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(54) **Title:** BAND-EFFICIENT METHOD AND SYSTEM FOR TRANSMITTING/RECEIVING A COMMUNICATION SIGNAL USING A CHANNEL BAND

FIG. 1
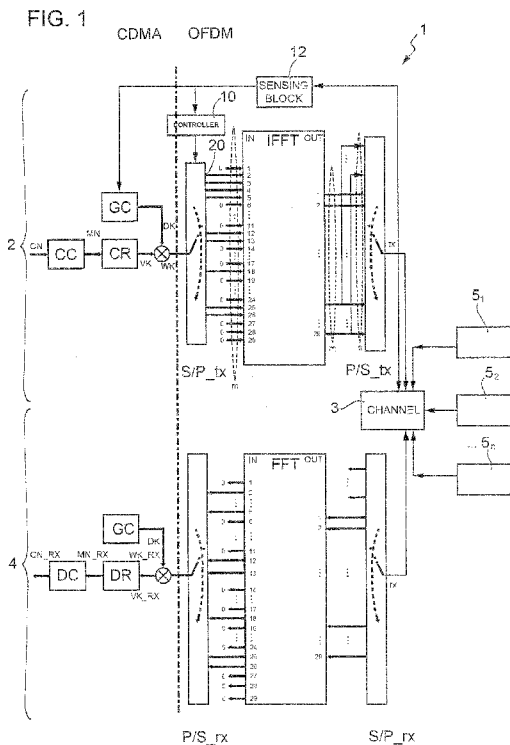
(57) **Abstract:** A method for transmitting a further signal on a channel having a transmission band including a plurality of used subbands occupied by transmission signals. According to the method, the presence of free subbands not occupied by the transmission signals is detected and the further signal is transmitted using the free subbands. According to the method, the further signal is multiplexed by using a CDMA code and transmitted on OFDM subcarriers having frequencies within the free subbands.

BAND-EFFICIENT METHOD AND SYSTEM FOR
TRANSMITTING/RECEIVING A COMMUNICATION SIGNAL
USING A CHANNEL BAND

5   FIELD OF THE INVENTION

The present invention relates to the field of the
telecommunication systems. More in particular, the
present invention relates to the methods and the systems
for efficiently transmitting/receiving a communication
10   signal using a channel band.

BACKGROUND OF THE INVENTION

In a telecommunication system user data are
converted into signals suited to be transmitted over a
15   channel, which may comprise a copper wire, an optical
fiber, a free space channel, etc. Depending on physical
characteristics, the channel has a frequency band, also
known as channel band, or band, in which signals can be
effectively transmitted.

20   Based on the channel and on the channel band,
signals, which usually are electromagnetic signals, are
generated so as to optimize the telecommunication system
throughput, that is the amount of data effectively
transmitted by all the users of the telecommunication
25   system. Of course, more than one telecommunication
system may access the channel.

The generation of the signals comprises two main
operations: a modulation operation, including mapping

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the user data on changes of physical quantities of the electromagnetic signal, such as a carrier phase, frequency and/or amplitude; a multiplexing operation, including sharing the channel band among independent
5   users, that is among their data flows.

Besides advanced modulation schemes, such as Phase Shift Keying (PSK), Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM), etc., several multiplexing
10   techniques have been proposed in order to maximise the channel band exploitation.

Generally, in known telecommunication systems, the band is not used in an efficient manner. In fact, each user of the telecommunication systems exploiting the
15   channel is statically given a portion of the band, hereinafter referred to as subband, centred around a subband central frequency, which is typically the frequency of a corresponding subcarrier. The subband is used just when the user effectively transmits data,
20   being unused when the user is silent. In such a way, the occupation, meant as effective utilization, of each subband and, consequently, of the overall band, depends on the behaviour of the users. Since not all the users transmit all the time, partial inactivity periods occur,
25   leading to a low spectral efficiency, meant as the ratio between an amplitude of a range of frequencies carrying information and the overall channel bandwidth, because each subband is dedicated to a single user and cannot be

shared among different users.

Users may belong to different telecommunication systems, exploiting different modulation and/or multiplexing techniques. Generally, each telecommunication system accessing the channel makes use of a predetermined portion of the channel band. In any case, from a practical point of view, the less the users transmit, the lower is the overall spectral efficiency.

Furthermore, from a temporal point of view, the channel band is composed by a set of used subbands, occupied by signals emitted by users effectively transmitting, alternated with free frequency gaps, corresponding to subbands dedicated to users not transmitting. Of course, since user behaviour (to transmit or not) varies in time, the band occupation varies accordingly.

Besides spectral inefficiency, such a band occupation provides for high costs for those users who need to transmit just in a short time range. In fact, generally users have to pay for their subbands, irrespective of the effective time of use.

As an example, institutional organizations, such as Rescue Team or Fire Brigade, are badly affected by such a kind of band allocation, since they have to pay for a dedicated subband which, in practice, is used just for a small amount of time, that is when emergencies occur. These emergencies being rare, the dedicated subband stays unused nearly all the time.

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Besides these commercial aspects, from a technical point of view the spectral efficiency is further reduced by the necessity of keeping as low as possible the interference between adjacent subbands. In fact, since the spectrum of the signals transmitted in the subbands is not limited in frequency, each signal spectrum has queues extending beyond the frequency boundaries of the respective subband, thus interfering with signals transmitted in adjacent subbands. In order to keep interferences under control, guard bands are introduced between adjacent subbands. From a practical point of view, these guard bands comprise unused portions of the band, that is free frequency gaps alternating with the subbands used by the users of the telecommunication systems accessing the channel.

In such a way, the interference is reduced, because just the reduced parts of the spectrum queues overlap with other transmitted signals. Unfortunately, the overall band occupation is reduced, entailing a further spectral efficiency reduction.

