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(54) **POSITION ADJUSTED GUARD TIME
INTERVAL FOR OFDM-COMMUNICATIONS
SYSTEM**

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See application file for complete search history.

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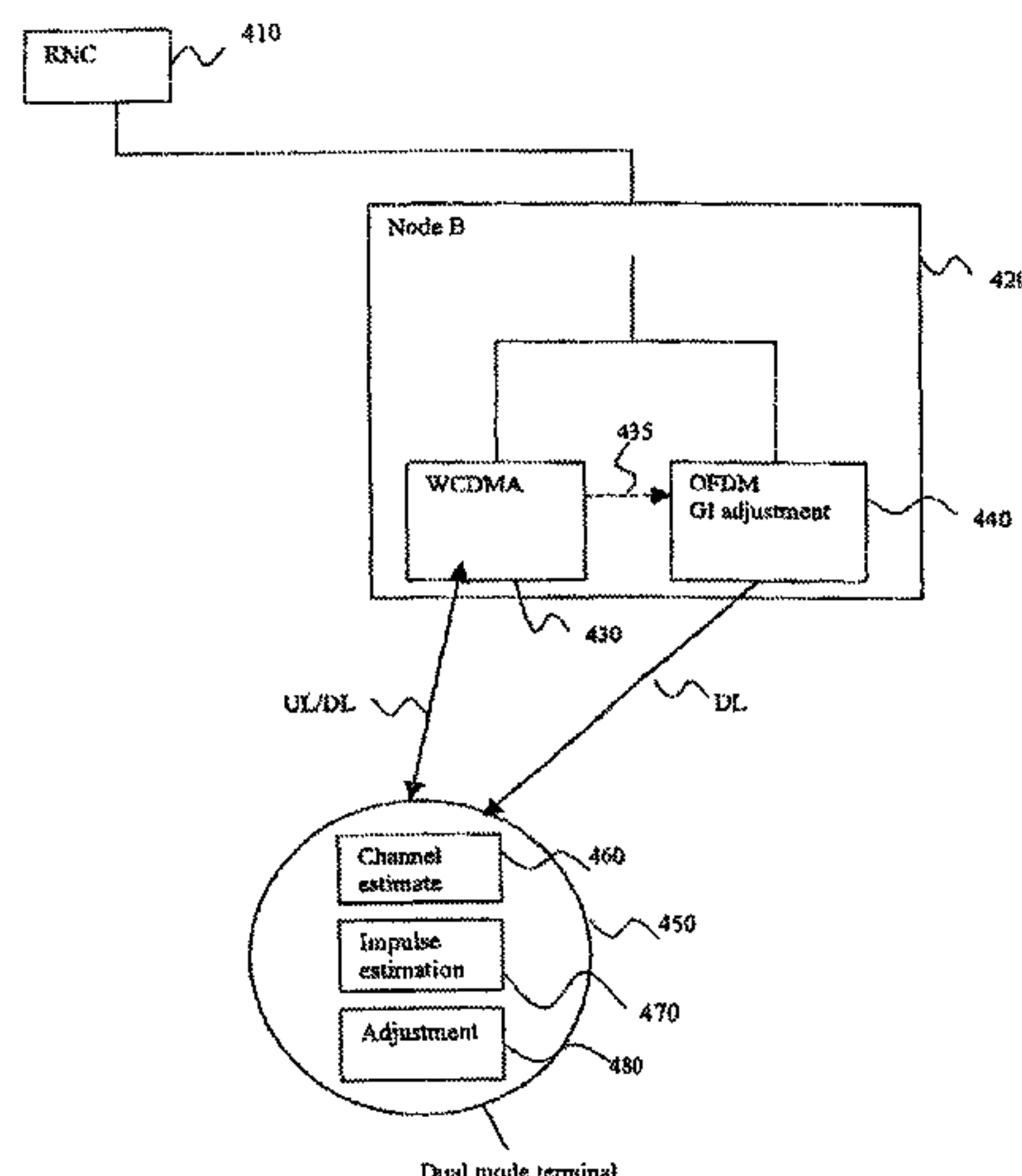
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(57) **ABSTRACT**

A device and a method within a communications system
where at least some part of the transmission is executed by
means of radio waves, and where symbols are transmitted by
means of Orthogonal Frequency Divisional Multiplexing, so
called OFDM-technology, between a transmitting unit and a
receiving unit, at which the symbol transmission is executed
over a transmission channel in blocks of binary digits with
a guard interval GI between said blocks, where transmitting
unit is equipped with means to control the length of the
guard interval (GI) with regard to the physical conditions
for/of the transmission channel, so that the guard interval
can be reduced without the disturbance susceptibility being
increased, but instead increasing the capacity/throughput of
the transmission channel by the time that is set free/made
available being used to transmit information. One embodi-
ment of the invention includes a guard interval adjustment

(Continued)



unit connected to other OFDM-equipment in transmitting and/or receiving unit.

