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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 January 2002 (17.01.2002)

PCT

(10) International Publication Number
WO 02/05456 A1

(51) International Patent Classification[7]: H04B 7/08

(21) International Application Number: PCT/SE01/01587

(22) International Filing Date: 6 July 2001 (06.07.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0002585-8 7 July 2000 (07.07.2000) SE

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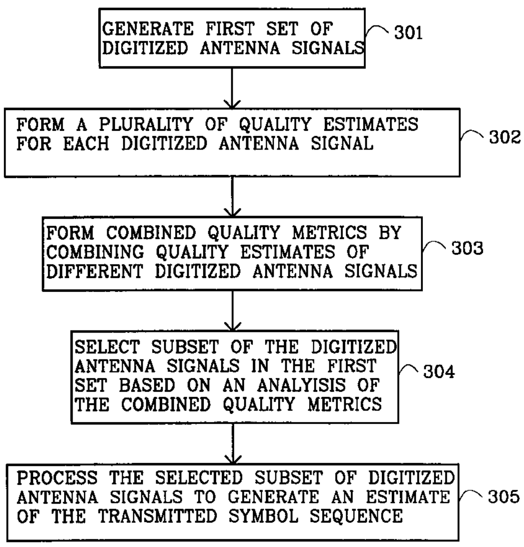
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND APPARATUS IN A RADIO COMMUNICATION SYSTEM



(57) Abstract: A method and a receiver apparatus for receiving a digital symbol sequence including at least one occurence of a predetermined training sequence. A first set of digitized antenna signals is generated (301) by receiving and digitizing a plurality of radio signals representing the transmitted digital symbol sequence. A plurality of quality estimates, reflecting the degree of match between the predetermined training sequence and each digitized antenna signal in the first set for different possible synchronization positions of each signal, are formed (302). A plurality of combined quality metrics are formed (303) by combining quality estimates of different digitized antenna signals in the first set. A subset of digitized antenna signals is selected (304) from the first set based on a analysis of the combined quality metrics. The selected subset of digitized antenna signals is processed to generate an estimate of the transmitted digital symbol sequence.

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METHOD AND APPARATUS IN A RADIO COMMUNICATION SYSTEM

TECHNICAL FIELD OF THE INVENTION

The invention relates to a method and an apparatus in a radio communication system. More in particular, the invention concerns a method for receiving a digital symbol sequence transmitted by radio and an apparatus implementing the method.

DESCRIPTION OF RELATED ART

A commonly used technique for improving radio receiver performance is to use "receiver antenna diversity". This means that a set of receiver antennas, each one with its own analogue receiver chain, are mounted and directed in such a way that their lobes cover the same area. A transmitter, e.g. a mobile station, anywhere in the coverage area is received by all antennas, but since the path between transmitter and antennas differ, each of the received signals will fade independently.

International patent application WO 97/40588 discloses a digital radio communication system using receiver antenna diversity combining and interference rejection to jointly mitigate the deleterious effects of fading, time dispersion and interference. According to some embodiments of the system, a selection processor is employed for reducing the number of signals used for interference rejection and diversity combining based on one or more criterion. An embodiment of the selection processor is disclosed wherein the processor generates signal quality measures of its M input signals, compares the signal quality of the M input signals relative to each other and chooses the N signals (out of M) that have the best measure. The measures used to evaluate the signals may be defined to represent one or more of e.g. measured instantaneous branch power, measured average branch power, beam center direction relative to desired signal direction or signal quality as measured from sync word (the sum of measured signal power and impairement power divided by impairement power).

U.S. Patent 5,199,047 discloses a receiver for a digital transmission system in which transmitted data contain a training data sequence, and the receiver stores a copy of the sequence as it was transmitted. A channel impulse response is estimated based on this stored copy. The received training data sequence is compared with a version of the stored copy that has been modified by the estimated impulse response, and an estimate of the receiving quality is formed based on the degree of match with the modified version. U.S. 5,199,047 further discloses a diversity receiver comprising at least two receive loops and a decision circuit for selecting one of these two loops, while estimates of the receiving quality of the at least two receive loops are formed as disclosed above.