This being the typical band occupation of a physical channel, the signals sent within the subbands may be modulated and multiplexed in several known manners. Furthermore, signals in different subbands are generally managed by different telecommunication systems, exploiting different modulations and multiplexing techniques. In particular, one of the most important multiplexing techniques is Orthogonal

Frequency Division Multiplexing (OFDM).

In an OFDM system the overall channel band available to the system itself is divided into a large number of subcarriers closely-spaced in frequency and arranged within the channel band so as to be orthogonal to each other. Each subcarrier corresponds to a respective subband and is modulated with a conventional modulation scheme (PSK, QAM, etc.) at a low bit rate, maintaining data rates similar to those of a conventional single-carrier modulation scheme operating in the same subband.

From a practical point of view, OFDM signals are generated and received by using the Fast Fourier Transform (FFT) algorithm.

The OFDM technique makes a transmission more resilient with respect to harsh channel conditions, such as high frequency attenuation in a long copper wire, narrowband interferences, frequency-selective fading due to multipath, etc., without the need for complex signal processing techniques, such as channel equalization. For example, in ODFM systems, the channel equalization may be accomplished in a simplified manner, because the OFDM signal may be regarded as a number of slowly-modulated narrowband signals, rather than one rapidly-modulated wideband signal.

OBJECT AND SUMMARY OF THE INVENTION

The aim of the present invention is to solve at least in part the drawbacks of the prior art.

According to the invention, a method and a system for transmitting/receiving a communication signal using a channel band are provided, according to claim 1 and, respectively, claim 13.

5   DESCRIPTION OF THE FIGURES

For the understanding of the present invention, a preferred embodiment is now described, purely as a non-limitative example, with reference to the enclosed drawings, wherein:

10   -   Figure 1 shows a block scheme of an OFDM transceiver;

      -    Figure 2 shows an illustrative scheme of a band occupation;

      -    Figure 3 shows an illustrative example of an

15   efficient band occupation;

      -    Figures 4, 5 and 6 show the band occupation of Fig. 2 in subsequent steps of the present method.

          DETAILED DESCRIPTION OF THE INVENTION

20   Figure 1 shows an OFDM telecommunication system 1, comprising a transmitting part 2 and a receiving part 4, connected to a channel 3. The channel 3 is shared with existing telecommunication systems 5_1, 5_2, …, 5_n. The OFDM telecommunication system 1 and the existing telecommunication systems 5_1, 5_2, …, 5_n are wireless

25   (such as WiMAX or satellite), or wired.

The illustrated OFDM telecommunication system 1 makes use of a Code Division Multiple Access (CDMA)

technique. Accordingly, the transmitting part 2 comprises a modulator CC which receives a data stream CN, formed by signals issued by source and channel coding blocks (not shown in Figure 1) known to the man

5   skilled in the art. The modulator CC may be a BPSK modulator, a QPSK modulator, a 8-PSK modulator, or any known modulator, and, in a per se known manner, outputs a modulated symbol stream MN formed by a plurality of symbols, a symbol being the smallest amount of data

10 transmitted together by the OFDM telecommunication system 1. The modulated symbol stream MN is inputted to a repetition coder CR, which generates a repeated symbol stream VK wherein each input symbol of the modulated input stream MN is repeated a number of times equal to

15 the length L of a CDMA code DK. Therefore, for each input symbol of the modulated input stream MN the repetition coder CR generates a corresponding sequence of L samples, all of them equal to the input symbol. The time duration of each sequence corresponding to a single

20 input symbol is equal to the time duration of the input symbol itself, that is the L samples, hereinafter referred to as chips, have a time duration L times shorter than the time duration of an input symbol. Equivalently, the chips have a frequency L times greater

25 than the input symbol frequency.

The repeated symbol stream VK outputted by the repetition coder CR is further multiplied by the CDMA code DK, that is a code having a length of L chips,

generated in a per se known manner by a spreader GC at a frequency equal to the frequency of the chips, and made up of a sequence of ±1. This multiplication is known as "spreading" and characterizes the CDMA technique,

5   allowing to obtain a spread sequence WK having a power spectral density in a band which is L time larger than the band of the signal object of the spreading, that is the modulated symbol stream MN. Because of the content of the CDMA code DK, that is the ±1 chips, the spread

10   sequence WK has the same power as the modulated symbol stream MN and a band which is L times larger than the band of the modulated symbol stream MN, thus its power spectral density is L times lower than the power spectral density of the modulated symbol stream MN.

15   The spread sequence WK is sent to a serial to parallel converter S/P_tx having two input ports and a number n_out of output ports, equal to the number of OFDM subcarriers employed by the OFDM telecommunication system 1. As explained in more detail hereinafter, the

20   chips of the spread sequence WK inputted to the serial to parallel converter S/P_tx are outputted on just n (with $n \leq n\_out$) output ports (shown in Figure1) of the serial to parallel converter S/P_tx itself, which parallelizes the spread sequence WK into so-called OFDM

25   symbols, that is groups of n chips. From an operative point of view, one input port of the serial to parallel converter S/P_tx is connected to a controller 10, in turn connected to a sensing block 12, as discussed in

more detail later on. The n output ports of the serial to parallel converter S/P_tx are connected to n input ports of an Inverse Fast Fourier Transform block IFFT, having m input ports in total, with $m \geq n$. The m-n ports of the Inverse Fast Fourier Transform block IFFT not connected to the n output ports of the serial to parallel converter S/P_tx are fed with zeros.

The Inverse Fast Fourier Transform block IFFT performs an Inverse Fast Fourier transform of the OFDM symbol, outputting m IFFT output samples on the m output ports of the Inverse Fast Fourier Transform block IFFT.