16 Claims, 6 Drawing Sheets

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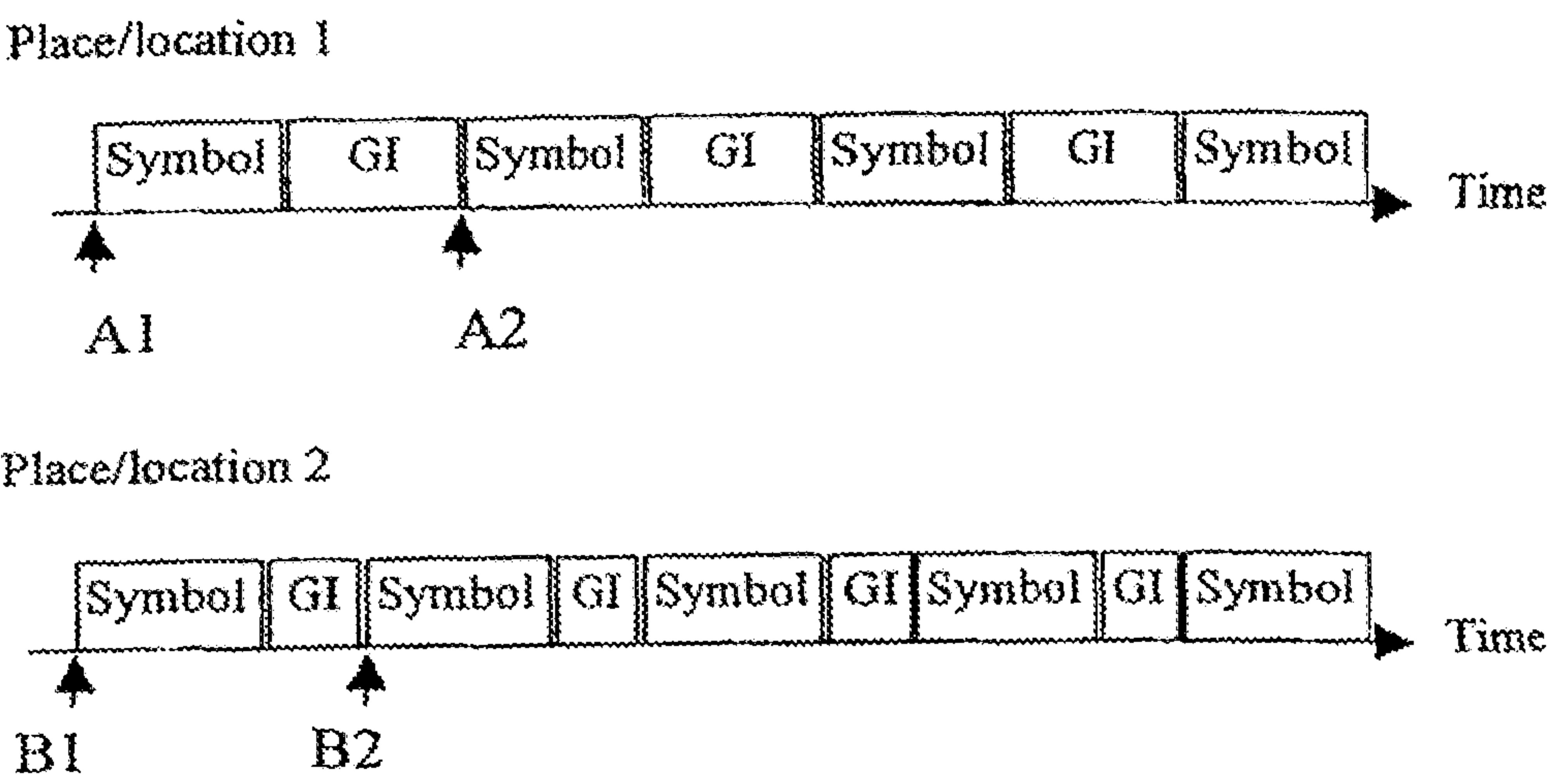