SUMMARY OF THE INVENTION

The present invention addresses the problem of providing an alternative way of receiving a digital symbol sequence transmitted by radio.

The problem is solved by a method for receiving and a receiving apparatus wherein selection of digitized antenna signals for processing to generate an estimate of the transmitted digital symbol sequence is based on an analysis of combined quality metrics formed by combining quality estimates of different digitized antenna signals.

More specifically, the problem is solved by a method according to claim 1 and a receiving apparatus according to claim 15.

A general object of the invention is to provide an alternative way of receiving a digital symbol sequence transmitted by radio.

Another object of preferred embodiments of the invention is to provide more reliable estimates of the transmitted digital symbol sequence during bad conditions for radio communication and in particular to effect selection of digitized antenna signals for use in the estimation process in a way that offers increased robustness during bad conditions for radio communication.

An advantage of preferred embodiments of the invention is that they afford more reliable estimates of the transmitted digital sequence during bad conditions for radio communication.

A more specific advantage of preferred embodiments of the invention is that they afford selection of digitized antenna signals for use in the estimation process to be performed in ways that offer increased robustness during bad conditions for radio communication.

The invention will now be described in more detail with reference to exemplary embodiments thereof and also with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view illustrating a radio communication system.

Fig. 2 is a block diagram illustrating TDMA frames, time slots and bursts according to TIA/EIA-136.

Fig. 3 is a flow diagram illustrating a basic method according to the invention.

Fig. 4-6 are block diagrams illustrating an exemplary embodiment of a receiving apparauts according to the invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Fig. 1 illustrates schematically a radio communication system SYS1 comprising a radio communication network in the form of a cellular network NET1 and a first mobile station MS1. In the exemplary radio communication system SYS1 illustrated in Fig. 1, communication between the cellular network NET1 and the first mobile station MS1 is based on the TIA/EIA-136 air interface specifications. Note that the invention is applicable to a multitude of different air interface specifications and is in no way limited in its application to only TIA/EIA-136 compliant radio communication systems. The cellular network NET1 comprises a mobile switching centre MSC1 and a number of base stations including base station BS1 connected to the mobile switching centre MSC1. The base stations provide radio coverage in a geographical area served by the mobile switching centre MSC1. The geographical area is divided into a number of cells. In each cell radio coverage is provided by one of the base stations, e.g. base station BS1. The cell in which the first mobile station MS1 is currently located is denoted the serving cell and the corresponding base station is denoted the serving base station. In Fig. 1, base station BS1 is currently acting as the serving base station to the first mobile station MS1. The mobile switching centre MSC1 is responsible for switching calls to and from mobile stations located in the geographical area served by the mobile switching centre MSC1. Note that Fig. 1 only serves to illustrate the present invention and that a typical cellular network comprises several mobile switching centres, a greater number of base stations as well as other types of nodes such as home location registers.

Fig. 2 illustrates the Time Division Multiple Access (TDMA) scheme according to TIA/EIA-136 used for communication of information by radio between the first mobile station MS1 and the serving base station BS1. Time is divided into time slots 201-206 which are organized into TDMA-frames 200. Each TIA/EIA-136 TDMA frame 200 consists of six consecutive time slots 201-206. Digital traffic channels and digital control channels are assigned specific time slots on specific radio carrier frequencies. The first mobile station MS1 and the serving base station BS1 communicates on a digital traffic channel or digital control channel by transmitting bursts of data to each other in the appropriate time slots on the the radio carrier frequency assigned to the channel used for communication. Slightly different burst formats are used in the uplink direction, i.e. from the first mobile station MS1 to the serving base station BS1, and in the downlink direction, i.e. from the serving base station BS1 to the first mobile station MS1. Fig. 2 illustrates a burst 207 according to the format used in the uplink direction. The burst comprises three data fields 208-210, a synchronization and training field 211, a slow associated control channel (SACCH) field 212 and a Coded Digital Verification Color Code (CDVCC) field 213.