According to the OFDM technique, each input port of the Inverse Fast Fourier Transform block IFFT corresponds to a subcarrier of the OFDM telecommunication system 1; therefore, when an output port (e.g., output port 20) of the serial to parallel converter S/P_tx is connected to an input port of the Inverse Fast Fourier Transform block IFFT, the symbols coming out from output port 20 are transmitted using the subcarrier associated with the connected input port of the Inverse Fast Fourier Transform block IFFT.

The Inverse Fast Fourier Transform block IFFT is connected to a parallel to serial converter P/S_tx, having s input ports and one output port, with s greater than m. In practice, the m output ports of the Inverse Fast Fourier Transform block IFFT are connected to the last m input ports of the parallel to serial converter P/S_tx, whereas the first s-m input ports of the

parallel to serial converter P/S_TX are fed with copies
of the last $s-m$ IFFT output samples, so as to preserve
the intelligibility of the OFDM symbol. The $s-m$ copies
of the last $s-m$ IFFT output samples form a so-called
5   guard interval.

The output of the parallel to serial converter
P/S_tx is connected to the channel 3, eventually by
means of a proper transmitter, such as an antenna, an
optical source or the like (not shown in Figure 1).

10   On the receiving part 4 of the OFDM
telecommunication system 1, operations inverse to those
done at the transmitting part 2 are performed. In
particular, incoming signals are firstly parallelized by
a serial to parallel converter S/P_rx, so as to
15   reproduce the OFDM symbols and, at the same time, remove
the guard intervals. Afterwards, the OFDM symbols
undergo a Fast Fourier Transform operation, performed by
a Fast Fourier Transform block FFT. In particular the
Fast Fourier Transform block FFT outputs a set of chips
20   which, after the removal of the zeros inserted in
transmission, are serialized by a parallel to serial
converter P/S_rx, outputting a sequence WK_RX. The
serialized chips of the sequence WK_RX are multiplied by
the CDMA code DK, this operation being known as
25   "despreading", and the sequence VK_RX so obtained is
inputted to a repetition decoder DR, which integrates L
chips of the sequence VK_RX so as to get a replica MN_RX
of the original modulated input stream MN. Finally, a

constellation decoder DC demodulates the replica MN_RX to recover the data stream CN.

In order to understand the present method, please refer to Figure 2, showing an illustrative example of a band occupation of the channel 3 at a given time instant t0. In particular, B1, B2 and B3 represent used subbands, that is subbands dedicated to users of the telecommunication systems 5_1, 5_2, …, 5_n accessing the channel 3 at the time instant t0, therefore effectively transmitting at the time instant t0. The telecommunication systems 5_1, 5_2, …, 5_n manage the communications of their users exploiting any modulation and multiplexing techniques. G1-G4 are free subbands, that is both guard bands and dedicated subbands assigned to users of telecommunication systems 5_1, 5_2, …, 5_n not transmitting at the considered time instant t0, these dedicated subbands assigned to telecommunication systems 5_1, 5_2, …, 5_n not transmitting in the considered time instant becoming used subbands at time instants at which their respective users transmit. It is clear that the definitions "free subbands" and "used subbands" are referred to a given time instant, the dedicated subbands assigned to users not transmitting in the considered time instant having to be considered as free subbands.

In order to efficiently exploit the available band, it is important to rationally occupy all the subbands, making use also of the free subbands, which, in known telecommunication systems, stay unused.

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Furthermore, a full band exploitation has to be accomplished without affecting signals transmitted in the used subbands, that is the signals transmitted in the dedicated subbands by the telecommunication systems

5   accessing the channel 3 at the time instant t0. It has to be noted that signals in the used subbands can be transmitted by exploiting whatever modulation and/or multiplexing technique. For the present method, used subbands are simply subbands not available for

10 transmission.

Figure 3 shows how it is possible to achieve a full exploitation of the free subbands. In particular, given a physical channel 3 having its predetermined subband allocation scheme, meant as predetermined number

15 of telecommunication systems 5_1, 5_2, …, 5_n accessing the channel 3 and corresponding assignment of the dedicated subbands, let's suppose that a further signal, not provided at the time instant t0 and having a band *Bsignal*, is to be transmitted later, at a time instant

20 t1. The further signal can be transmitted and received by dividing its band *Bsignal* into a suitable number of parts such as to fill the free subbands, transmitting it, and then reconstructing it, simply by reconstructing its spectrum, as explained in more detail below.

25 For the sake of simplicity, the following description refers to the case of just one further signal, but the present method can be directly extended to the case of more further signals. The transmission of

the further signal is obtained by exploiting the OFDM technique, which provides for a subdivision of the overall band of the physical channel 3 into subbands whose subcarrier central frequencies are orthogonal to each other. In fact, given a period Ts, equal to the time duration of each symbol transmitted in a OFDM system, the subcarriers of a OFDM system have frequencies multiple of a fundamental frequency equal to the inverse of the period Ts. Because of trigonometric properties, integrating any two subcarriers over a period Ts leads to zero.

Orthogonal subcarriers are independent one another and can be turned on or off independently, therefore it is possible to decide whether to use specific subcarriers, according to the user needs. Consequently, when using a OFDM technique, a signal occupying a certain band $Bsignal$ does not have to be transmitted over a single subband whose amplitude is equal to the signal bandwidth, but it can be transmitted over non-adjacent subbands, provided that the overall used bandwidth is equal to the width of the band $Bsignal$.

More in detail, the transmission of the further signal in the free subbands is accomplished by the OFDM telecommunication system 1 shown in Figure 1. In particular, the sensing block 12 detects the n free subcarriers and generates corresponding signals fed to the controller 10. The sensing block 12 also calculates the available free band length, that is the sum of the

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free subband lengths, and provides it to the spreader GC, which uses the available free band width to determine the length L of the CDMA code DK.