Figure 1a

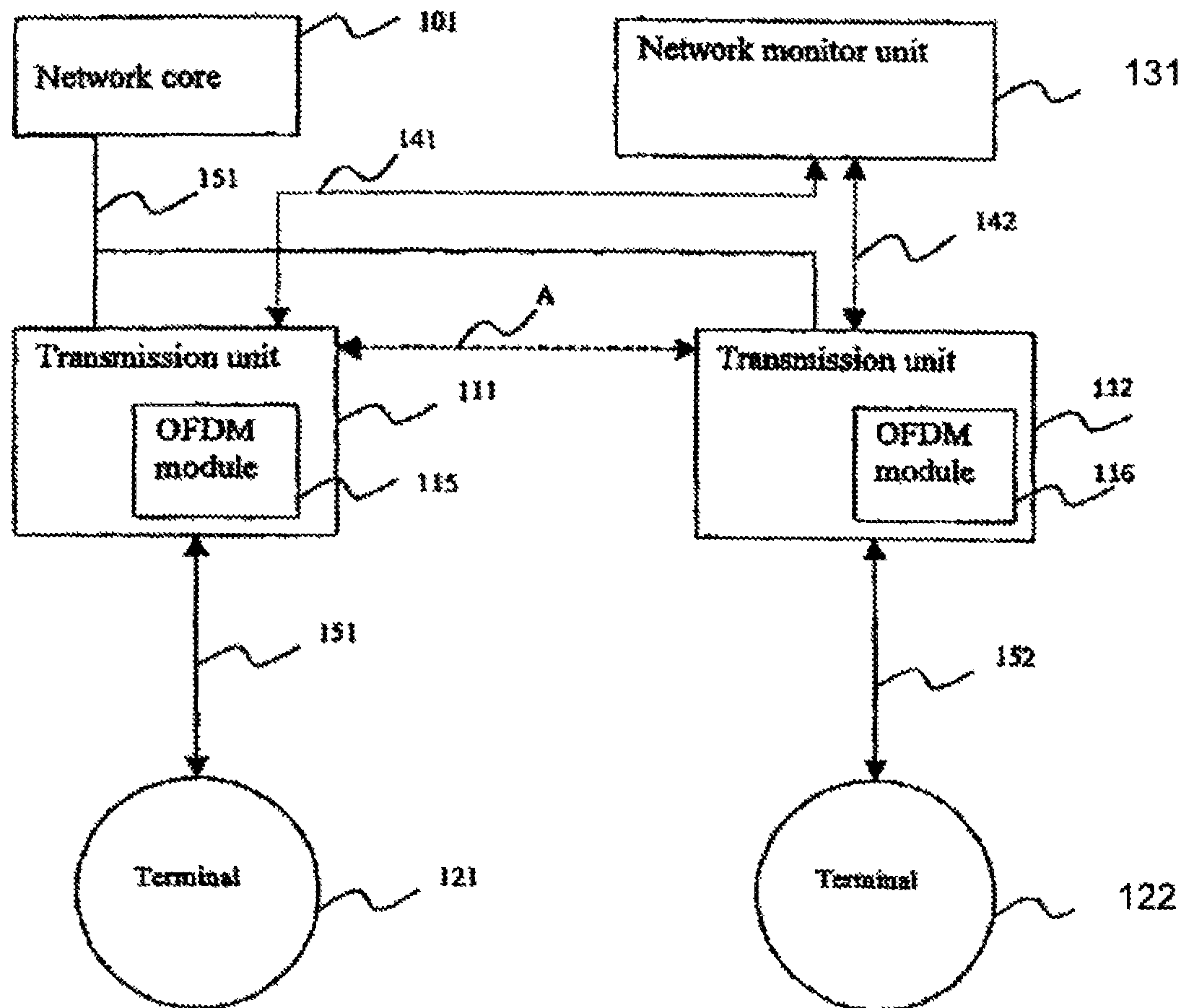


Figure 1b

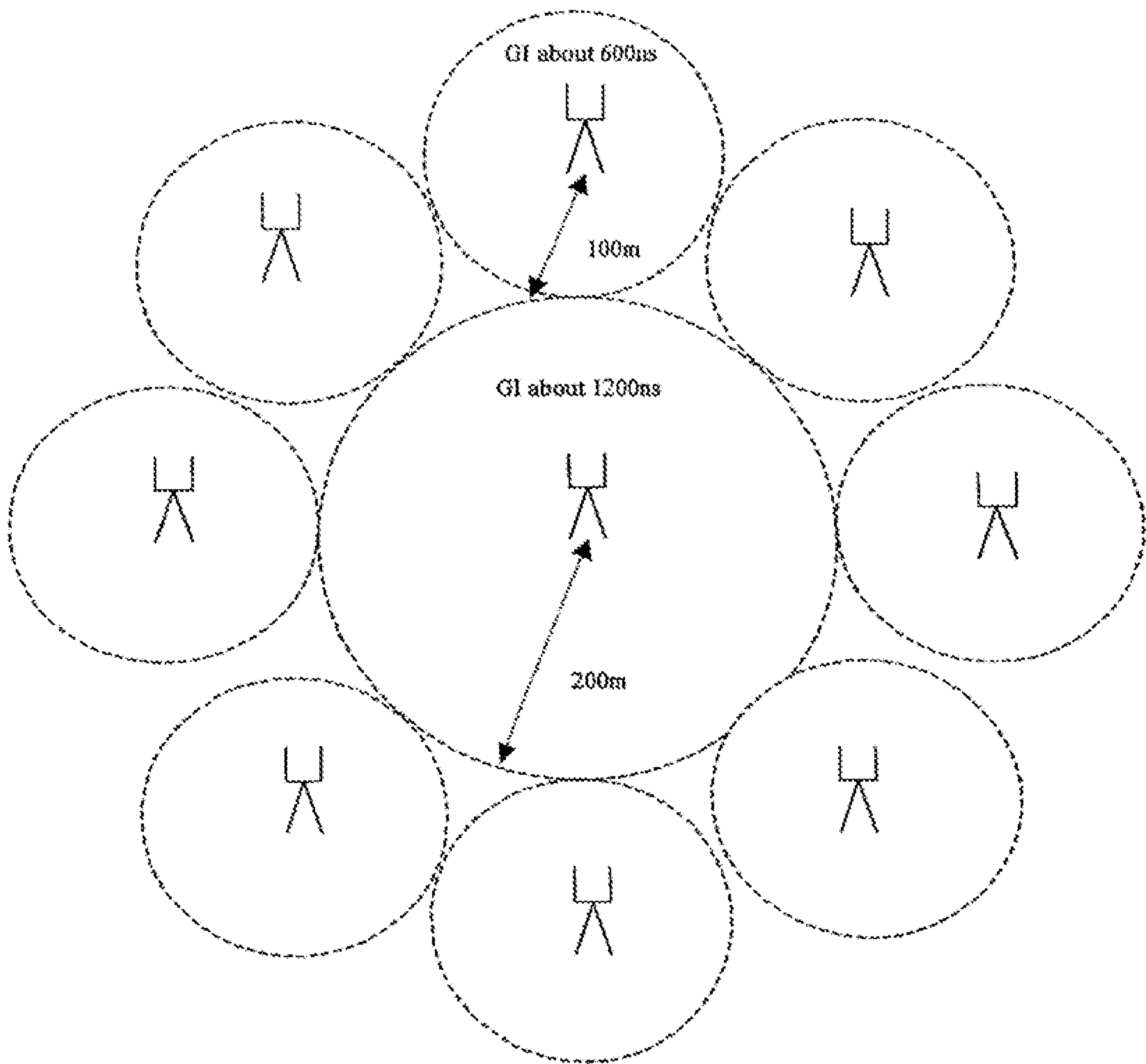


Figure 2