The content of the synchronization and training field 211 is used for time slot synchronization and equalizer training. TIA/EIA-136 defines six different so called "synchronization words", alternatively referred to as synchronization sequences or training sequences. The serving base station BS1 in Fig. 1 determines which specific training sequence (out of the six possible alternatives) should be used for communications with the first mobile station MS1 and thus each burst 207 transmitted by the first mobile station MS1 to the serving base station BS1 will always include a predetermined training sequence which is known by the serving base station BS1.

The base station BS1 in Fig. 1 utilizes an antenna system comprising one or several antennas providing a plurality of antenna lobes L1-L4 for providing radio coverage in the area served by the base station BS1. The different antenna lobes L1-L4 are arranged to cover different geographical areas while having a substantial overlap between adjacent antenna lobes.

When the first mobile station MS1 desires to communicate information in the uplink direction to the serving base station BS1, it transmits a sequence S of digital symbols in one or several bursts to the serving base station BS1. For detecting the transmitted sequence of digital symbols, circuitry in the serving base station BS1 perform diversity combining of digitized antenna signals generated by receiving and digitizing radio signals associated with the different antenna lobes L1-L4.

In order to reduce the complexity of the diversity combining operation, it is highly desirable to reduce the number of digitized antenna signals used when performing the diversity combining operation. Also, since not all antenna lobes cover the area where the first mobile station MS1 is currently located, antenna signals associated with antenna lobes not covering the area in which the first mobile station MS1 is currently located are likely to only introduce noise and interference. It would thus be preferable to not include these antenna signals when performing the diversity combing operation.

International patent application WO 97/40588 discloses a receiving apparatus performing interference rejection diversity combining in which a selection processor is employed to reduce the number of digitized antenna signals used for diversity combining. The selection processor selects a set of digitized antenna signals most representative of a transmitted digital symbol sequence by generating signal quality measures of its M input signals, comparing the signal quality of the M input signals relative to each other and choosing the N signals (out of M) that have the best measure. The measures used to evaluate the signals may be defined to represent one or more of e.g. measured instantaneous branch power, measured average branch power, beam center direction relative to desired signal direction or signal quality as measured from synchronization word (the sum of measured signal power plus impairement power divided by impairement power).

It is well known to a person skilled in the art that the degree of match between the predetermined training sequence and corresponding sample sequences of the respective digitized antenna signals, i.e. the portions of the digitized antenna signals in which the predetermined training sequence is received, provides a measure reflecting the signal to interference ratio for the digitized antenna signals. Since the signal to interference ratio is of primary importance in deciding whether it will be possible to estimate the transmitted symbol sequence correctly, this is a very useful measure for deciding which digitized antenna signals should be used when performing the diversity combining operation. The degree of match between the predetermined training sequence and different sample sequences of the digitized antenna signals can also be used to evaulate different hypothetical synchronization positions of the digitized antenna signals.

However, if the conditions for radio communication between the first mobile station MS1 and the serving base station BS1 are bad with severe fading and weak signals, it may happen that when a certain burst is received in one of the antenna lobes, the synchronization and training field (211 in Fig. 2) of the burst is more faded than other parts of the burst. For the digitized antenna signal associated with said antenna lobe, this situation can result in that a sequence of samples derived from a part of the burst outside the synchronization and training field more closely matches the predetermined training sequence than the sequence of samples actually derived from the synchronization and training field. Thus when attempting to determine which samples of the digitized antenna signal corresponds to the synchronization and training field of the burst, i.e. the synchronization position of the digitized antenna signal, the first mentioned sequence of samples will erronously be considered as corresponding to the synchronization and training field causing a false synchronization of the digitized antenna signal. Furthermore, the determined degree of match between the predetermined training sequence and the first mentioned sequence of samples will erronously be regarded as the degree of match between the predetermined training sequence and a corresponding portion of the digitized antenna signal in which the predetermined training sequence is received. Thus, if selection of digitized antenna signals for diversity combining is performed using quality measures based on the degree of match between the predetermined training sequence and corresponding portions of the digitized antenna signals in which the predetermined training sequence is received, there is a risk that said digitized antenna signal is erronously selected for diversity combining under these circumstances. Since the digitized antenna signal suffers from false synchronization, the digitized antenna signal will not provide any useful contribution but instead act as a strong source of interference in the diversity combining process.