The controller 10 causes the spread sequence WK to
5   be sent to the n output ports of the serial to parallel converter S/P_tx and onto the inputs of the Inverse Fast Fourier Transform block IFFT corresponding to free subcarriers. The inputs of the Inverse Fast Fourier Transform block IFFT corresponding to the used
10   subcarriers, as well as any $m-n$ input ports of Inverse Fast Fourier Transform block IFFT are fed with zeros.

The described relationships between the serial to parallel converter S/P_tx, the Inverse Fast Fourier Transform block IFFT and the subcarriers of the OFDM
15   telecommunication system 1 allow to transmit the further signal in the free subbands. The input ports of the Inverse Fast Fourier Transform block IFFT connected to zeros indicate that the corresponding subcarriers are not used for transmission by the OFDM telecommunication
20   system 1, because they correspond to used subbands, that is dedicated subbands in use by the users of the telecommunication systems 5_1, 5_2, …, 5_n effectively transmitting. More in detail, the illustrative representation of the OFDM telecommunication system 1 in
25   Figure 1 refers to the band occupation illustrated in Figure 4, which shows the band occupation at a time instant t0, analogously to Figure 2, as well as the arrangement of the OFDM subcarriers in the subbands. The

correspondence between subcarriers and input ports of
the Inverse Fast Fourier Transform block IFFT shown in
Figure 1 may be appreciated considering the known
frequency shift characterizing the Inverse Fast Fourier
5   transform and the addition, with respect to the
subcarrier arrangement shown in Figure 4, of four
lateral subcarriers, that is two lateral subcarriers per
side of the channel band, set to zero. In Figure 4, the
subcarriers used by the OFDM telecommunication system 1
10   are shown by arrows, while the unused subcarriers are
shown by crosses. It is important to note that in the
OFDM telecommunication system 1 the subdivision of the
overall band in subbands is accomplished independently
from the effective band occupation, thus prior to any
15   sensing of the channel 3. When the OFDM
telecommunication system 1 receives a request of
transmission of a further signal, it senses all the
subcarriers so as to detect the guard bands and the
subcarriers unused by the telecommunication systems 5_1,
20   5_2, …, 5_n. Afterwards, the OFDM telecommunication system
1 turns on all the subcarriers corresponding to the free
subbands.

In known OFDM systems, subcarriers are turned on
and off in case the channel is selective in frequency:
25   signals are transmitted just over subbands with low
losses, so as to preserve the transmission quality,
turning off subcarriers experiencing a high degradation
along the channel.

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According to the present method, the further signal is transmitted using the free subbands, that is in free frequency ranges, so as not to overlap it with other already established communications exploiting the dedicated subbands, therefore transmitting the further signal transparently to the users of the telecommunication systems 5_1, 5_2, …, 5_n; in fact, the dedicated subbands used by the users of the telecommunication systems 5_1, 5_2, …, 5_n are unchanged, so the users do not experience any communication degradation.

The described method may be easily implemented on a terminal capable of sensing the channel 3 by using known means and techniques, so as to determine the subcarrier frequency, as well as if the subcarriers are in use or not, irrespective of whether free subcarriers correspond to dedicated subbands assigned to users silent in the considered instant, or to guard bands.

For example, assuming that, as shown in Figure 4, the overall band is virtually divided into 25 OFDM subcarriers, it is possible to transmit a further signal by using the subcarriers n. 1, 8, 9, 14, 15, 16, 17, 24 and 25, that is the subcarriers corresponding to the G1, G2, G3 and G4 free subbands, and turning off the other subcarriers.

Since the guard bands and the originally unused dedicated subbands are now used by the OFDM telecommunication system 1 to carry the further signal,

the interference, due to the overlapping between the
queues of the further signal spectrum and the spectra of
the signals transmitted by the telecommunication systems
5_1, 5_2, …, 5_n, is no more mitigated by free frequency

5   gaps. In order to overcome this problem, the data stream
corresponding to the further signal is managed according
to the CDMA technique.

As said before, according to this technique, the
further signal data stream is multiplied with a CDMA

10   code made up of a sequence of ±1, this code length being
equal to L. By performing this operation, the power
spectral density of the further signal is spread over a
band which is L times larger than the further signal
original bandwidth, that is the band strictly necessary

15   to transmit the further signal. Since the CDMA code
contribution to a power spectral density is unitary, the
further signal power is unchanged and, consequently, its
power spectral density is reduced by L times.

Therefore, the transmission of the further signal

20   causes an interference with the communications of the
telecommunication systems 5_1, 5_2, …, 5_n, but this
interference is in the order of the thermal noise, thus
not damaging significantly the users of the
telecommunication systems 5_1, 5_2, …, 5_n. In any case,

25   possible transmission errors can be managed in known
manners (e.g. by means of Forward Error Correction
codes).

As apparent from the above description, the CDMA

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technique helps keep as low as possible the interference induced by the further signal transmitted in the free subbands on the signals transmitted by the telecommunication systems 5_1, 5_2, …, 5_n according to the subband allocation scheme of the channel 3.

Furthermore, the CDMA technique helps limit the interference that signals transmitted by the users of the telecommunication systems 5_1, 5_2, …, 5_n according to the subband allocation scheme induce on the further signal transmitted in the free subbands. In fact, in reception, in order to recover the further signal, another multiplication with the same CDMA code used in transmission is accomplished. This operation reduces the band of the received signal to the original band *Bsignal* of the further signal, and spreads all the interfering signals, because these latter signals experience just one multiplication with the CDMA code, which reduces their impact on the further signal to a level in the order of the thermal noise.