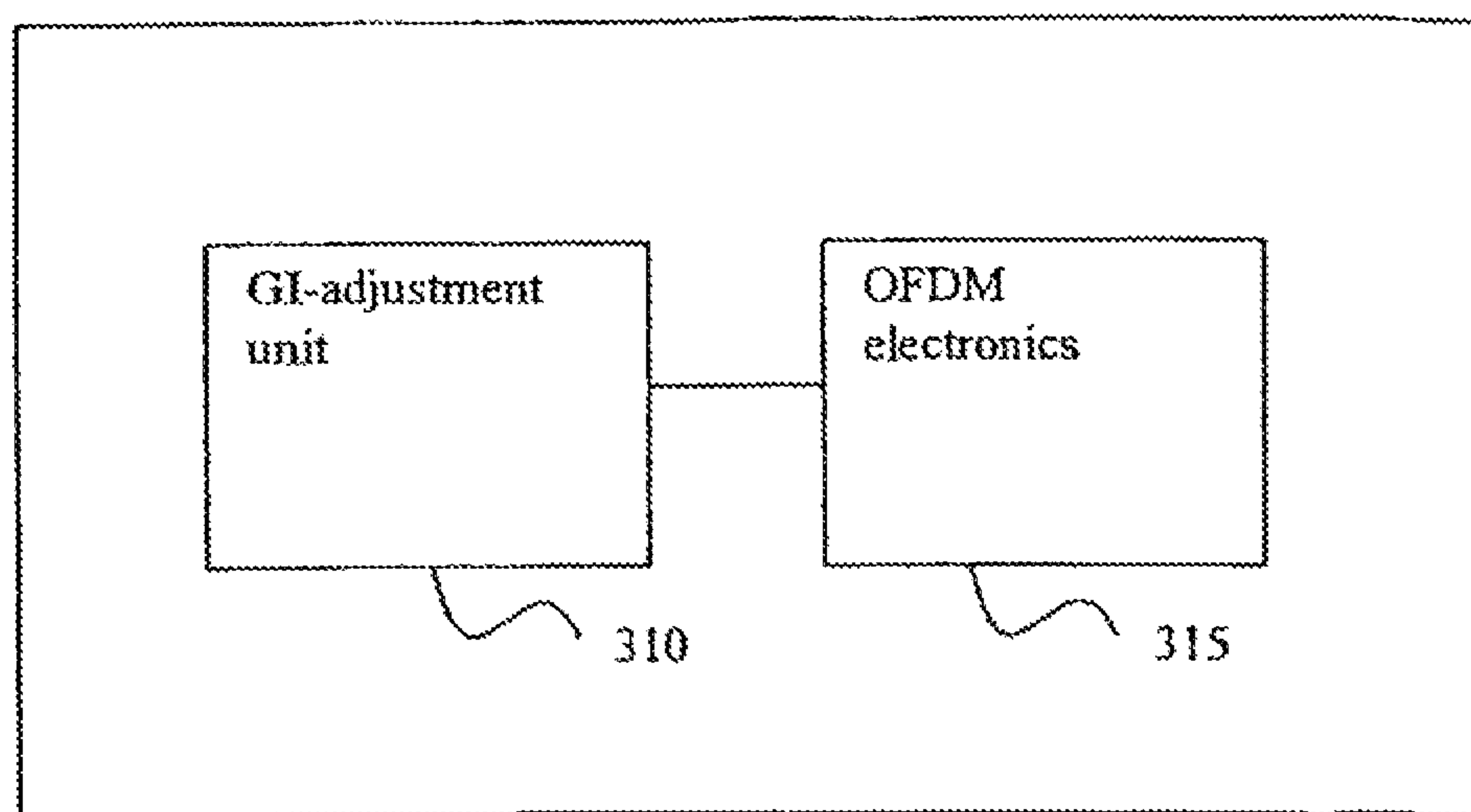


Figure 3

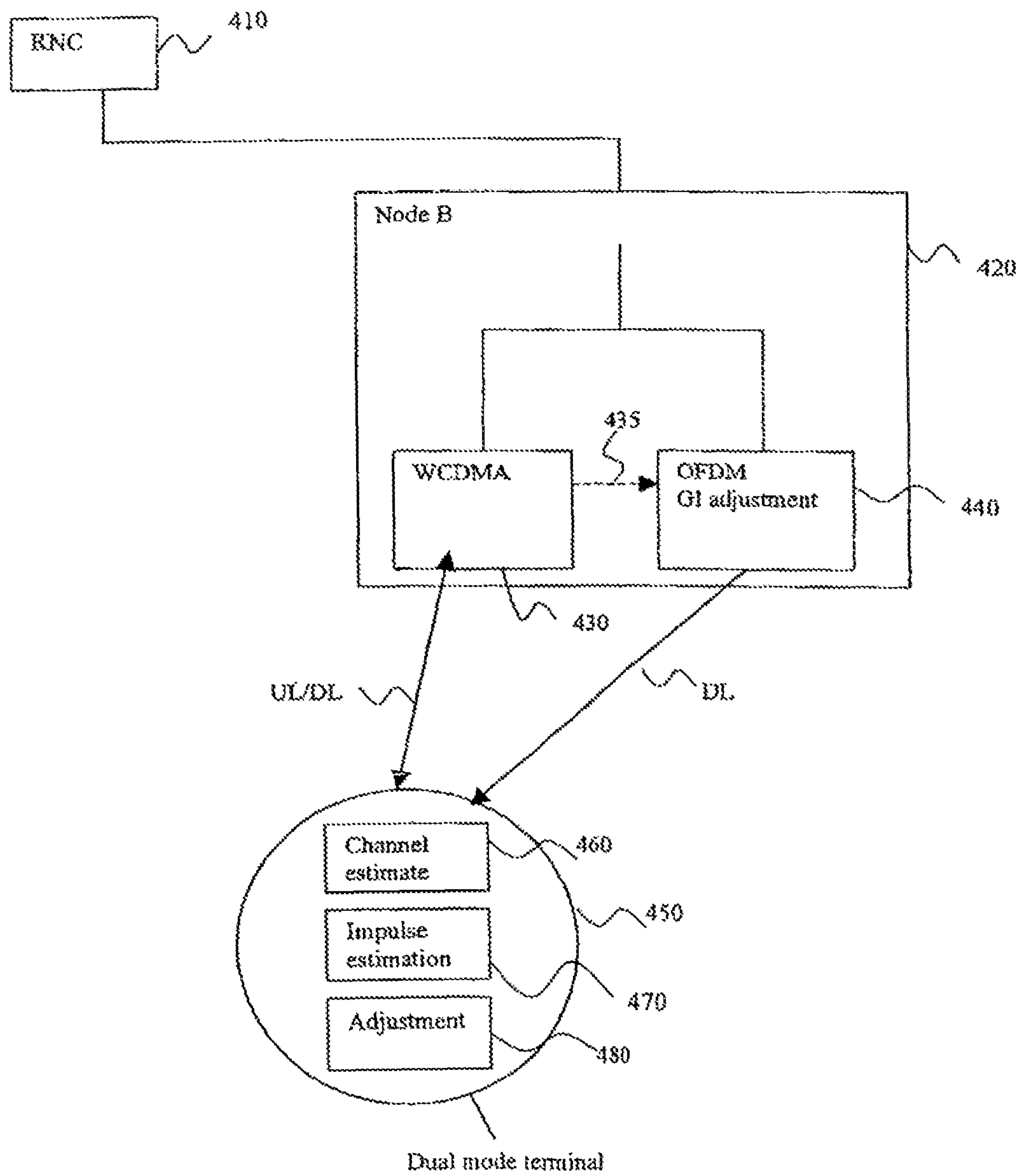
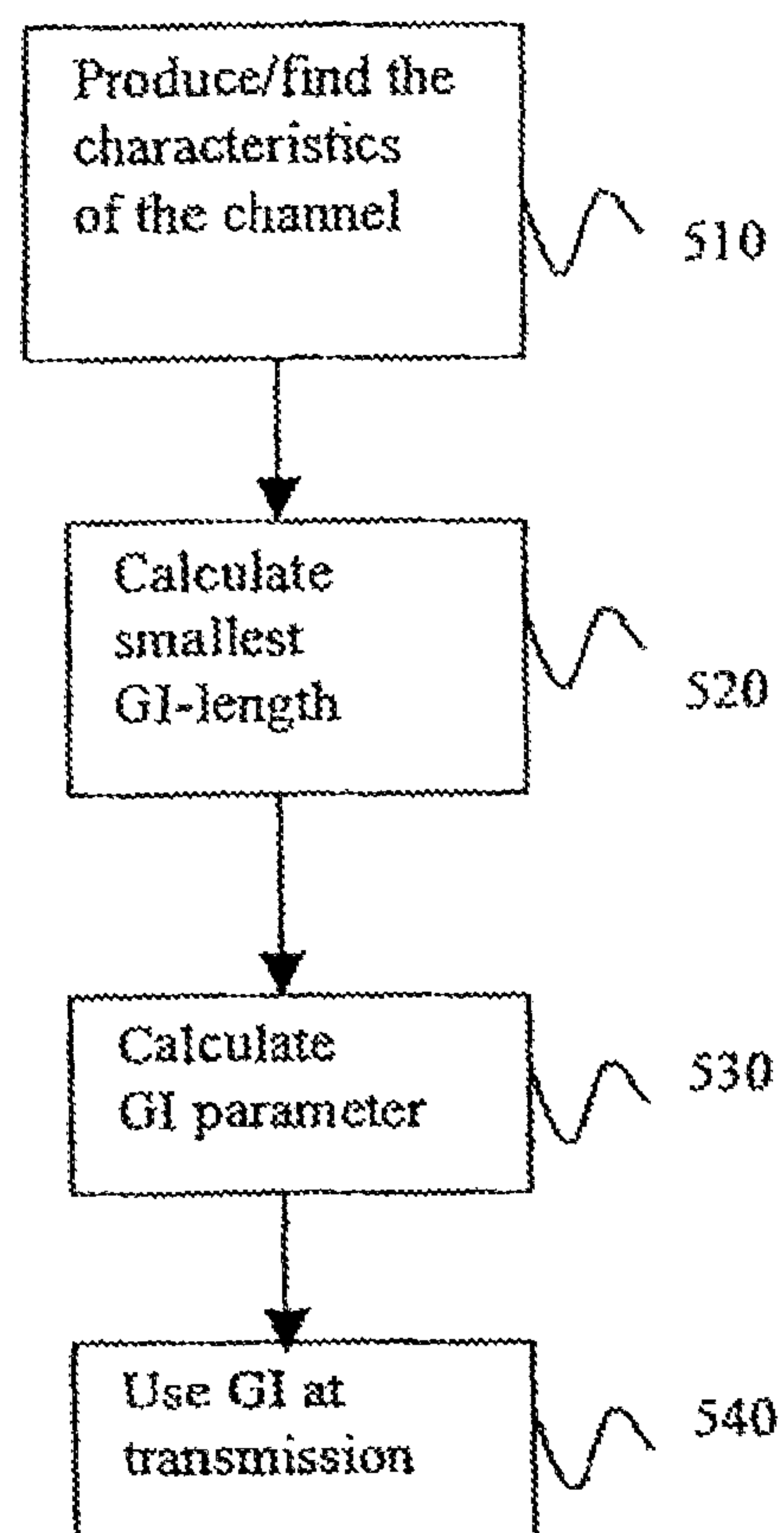