The present invention provides a way of receiving a digital symbol sequence transmitted by radio wherein the selection of digitized antennna signals is performed in a way that enables embodiments of the invention to effect selection of digitized antenna signals with increased robustness which results in more reliable estimates of the digital symbol sequence during bad conditions for radio communication.

According to the invention, the selection of digitized antenna signals is based on an analysis of combined quality metrics formed by combining quality estimates of different digitized antenna signals. Embodiments of the invention achieves the increased robustness in the selection process by applying different restrictions in terms of which quality estimates may and which may not be combined when forming the combined quality metrics.

The flowchart of Fig. 3 illustrates a basic method according to the invention for receiving a digital symbol sequence transmitted by radio which e.g. may be applied in the serving base station BS1 of Fig. 1 for receiving information from the first mobile station MS1.

At step 301 a first set of digitized antenna signals comprising at least three digitized antenna signals is generated by receiving and digitizing a plurality of radio signals representing the transmitted digital symbol sequence.

At steps 302-304 a true subset of digitized antenna signals, i.e. a subset containing fewer digitized antenna signals, is selected from the first set.

A plurality of quality estimates for each of the digitized antenna signals in the first set are formed at step 302. The quality estimates of each digitized antenna signal is formed to reflect the degree of match between the predetermined training sequence and the digitized antenna signal for different possible synchronization positions of the digitized antenna signal.

A plurality of combined quality metrics are formed at step 303 by combining at least two quality estimates of different digitized antenna signals in the first set.

The true subset of antenna signals is selected at step 304 based on an analysis of the combined quality metrics formed at step 303.

An estimate of the transmitted digital symbol sequence is finally generated by processing the selected subset of digitized antenna signals at step 305.

The block diagrams of Fig. 4, Fig. 5 and Fig. 6 illustrate one exemplary embodiment of a receiver apparatus according to the invention implemented by the base station BS1 in Fig. 1.

Fig. 4 illustrates that the receiver apparatus includes four antennas each providing one of the antenna lobes L1-L4 in Fig. 1. Each antenna 401 is coupled to a receiver unit 402 which amplifies, downconverts and filters radio signals received via the antenna according to known methods to produce analog signals. Each receiver unit 402 is coupled to an analog-to-digital (A/D) converter 403 which converts the analog signal from the receiver unit 402 into a received signal sample stream, i.e. a digitized antenna signal. The digitized antenna signals S41-S44 thus provided forms a first set 405 of digitized antenna signals which are input to a processing unit 404, e.g. a Digital

Signal Processor such as a TMS320C548 manufactured by Texas Instruments, which processes the digitized antenna signals S41-S44 to produce an estimate of a digital symbol sequence transmitted by the first mobile station MS1 to the base station BS1. The antennas 401, the receiver units 402 and the analog-to-digital converters 403 in Fig. 4 collectively functions as receiving means for generating the first set 405 of digitized antenna signals.

Fig. 5 illustrates more in detail the logical structure of the processing unit 404. The first set 405 of digitized antenna signals S41-S44 are received by a preprocessor block 501 which selects two of the digitized antenna signals S41-S44, i.e. a true subset 506 of the first set 405 of digitized antenna signals S41-S44, as output signals for futher diversity combining and detection processing to produce an estimate S_{EST} of the digital symbol sequence S transmitted by the first mobile station MS1 (see Fig. 1). The preprocessor block 501 also performs synchronization of the selected two antenna signals.