Besides these advantages in terms of resilience to the interference, by employing the CDMA technique and the OFDM technique, it is possible to practically implement the division of the band *Bsignal* of the further signal into the free subbands, as well as to manage more than one further signal. In fact, the presence of more than one further signal is managed simply by assigning different CDMA codes to different signals, corresponding to different users of the OFDM

telecommunication system 1. In reception, the multiplication with the same CDMA codes allows to understand which user is associated with the received further signal.

Concerning the division of the band of the further signal, in order to spread the further signal Band *Bsignal* over all the free subbands, the transmitting part 2 calculates a length L of the CDMA code, as a function of the overall free band (sum of all the free subbands) and the band *Bsignal* of the further signal. Then, the assignment of the further signal to each free subcarrier is accomplished by the OFDM technique, by connecting the outputs of the serial to parallel converter S/P_tx to all the input ports of the Inverse Fast Fourier Transform block IFFT corresponding to the free subcarriers.

From a practical point of view, the present method dynamically controls, instant by instant, the subcarriers turned on or off, that is the subbands used or not by the telecommunication systems 5_1, 5_2, …, 5_n. In fact, in real telecommunication systems users initiate and conclude transmissions, respectively setting free or occupying their dedicated subbands. Furthermore, the transmission of the further signal occurs in a finite time, thus leading to continuous changes in the band occupation. In both cases the present method tracks the changes in the subband allocation scheme. Thanks to the ease of controlling the subcarriers (turned on or off)

within an OFDM system, the present method provides for adapting to the instant band occupation. Of course, this result may be achieved provided that both the transmitter and the receiver can be configured while in use; for example, they could be Software Radio terminals.

The present method can be implemented by CDMA over OFDM terminals capable of sensing the channel 3 not only before setting up the transmission, but also during the transmission itself, so as to promptly respond to changes in the use of the subbands. Figure 5 shows an illustrative example of the band occupation in a time instant t2>t1, and shows, if compared with Figure 4, the time evolution of the band occupation, supposing that the user who, at the time instant t0, was transmitting in the dedicated subband B2 has concluded the transmission at the time instant t2. The subcarriers overlapping with the dedicated subband B2, that is subcarriers n. 10, 11, 12 and 13, can be turned on to transmit the further signal.

On the contrary, let's assume that in a time instant t3 the user to whom the G3 band (please refer to Figure 4 and Figure 6) is dedicated, previously silent, decides to start a communication. In such a situation, the OFDM telecommunication system 1 realizes that the G3 subband is no more available for transmission, therefore it turns off the subcarriers n. 14, 15, 16 and 17, overlapping with the G3 subband, and modifies the length

L of the CDMA code, so as to transmit the further signal using the available subcarriers n. 1, 8, 9, 24, 25. This leads to the overall band occupation shown in Figure 6, wherein B4 indicates the former subband G3. Alternatively, instead of modifying the length of the CDMA code, the OFDM telecommunication system 1 may reduce the number of users who can transmit at the same time, as explained in more detail below. In any case, before the turning off of the subcarriers corresponding to the B4 subband, there is a small amount of time during which the further signal and the signals transmitted by the telecommunication systems 5_1, 5_2, …, 5_n coexist within the same subband B4. That occurs because the OFDM telecommunication system 1 reacts to changes in the band occupation in a finite time. In any case, the CDMA technique, which enlarges the bandwidth of the further signal, guarantees good transmission performances, because the interference is in the order of the thermal noise.

On reception, the receiving part 4 of the OFDM telecommunication system 1 implementing the present method reconstructs the band *Bsignal* of the further signal based on the symbols carried by the subcarriers used on the transmitting part 2 to transmit the further signal itself. In order to understand which subcarriers effectively carry information associated with the further signal, the receiving part 4, like the transmitting part 2, periodically senses the channel 3

so as to understand the used subbands and the free
subbands. For example, referring to Figure 4, showing
the band occupation at the time instant t0, the
receiving part realizes that the subcarriers n. 1, 8, 9,
14, 15, 16, 17, 24 and 25 correspond to free subbands.
Assuming that the transmission of the further signal
over the channel 3 starts at the time instant t1, and
assuming that the time required for a signal to pass
through the channel 3 is negligible, at the time instant
t1 the receiving part 4 realizes that the subcarriers
n. 1, 8, 9, 14, 15, 16, 17, 24 and 25, free at the time
instant t0, are occupied at the time instant t1,
therefore the receiving part 4 understands that the
further signal is being transmitted on the subcarriers
n. 1, 8, 9, 14, 15, 16, 17, 24 and 25. From a practical
point of view, the receiving part 4 reconstructs the
further signal based on the information (symbols)
carried by the subcarriers detected as free at the time
instant t0. The receiving part 4 keeps track of the
subcarriers detected as free at the time instant t0
until a next sensing of the channel 3, e.g. performed at
a time instant t4. The receiving part 4 senses the
channel 3 and keeps track of the subcarriers detected by
means of known techniques, implemented by known blocks
not shown in Figure 1.

From an operative point of view, it has to be noted
that, when the telecommunication systems 5_1, 5_2, …, 5_n
not using the subbands effectively begin to transmit

data, and thus begin to effectively use their dedicated subbands, the present method has less subcarriers available, because of the turning off of the subcarriers corresponding to said dedicated subbands. Nevertheless, according to the present method, the users of OFDM telecommunication system 1 do not reduce their throughput: they can keep constant their transmission bit-rates, as far as these bit-rates are low with respect to the maximum bit-rate permitted to each user of the OFDM telecommunication system 1, this maximum bit-rate being equal to $1/T_u$, where T_u is the OFDM symbol time. For example, transmission bit-rates may be in the range 30 Kb/s – 300 Kb/s.