Figure 4

**Figure 5**

POSITION ADJUSTED GUARD TIME INTERVAL FOR OFDM-COMMUNICATIONS SYSTEM

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED *PATENT* APPLICATIONS

This application is a *Broadening Reissue of U.S. Pat. No. 9,008,026 (previously U.S. patent application Ser. No. 14/011,188), filed Aug. 27, 2013, which is a continuation of U.S. application Ser. No. 10/549,846, filed Nov. 29, 2006, which is a National Stage of PCT/SE04/00390, filed Mar. 17, 2004 and claims the benefit of Swedish Application No. 0300824-0, filed Mar. 25, 2003. The entire contents of which are incorporated herein by reference.*

TECHNICAL FIELD

The present invention relates to a transmission method and a transmission device, and a reception method and a reception device, and a system using them. More particularly is related to such ones within communications systems which are using OFDM (Orthogonal Frequency Divisional Multiplexing).

PRIOR ART

An information transmission system generally transmits symbols, where each symbol for instance can be a sequence of ones and zeros in succession over a transmission channel, and there occupies a frequency band which of necessity must be wider/larger than the inverse of the time length of a symbol.

When the transmission speed is increased it finally will be impossible to guarantee that the transmission channel retains identical amplitude and phase characteristics over the whole frequency range which constitutes the pass band. These in this way developed distortions in the channel give rise to interference between symbols, which interference can be fought against by means of an equalizing device, a so called equalizer. Such systems, however, are rather complex.

One technology to handle/manage this problem includes that the signal which shall be transmitted is spread/distributed over a large number of carriers in a parallel way, individually modulated with/by low speed. Because the speed is low, the pass band width which is needed is smaller, and therefore it is more probable that amplitude and phase characteristics will be identical for all frequencies which constitute this band. This technology is known to the expert as "Orthogonal Frequency Divisional Multiplexing" or OFDM. Frequency spectra of the signals which modulate the carriers overlap in such a way that they fulfill the conditions for orthogonality, which makes elimination of interference between modulated sub-carriers possible and also makes it possible to achieve much larger spectral benefit.

The space between two adjacent sub-carriers corresponds to the inverse of the time length of a symbol.

The OFDM-modulation is usually incorporated with a Fourier-transform, so that it can be implemented by means of FTT (Fast Fourier Transform). The main steps to implement transmission of a message by means of OFDM-modulation is specified below.

First of all the binary data which constitute the message which shall be transmitted in data blocks are grouped. Each one of these blocks is transmitted independent of each other and constitutes, after base band modulation, an OFDM-signal. In each data block also the binary digits are grouped in subset. Each subset after that is subject to a "bijective mapping" over a discrete amount of points in the Fresnel-space, where each point represents a possible phase and amplitude. If, for instance, a message consisting of the following series of bits (00001110010001111000 . . .) is considered, it will be possible to from that extract a block of 16 bits 0000111001000111, with which are associated, by mapping, the following amount of points in the complex plane:

1+j, 1+j, -1-j, 1-j, -1+j, 1+j, -1+j, -1-j.

This consequently gives an amount consisting of eight complex elements, which define a vector V.

