a plurality of two OFDM symbols in the selected plurality of the two frequency sub-ranges in accordance with the frequency hopping pattern;
wherein the selector is configured to select the first plurality of the two frequency sub-ranges of the frequency range for transmission such that the device transmits the plurality of the two OFDM symbols at a same transmission time period with another ad-hoc radio communication device that is within the same ad-hoc communication devices' group, wherein the other device uses a second plurality of

two frequency sub-ranges of the frequency range for transmission, and wherein the first plurality of the two frequency sub-ranges has no overlap with the second plurality of the two frequency sub-ranges.

35. The ad-hoc radio communication device according to claim 34, wherein the frequency hopping pattern is with reference to a fixed time.
36. The ad-hoc radio communication device according to claim 35, wherein the fixed time is the start of a beacon slot or the start of a Medium Access Slot (MAS).
37. The ad-hoc radio communication device according to claim 34, wherein the other device uses the second plurality of the two frequency sub-ranges of the frequency range for transmission in accordance with a time shifted version of the frequency hopping pattern.
38. The ad-hoc radio communication device according to claim 34,
wherein the frequency range is a frequency band group, and the frequency sub-range is a frequency band within the frequency band group.

39. The ad-hoc radio communication device according to claim 38, wherein the frequency band group comprises at least eight frequency bands.
40. The ad-hoc radio communication device according to claim 34 wherein the frequency hopping pattern is a Time-Frequency Code (TFC).
41. The ad-hoc radio communication device according to claim 34, further comprising a synchronization circuit, wherein the synchronization circuit is configured to synchronize the device with other devices within the ad-hoc radio communication devices' group.
42. The ad-hoc radio communication device according to claim 34, wherein in each frequency range, the transmitter is configured to transmit an OFDM symbol such that the OFDM Symbol Transmission Duration (OSTD) of an OFDM symbol transmission follows an OSTD of another OFDM symbol transmission with no time interval between them.

43. The ad-hoc radio communication device according to claim 42, wherein an OSTD includes OFDM symbol transmission time and OFDM frequency sub-range switching time.
44. The ad-hoc radio communication device according to any of the claims 34 and 38, wherein the selector is configured to reserve or use a default plurality of two frequency sub-ranges of the frequency range for transmission in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern.
45. The ad-hoc radio communication device according to claim 44, wherein the frequency hopping pattern is with reference to a fixed time.
46. The ad-hoc radio communication device according to claim 44, wherein when the times are reserved or selected within the default plurality of the two frequency sub-ranges in accordance to the frequency hopping pattern, the selector is configured to select another plurality of two frequency sub-ranges in accordance with a time shifted version of the frequency hopping pattern for transmission.

47. The ad-hoc radio communication device according to claim 46, wherein when the times are reserved or selected within the other plurality of the two frequency sub-ranges in accordance to the time shifted version of the frequency hopping pattern, the selector is configured to select another plurality of two frequency sub-ranges in accordance with a still larger time shifted version of the frequency hopping pattern for transmission.
48. The ad-hoc radio communication device according to claim 34, wherein the selector is configured to select a plurality of two frequency sub-ranges of the frequency range in accordance with a random time shifted version of the frequency hopping pattern, or a prior fixed time shift of the frequency hopping pattern at every OFDM symbol transmission duration during a fixed time slot for transmitting OFDM symbols.
49. The ad-hoc radio communication device according to claim 48, wherein the fixed time slot is a beacon slot or a Medium Access Slot.
50. The ad-hoc radio communication device according to claim 34, wherein the selector is configured to select a

plurality of two frequency sub-ranges in accordance with a time shifted version of the frequency hopping pattern, the plurality of the two frequency sub-ranges being different from a plurality of two frequency sub-ranges that has been reserved or selected by another device in the ad-hoc radio communication devices' group in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern.

51. The ad-hoc radio communication device according to claim 34, wherein if all the frequency sub-ranges are already reserved or used, the selector is configured to select a plurality of two frequency sub-ranges in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern that will be first released from being used in accordance with the frequency hopping pattern or the time shifted version of the frequency hopping pattern for transmitting two OFDM symbols.
52. The ad-hoc radio communication device according to claim 51, further comprising a counter clock applied to the frequency hopping pattern and to each time shifted version of the frequency hopping pattern, wherein upon the release of a plurality of two frequency sub-ranges from being used

in accordance with the frequency hopping pattern or a time shifted version of the frequency hopping pattern, the counter clock corresponding to the frequency hopping pattern or that time shifted version of the frequency hopping pattern starts being decremented from a predetermined value, and when the counter clock reaches zero, the device starts to transmit the two OFDM symbols at the plurality of the two frequency sub-ranges in accordance with that frequency hopping pattern or that time shifted version of the frequency hopping pattern.

53. The ad-hoc radio communication device according to claim 34, wherein in each frequency range, the transmitter is configured to transmit an OFDM symbol such that the OFDM Symbol Transmission Duration (OSTD) of an OFDM symbol transmission follows an OSTD of another OFDM symbol transmission with a fixed guard time interval between them.