In fact, when dedicated subbands are turned on by the users of the telecommunication systems 5_1, 5_2, …, 5_n, the number of users of the OFDM telecommunication system 1 is reduced, but the throughput of the users effectively transmitting stays unchanged.

More in detail, assuming that B is the overall band available and N is the number of the OFDM subcarriers, each subcarrier has a corresponding subband equal to B/N. Furthermore, if a certain band W is shared by N_U users communicating with a CDMA technique employing a code whose length is equal to L, each user is given a useful band whose bandwidth is equal to $W/(L*N_U)$. According to the present method, each user of the OFDM telecommunication system 1 avails of a band equal to $B/(N*L*N_U)$. Therefore, if the number N of subcarriers

decreases, it is still possible to keep constant the band accorded to each user by dynamically varying either the CDMA code length L, as previously described, or the number N_U of users who can transmit at the same time (that is the number of further signals which can be transmitted at the same time), allowing to keep constant the transmission quality for the users transmitting.

Therefore, the present system and method allow to increase the exploitation of the band of a channel 3, transparently to the users having dedicated subbands. Given an existing channel 3 having a band shared among a plurality of existing telecommunication systems 5_1, 5_2, …, 5_n, it is possible to manage more communications, thus providing more services, without affecting the pre-existing communications. More in particular, it is no more necessary to assign dedicated subbands to users rarely transmitting: when users intend to transmit, the present technique allows to use previously unused subbands, transparently to said users and to the users of the telecommunication systems 5_1, 5_2, …, 5_n.

Furthermore, the present technique allows to manage a particular situation which, in real wireless systems, is likely to occur. In particular, in case a user having his dedicated subband needs more bandwidth to transmit, it is no more necessary to rearrange all the subband allocation scheme to assign to the user one or more subbands adjacent to his dedicated subband. By using the present method, the user is given an additional subband,

even not adjacent to his dedicated subband. The same happens in case the user requiring more bandwidth does not use an existing telecommunication system 5_1, 5_2, …, 5_n.

5   Finally, it is clear that numerous variations and modifications may be made to the system and method described and illustrated herein, all falling within the scope of the invention as defined in the attached claims.

10   In particular, even if the OFDM telecommunication system 1 has been described in terms of hardware components, all the described functionalities may be implemented by software modules.

In addition, the allocation of the further signal
15   on the available free subbands may be different from the described one. For example, the further signal may be allocated onto one or more free subbands, depending on the bandwidth of the further signal and the bandwidth of the free subbands, so as to minimize the number of used
20   free subbands. In the alternative, any other spreading algorithm may be used, intermediate between a complete spreading of the one or more further signals onto all the free subbands described above and the minimum subband allocation.

25   Furthermore, the method may use as free subbands only the guard bands, even if in this case the efficiency is lowered.

CLAIMS

1.   A method for transmitting a further signal on a channel having a transmission band comprising a plurality of used subbands occupied by transmission

5   signals, characterized by:

- detecting the presence of free subbands not occupied by said transmission signals; and

- transmitting the further signal using the free subbands.

10   2.   A method according to claim 1, wherein, at each time instant, the transmission band comprises dedicated subbands assigned to external systems and guard bands, said used subbands comprising dedicated subbands used by said external systems at said time instant and said

15   free subbands comprising guard bands and/or dedicated subbands not used by said external systems at said time instant.

3.   A method according to claim 1 or 2, wherein the further signal is transmitted on OFDM subcarriers having

20   frequencies within the free subbands.

4.   A method according to claim 3, wherein the further signal is multiplexed by using a CDMA code.

5.   A method according to claim 4, wherein the further signal has a signal band, comprising spreading the

25   signal band over all the free subbands by controlling the length L of the CDMA code.

6.   A method according to claim 4, wherein the further signal has a signal band, comprising allocating the

signal band in a subset of the free subbands.

7. A method according to claim 5 or 6, comprising detecting a plurality of further signals, wherein each further signal is multiplied by a respective CDMA code.

8. A method according to claim 7, further comprising the varying the length L of the CDMA codes, thereby spreading the further signal on the free subbands.

9. A method according to claim 7, further comprising the steps of detecting variations in the number of the free subbands and varying the numbers of further signals which are transmitted at a same time.

10. A method according to any of the preceding claims, comprising repeating the steps of detecting the presence of free subbands and transmitting the further signal and any further signal using the free subbands.

11. A method for receiving a further signal transmitted on a channel using the method according to any of claims 1-10, characterized by:

- detecting first subbands which are free on the transmission channel at a first time instant;

- detecting if the first subbands are occupied at a second time instant;

- if at the second time instant the first subbands are occupied, extracting a received signal from the first subbands.

12. A method for receiving according to claim 11, comprising repeating the steps of detecting first subbands, detecting if the first subbands are occupied

and extracting.

13. A transmission system for transmitting a further signal on a channel having a transmission band comprising a plurality of used subbands occupied by

5   transmission signals, characterized by:

-      means for detecting the presence of free subbands not occupied by said transmission signals; and

-      means for transmitting the further signal using the free subbands.

10   14. A transmission system according to claim 13, comprising means for transmitting the further signal on OFDM subcarriers having frequencies within the free subbands.

15. A transmission system according to claim 13 or 14,

15   further comprising a CDMA coder multiplexing the further signal using a CDMA code.

16. A transmission system according to claim 15, comprising means for calculating an available free band from said free subbands, wherein the further signal has

20   a signal band, and the CDMA coder spreads the signal band over said available free band by controlling the length L of the CDMA code.

17. A transmission system according to claim 15, comprising means for calculating an available free band

25   from said free subbands, wherein the further signal has a signal band, and the CDMA coder spreads the signal band over a portion of said available free band.