An inverse discrete Fourier Transform with a matrix A then is allowed to be active/influence on the vectors V which have been obtained from the original message, which gives rise to an OFDM-signal consisting of a series of complex amplitudes. Each transmitted/transferred symbol then is received, after having passed the transmission channel, by a demodulator, from which there is extracted a vector V which holds complex elements, by multiplying the amplitudes which describe the symbol by/with a direct discrete Fourier-transform matrix A' so that $A \cdot A' = I$, where I indicates the unit matrix.

The use of a decision criterion based on "Maximum likelihood" on the real part and on the imaginary part of each vector V' makes regain of the original symbol sequence possible and further reconstruction of the to that associated binary elements.

The different symbols in each block are linked up due to the linear combination which is obtained by multiplying the elements in the transmitted vector V by the inverse discrete Fourier-transform matrix A. This linear combination guarantees a certain degree of hardness and protects the symbols against interference between complex symbols within one and the same OFDM-symbol.

On the other hand, this protection/guard effect does not extend from one OFDM-symbol to another, that is, not from one block to another.

In order to prevent interference between blocks, it is known that a technology can be used which includes to arrange a time period of silence or non-transmission, also called guard (time) interval, between successive symbols.

In prior art, however, the guard interval preceding current symbol is decided pragmatically, usually after an evaluation by an expert, of the time period which is necessary to attenuate the echo of the transmission of preceding OFDM-symbol.

Some variants including adjustment of the guard interval are also described below. U.S. Pat. No. 6,115,354-A shows a method which adapts the "guard intervals for the OFDM symbols" to those differences in delay which exist in the network. The first guard interval for a frame, however, is adjusted to "worst case" (see column 2, line 9-column 3, line 9). According to this document, the flexibility of the guard interval results in that the OFDM-system can be optimized both from implementation and network planning perspective (see column 3, lines 36-40).

U.S. Pat. No. 6,175,550-B1 shows an OFDM-system in which a "guard time interval" is adjusted dynamically depending on the communication conditions in the environment (see column 3, lines 3-65), column 6, lines 24-32, and independent patent claims).

EP-1065855-A1 shows adjustment of "cyclic extensions" in an OFDM-system. The length of the cyclic extension is adjusted to the delays which are existing at/in the channel. (See abstract)

WO97/30531-A1 says that a "guard space" can be varied so that a minimal guard space is used (see patent claims).

EP-1061687-A1 shows automatic adjustment of "guard interval" depending on the quality of received signal.

EP-1014639-A2 shows an OFDM-transmitter/receiver for which an optimal selection of guard interval is decided.

SUMMARY OF THE INVENTION

At construction of a communications system it is in most cases adjusted to a "worst case". This results in that in all other cases than the worst possible, capacity will be wasted. This invention solves a large part of above mentioned waste of/for an OFDM-system, where the capacity goes down proportionally with the guard interval against the time delay of the channel, "Guard Interval GI". The problem is solved by adjustment of the basic OFDM-structure for each transmitter/base station so that not utilized time between symbols will be negligible and the larger part of the transmitted power can be utilized by the terminals.

The invention relates to a communications system where at least some part of the transmission is executed by means of radio waves, and where symbols are transmitted by means of Orthogonal Frequency Divisional Multiplexing, so called OFDM-technology, between a transmitting unit and a receiving unit, at which the symbol transmission is executed over a transmission channel in blocks of binary digits with a guard interval GI between said blocks, where transmitting unit is equipped with means to control the length of the guard interval with regard to the physical conditions for/of the transmission channel.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in more details in the following with reference to the enclosed drawings, of which:

FIG. 1a shows symbol start points of time and guard intervals in a symbol transmission sequence;

FIG. 1b shows a block diagram over a system solution comprising guard interval adjustment according to one embodiment of the present invention;

FIG. 2 shows geographical distribution of cells and to that associated guard interval;

FIG. 3 shows a block diagram over a two-way communications system where the guard interval adjustment is based on current channel estimate from a WCDMA-receiver;

FIG. 4 shows a block diagram over a system solution according to another embodiment of the present invention; and

FIG. 5 shows a block diagram of a guard interval designed as a copy of the last symbols in each block and are also inserted first in each block before transmission.

DESCRIPTION OF PREFERRED EMBODIMENTS

An OFDM-system is defined by certain basic parameters such as the number of FFT-points, the size of the so called

guard interval GI, sampling speed, bandwidth etc. Several of these parameters are selected for the worst case, that is, for the most difficult possible communications condition in which the system shall be functioning satisfactorily. The guard interval means that power and time between OFDM-symbols are not utilized. The guard interval is decided for such a system so that all receivers shall have possibility to receive and detect symbols without intersymbol interference ISI occurring. The worst conceivable propagation delay in the radio channel therefore will be dimensioning for the length of the guard interval.

At normal use of a communications system, however, there sometimes will be considerably better conditions, which means that the parameters which have been selected at the design/construction of the system are too resource exacting because they are not adjusted to at present existing conditions. The inventors have realized that, by adequate measures, it will be possible to, by reducing the guard interval from $\frac{1}{4}$ to $\frac{1}{8}$, $\frac{1}{16}$, and $\frac{1}{32}$, increase the system capacity correspondingly. In a system for distribution "one-to-many" (point-to-multipoint), however, it is not practical to change the guard interval GI for each separate receiver because all OFDM-symbols are transmitted to all receivers within the coverage area.

One of the ideas behind the invention includes to by, in access points AP or base stations BS in a communications system, designing/constructing the OFDM-transmitter in such a way that the guard interval GI can be adjusted as an installation parameter, the guard interval of the OFDM-signal can be adjusted to existing channel conditions from the transmitter within each separate coverage area, also called cell. When a new receiver is connected in this cell, it will be possible to, for instance, via an adjustment algorithm, for instance such as is described by Kim et al, "Frame Selection Algorithm with Adaptive FFT input for OFDM Systems", at ICC, the International Chamber of Commerce 2002, automatically change to the guard interval selection of this cell.

The algorithm is functioning in such a way that it identifies where the OFDM-symbol really starts, that is, estimates how wide/large guard interval that is used. In FIG. 1 a consequently is visualized that the algorithm identifies the occasions which have been marked with arrows A1, A2, B1, B2 at the time axis, that is, where OFDM-symbols start. The figure includes examples of two different places, Place 1 and Place 2, where on the one hand a long and on the other a short guard interval is used. By the algorithm, which is built-in in receiving unit, here called the terminal, identifying where the OFDM-symbol starts, the guard interval can be selected by the operator based on what each specific cell looks like, without any setting needed to be changed in the terminal when the terminal is roved between different cells. In other words, the algorithm executes frame synchronization by in receiving unit calculating an estimate of the guard interval GI by using the in the time domain received signals, and by calculating an estimate of the difference between received and expected frame start time, the so called "coarse framing offset", $\hat{\delta}_{int}$ expressed as

$$\hat{\delta}_{int} = \underset{n}{\operatorname{argmin}} \left\{ \frac{1}{G} \sum_{i=0}^{G-1} |y_{i,t+n}|^2 - |y_{i,t+n+N}|^2 \right\}$$

where $n=0, 1, 2, \dots, 2G+2N-1$ and G indicating the sample length at the guard interval.

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The guard interval GI then can, as indicated above, in a flexible way be adjusted to/for each cell in the communications system, and the capacity/throughput can be improved in the system. This is illustrated in FIG. 1b. A communications system consists of a network core **101** which via a connection **151** is in connection with two adjacent/nearby located transmission units **111**, **112**. The physical distance between the transmission units **111**, **112** is α . Each transmission unit has, via ether communications **151**, **152**, contact with at least one terminal **121**, **122**. A network monitor unit **131** monitors the system and handles system parameters. The network monitor unit **131**, together with the OFDM-modules **115**, **116**, attends to that the guard interval GI is adjusted to the distance α between the transmission units in such a way that the guard interval is adjusted to the cell radius. Suitable guard interval parameter GI is applied to/in OFDM-module **115**, **116**, and further respective terminal **121**, **122** is arranged to adjust itself to the guard interval GI of the cell. The guard interval GI should be selected so that it corresponds to the maximum time dispersion a received signal can experience in respective coverage area. For instance, if there in a cellular system is about 100 m cell radius, the distance for a reflected signal can be up to about 200 m. The flexible guard interval GI consequently is adjusted to handle the delay 200 m, which corresponds to a guard interval GI of about 600 ns. For a cell with a radius of 200 m, about 1200 ns is selected, that is, so that the length of the guard interval in nanoseconds is set to, on the whole, six times the cell radius in meters. The principle for selection of size of the guard interval GI is illustrated in FIG. 2.

In one preferred embodiment, the parameter GI can be preset by the operator or the system administrator via the ordinary interfaces for setting/adjustment of a radio channel, modulation, etc., in each access point AP and each base station BS. Setting of the parameter guard interval GI by/from a centrally located administrator, operator or separate user results in that one continuously achieves optimal performance without need to change hardware at the place of respective access point AP or base station BS. The invention by that includes the possibility to improve capacity performance for an OFDM-system both initially and when the system is extended by more access points AP or base stations BS.

In a cellular two-way communications system based on OFDM and according to one embodiment of the invention, consequently a flexible adjustment of the guard interval GI is achieved. Said guard interval GI is adjusted to the existing transmission conditions in each cell. In another embodiment, each terminal **121**, **122** is equipped with an automatic adjustment unit **310** which automatically adjusts the guard interval GI in the cell of current interest so that mobile units can move in the cellular system and adjust their reception to the flexible parameter selections of the different cells.

In tests an OFDM-system according to one embodiment of the invention and based on IEEE 802.11a has been tested and verified in an indoor environment. In these comparatively small cells with maximum distances of about 50 m between transmitter and receiver, no symbol errors due to time dispersion of the channel have been measured. The standardized guard interval for OFDM in IEEE 802.11a is 800 ns, which by use of one embodiment of the present invention should be possible to reduce to 400 ns in most indoor environments.

In FIG. 3 a structure for/of the OFDM-module **115**, **116** according to FIG. 1b is described. An automatic guard interval adjustment unit **310** is in connection with other electronics **315** for execution of OFDM. The guard interval

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adjustment unit **310** calculates the under the circumstances best guard interval and transmits this to other electronics **315** for execution of OFDM.

In one preferred embodiment, the guard interval is adjusted according to longest delay in the impulse response. Because the delay, however, maximally can be about the time it takes for the signal to travel twice the cell radius, this value can be supposed to be a suitable guard interval, that is (distance between base stations)/(3*18.sup.8). As a rule of thumb, it can be assumed that radio waves travel 300 m in 1 microsecond, and if there is this distance between BS, and consequently 150 m max. between BS and terminal, the guard interval should be 1 microsecond in this typical example in city environment. For BS in suburb with 1 km between BS, one should have 3 microseconds guard interval.

It is not necessary to, in all situations, calculate the guard interval in an embodiment of the invention. The guard interval can be calculated before the base station is installed, for instance at the cell planning occasion, and after that only when changes in the network planning are made.

The guard interval consequently need not necessarily be calculated anywhere in the system. If one concentrates with more BS one can, via handling/managing system SNMP, reduce the guard interval with corresponding new shorter BS-distance so that more OFDM-symbols are transmitted within each time frame or block of symbols.

In yet another preferred embodiment there is in a receiver which receives the OFDM-signal a receiver adjustment module arranged which adjusts said receiver according to the current guard interval in the cell. Said adjustment is made by use of an adjustment algorithm described in "Frame Selection Algorithm with Adaptive FFT Input for OFDM Systems, ICC 2002", which has been described above.

In yet another embodiment of the present invention, an adjustable guard interval GI in a two-way communications system according to FIG. 4 is provided. In a two-way communications system, where communication is executed both in an uplink UL and in a downlink NL, an adjustment of the parameters of the OFDM-signal can be made to existing communication conditions, which increases the capacity/throughput of the system. In order to receive a transmitted signal, an estimation of the qualities of the transmission channel is made. For instance, the delays and the changes of amplitude which occur between transmitter and receiver are measured. This so called channel information from the receivers of the system by that can be utilized for the generation of the signals in the OFDM-transmitter, where one, by knowing the impulse response of the channel, can adjust the guard interval GI of the OFDM-signal to existing channel conditions from the transmitter within each separate coverage area, and also for each terminal within the coverage area. The impulse response is produced in receiving unit by estimating the channel from a transmitted symbol in a so called "preamble". The principle is illustrated in FIG. 4, where the guard interval GI is adjusted based on current channel estimate from a WCDMA-receiver **430**. The channel estimate is transmitted/transferred to the OFDM-unit **440** where the guard interval GI is adjusted on basis of current channel estimate.