18. A transmission system according to any of claims

13-17, comprising a receiving part including means for detecting the presence of said free subbands in a first time instant, means for detecting the presence of said free subbands in a second time instant, and means for

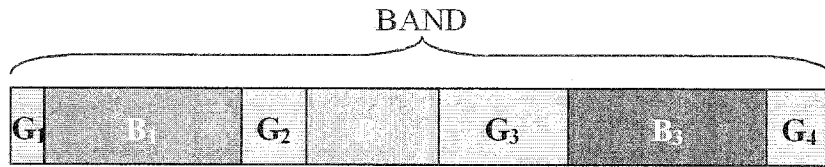5   detecting the transmission of said further signal from a comparison of free subbands detected in the first and in the second time instant.

FIG. 1

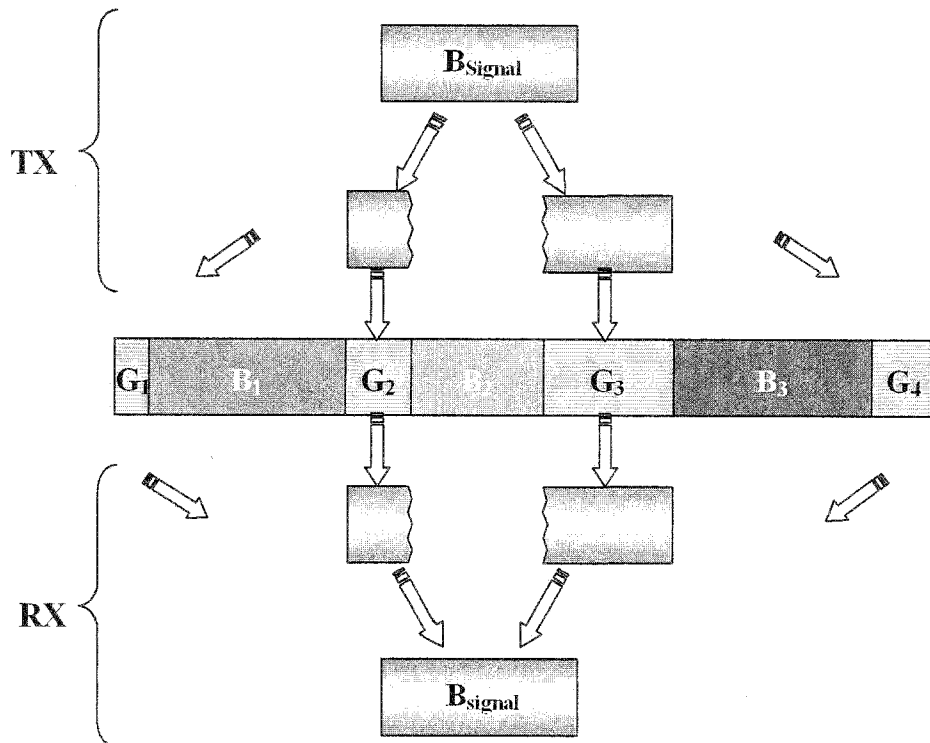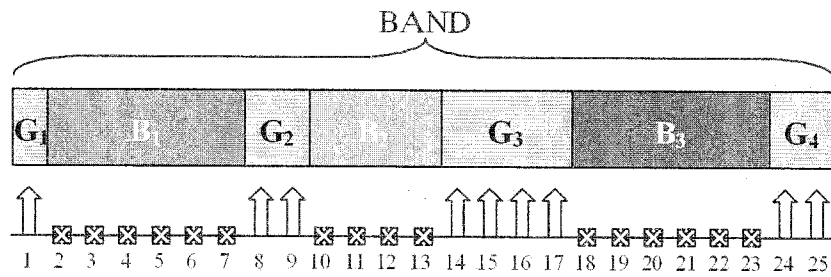CDMA   OFDM
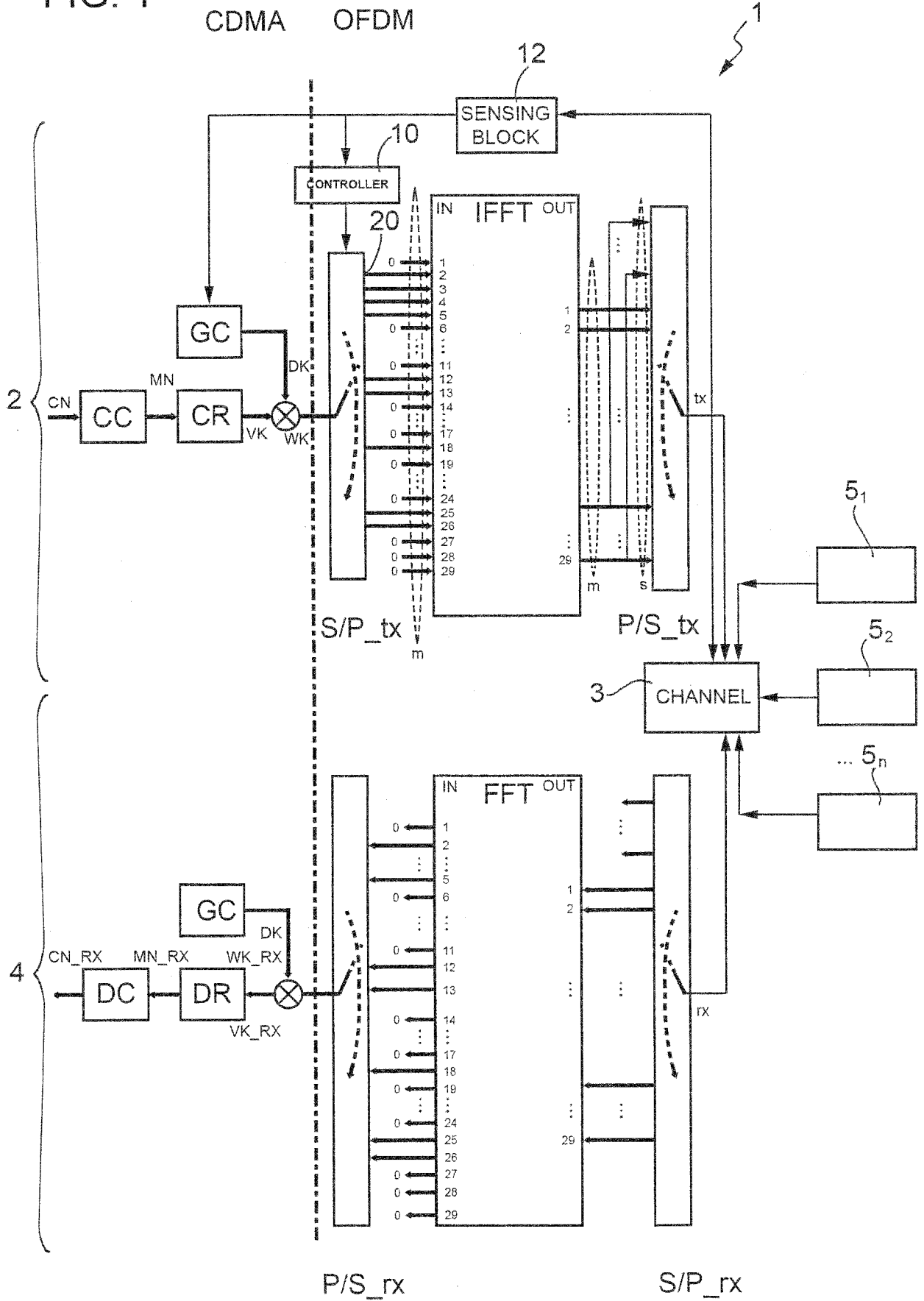
Fig. 2