A radio network control unit RNC is in (wire) connection with a number of nodes, one of which is node B.

The guard interval should be equal in up and down link; then in systems using TDD (Time Division Duplex), the up and downlink of the channel is identical, and the same guard interval should be used.

The system in FIG. 4 also includes a so called dual mode terminal **450**, which is arranged to receive both OFDM- and

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WCDMA-signals. This terminal **450** includes a channel estimation unit **460** for production of channel estimates and an estimation unit **470** for estimation of impulse responses from WCDMA-training sequences. Said estimate and estimation then is used to adjust the guard interval OFDM in downlink.

In yet another preferred embodiment, the guard interval is designed as a copy of the last symbols in each block. These symbols are copied and are also inserted first in each block before transmission.

The invention claimed is:

1. A transmitting unit comprising:

an electronic processor configured to:

determine a characteristic of a transmission channel between the transmitting unit and a receiving unit, wherein symbols are transmitted by Orthogonal Frequency Divisional Multiplexing (OFDM) between the transmitting unit and the receiving unit, wherein the symbol transmission is executed over the transmission channel in blocks of binary digits with a guard interval between the blocks;

determine a size of a cell in which the transmitting unit transmits based on the determined characteristic of the channel;

determine a guard interval length that causes intersymbol interference from other transmitting units to be below a predetermined threshold value based on the determined size of the cell; and

adjust the guard interval of the transmitting unit to be the guard interval length to reduce the intersymbol interference from the other transmitting units to be below the predetermined threshold value.

2. The transmitting unit of claim 1, wherein the electronic processor is further configured to adjust the length of the guard interval based upon an adjustable guard interval parameter.

3. The transmitting unit of claim 2, wherein the guard interval parameter can be changed via [handling/managing] a management system [SNMP].

4. The transmitting unit of claim 1, wherein the guard interval length is determined to be a radius of the cell in meters multiplied by six.

5. The transmitting unit of claim 1, wherein the characteristic of a transmission channel between the transmitting unit and the receiving unit takes into consideration a delay of an impulse response of the transmission channel.

6. A method comprising:

determining a characteristic of a transmission channel between a transmitting unit and a receiving unit, wherein symbols are transmitted by Orthogonal Frequency Divisional Multiplexing (OFDM) between the transmitting unit and the receiving unit, wherein the symbol transmission is executed over the transmission channel in blocks of binary digits with a guard interval between the blocks;

determining a size of a cell in which the transmitting unit transmits based on the determined characteristic of the channel;

determining a guard interval length that causes intersymbol interference from other transmitting units to be below a predetermined threshold value based on the determined size of the cell; and

adjusting the guard interval of the transmitting unit to be the guard interval length to reduce the intersymbol interference from the other transmitting units to be below the predetermined threshold value.

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7. The method of claim 6, wherein the determining the characteristic of the transmission channel comprises determining a delay of an impulse response of the channel.

8. The method of claim 6, further comprising estimating a received guard interval.

9. The method of claim 8, wherein the estimating is constituted by an operator decided guard interval.

10. The method of claim 8, wherein the estimating comprises calculating an estimate of a difference between a received and an expected block start point of time, the so called "coarse framing offset" δ_{int} according to the formula:

$$\hat{\delta}_{int} = \underset{n}{\operatorname{argmin}} \left\{ \frac{1}{G} \sum_{i=0}^{G-1} |y_{i,t+n}|^2 - |y_{i,t+n+N}|^2 \right\},$$

where $n=0, 1, 2, \dots, 2G+2N-1$ and G indicates the length of a sample at the guard interval and y_i indicates the received signal for/of the i th OFDM-symbol in a time domain.

11. The method of claim 6, wherein the determining the guard interval length comprises multiplying a radius of the cell in meters by six.

12. A communications system comprising:

a transmission unit configured to:

determine a characteristic of a transmission channel between the transmitting unit and a receiving unit, wherein symbols are transmitted by Orthogonal Frequency Divisional Multiplexing (OFDM) between the transmitting unit and the receiving unit, wherein the symbol transmission is executed over the transmission channel in blocks of binary digits with a guard interval between the blocks;

determine a size of a cell in which the transmitting unit transmits based on the determined characteristic of the channel;

determine a guard interval length that causes intersymbol interference from other transmitting units to be below a predetermined threshold value based on the determined size of the cell; and

adjust the guard interval of the transmitting unit to be the guard interval length to reduce the intersymbol interference from the other transmitting units to be below the predetermined threshold value.

13. The communications system of claim 12, further comprising a receiving unit configured to adjust the receiving unit according to the current guard interval in the cell.

14. The communication system of claim 13, wherein the receiving unit is further configured to estimate a length of a received guard interval.

15. The communication system of claim 14, wherein the receiving unit is configured to calculate an estimate of a difference between a received block and an expected block start point of time, the so called "coarse framing offset" δ_{int} according to the formula:

$$\hat{\delta}_{int} = \underset{n}{\operatorname{argmin}} \left\{ \frac{1}{G} \sum_{i=0}^{G-1} |y_{i,t+n}|^2 - |y_{i,t+n+N}|^2 \right\},$$

where $n=0, 1, 2, \dots, 2G+2N-1$ and G indicates the length of a sample at the guard interval and y_i indicates the received signal for/of the i th OFDM-symbol in a time domain.

16. A transmitting unit comprising:
 an electronic processor configured to:
- determine a characteristic of a transmission channel,
 wherein a symbol transmission is executed over the
 transmission channel in blocks of binary digits with 5
 a guard interval between the blocks;
 - determine a size of a cell in which a transmitting unit
 transmits based on the determined characteristic of
 the transmission channel;
 - determine a guard interval length that causes inters- 10
 ymbol interference from other transmitting units to
 be below a predetermined threshold value based on
 the determined size of the cell; and
 - adjust the guard interval of the transmitting unit to be
 the guard interval length to reduce the intersymbol 15
 interference from the other transmitting units to be
 below the predetermined threshold value.

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