Fig. 3

Fig. 4
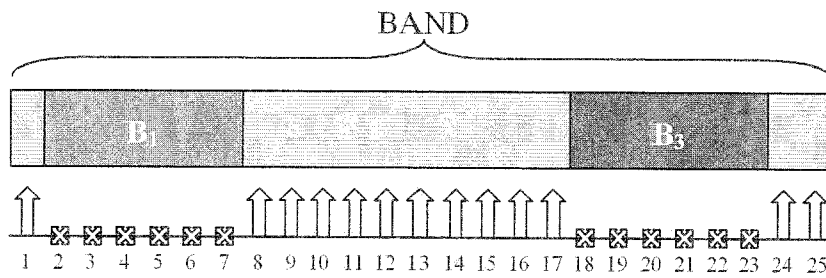
Fig. 5
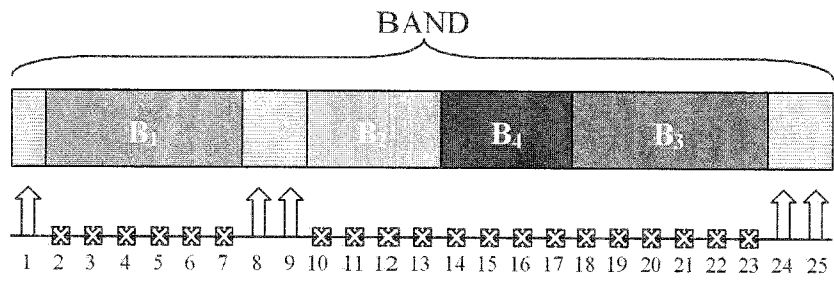
Fig. 6

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L27/26 H04L5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	RUILIANG CHEN ET AL: "Ensuring Trustworthy Spectrum Sensing in Cognitive Radio Networks" NETWORKING TECHNOLOGIES FOR SOFTWARE DEFINED RADIO NETWORKS, 2006. SDR '06.1ST IEEE WORKSHOP ON, IEEE, PI, 1 September 2006 (2006-09-01), pages 110-119, XP031124517 ISBN: 978-1-4244-0733-0 * I. Introduction * -/--	1-18

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

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 December 2008	17/12/2008

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Belloni, Paolo

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
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X	LEI CHEN ET AL: "An Adaptive Cooperative Spectrum Sensing Scheme Based on the Optimal Data Fusion Rule" WIRELESS COMMUNICATION SYSTEMS, 2007. ISWCS 2007. 4TH INTERNATIONAL SYMPOSIUM ON, IEEE, PISCATAWAY, NJ, USA, 1 October 2007 (2007-10-01), pages 582-586, XP031166836 ISBN: 978-1-4244-0978-5 * I. Introduction *	1-18
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X	WO 2007/052995 A (KOREA ELECTRONICS TELECOMM [KR]; HWANG SUNG-HYUN [KR]; SONG MYUNG-SUN) 10 May 2007 (2007-05-10) * Background Art *	1-18
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INTERNATIONAL SEARCH REPORT

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SHENG-YUAN TU ET AL: "Spectrum Sensing of OFDMA Systems for Cognitive Radios" IEEE INTERNATIONAL SYMPOSIUM ON PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS. PIMRC, IEEE; PI, XX, 1 September 2007 (2007-09-01), pages 1-5, XP031168658 ISBN: 978-1-4244-1143-6 the whole document	1-18
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A	WO 2007/056020 A (THOMSON LICENSING [FR]; LIU HANG [US]; GAO WEN [US]) 18 May 2007 (2007-05-18) the whole document	1-18

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PCT/EP2008/051761

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