The output signals $r_a(n)$ and $r_b(n)$ from the preprocessor block 501 are input to estimating circuits 502a and 502b which produce channel tap estimates $c_a(\tau)$ and $c_b(\tau)$ which are used to model the radio transmission channel associated with each particular antenna from which the selected digitized antenna signals originate. The output signals $r_a(n)$ and $r_b(n)$ from the preprocessor blocks 501, the channel tap estimates $c_a(\tau)$ and $c_b(\tau)$ and impairement correlation properties obtained from an impairement correlation estimator block 503 are fed into a branch metric processor block 504.

The estimate of the impairement correlation properties comprises information regarding the impairement correlation properties between the antennas 401. The impairement correlation estimator 503 uses impairement process estimates to update and possibly track the estimate of the impairement correlation properties.

The branch metric processor block 504 uses its received input data to form branch metric which is used in a sequence estimation processor block 505 to produce the estimate S_{EST} of the symbol sequence S transmitted by the first mobile station MS1.

The channel tap estimator blocks 502a and 502b, impairement correlation estimator block 503, branch metric processor block 504 and sequence estimator processor 505 of Fig. 5 collectively functions as estimating means for processing the selected subset 506 of digitized antenna signals to generate the estimate S_{EST} of the transmitted digital symbol sequence S. Since these blocks all operate in similar ways as the corresponding elements disclosed in detail in the international patent application WO 97/40588, they are not elaborated upon any further in the present application.

Fig. 6 illustrates more details of the logical structure of the preprocessor block 501 of Fig. 5 according to an exemplary embodiment.

The first set 405 of digitized antenna signals S41-S42 are input to respective signal quality estimator blocks 601. The signal quality estimator blocks 601 determine a plurality of quality estimates for each of the digitized antenna signals S41-S44. The quality estimates of each digitized antenna signal reflect the degree of match between the predetermined training sequence included in the digital symbol sequence transmitted by the first mobile station MS1 and the digitized antenna signal for different possible synchronization positions of the digitized antenna signal.

TIA/EIA-136 uses $\pi/4$-DQPSK (differential QPSK) and a training sequence length of 14 differential symbols. The 14 differential symbols can be converted to 15 coherent symbols (absolute phase values) by postulating the first coherent symbol in the training sequence to be 0. Due to intersymbol interference, the beginning and the end of a received training sequence may be influenced by symbols belonging to the data fields 208, 209 surrounding the synchronization and training field 211 (see Fig. 2). Thus preferably not all symbols in the training sequence are used to determine the quality estimates, but only an inner subsequence consisting of twelve consecutive coherent symbols starting with the second coherent symbol, i.e. the first coherent symbol and the last two coherent symbols of the training sequence are omitted from the inner subsequence.

In this particular embodiment of the preprocessor block 501, the quality estimates of each digitized antenna signal are simply calculated by correlating sequences of samples included in the digitized antenna signal with the inner subsequence of the predetermined training sequence. The sequences of samples used in the correlation are selected to each include samples corresponding to twelve symbols, i.e. the length of the inner subsequence of the predetermined training sequence, and are mutually displaced one sampling interval relative to each other so as to represent the different possible synchronization positions of the digitized antenna signal. Quality estimates are determined for a synchronization window of typically +/- 15 symbols, i.e. covering the worst possible time alignment error of the bursts received from the first mobile station MS1.

In order to reduce the effect of signal strength variations, each quality estimate is scaled with the average signal strength of the samples in the sequence of samples used to calculate the quality estimate.

The signal quality estimators 601 thus calculate quality estimate vectors δ_1, δ_2, δ_3 and δ_4 for each respective digitized antenna signal S41-S44. Since in this exemplary embodiment of a receiving apparatus according to the invention, the analog-to-digital converters 403 (see Fig. 4) provides 8 samples for each symbol interval, a total of 240 quality estimates will be determined for each digitized antenna signal.

The quality estimate vectors δ_1-δ_4 are fed into low pass filters 602 wherein each element of the quality estimate vectors are low pass filtered so as to provide quality estimate vectors accounting for the degree of match between the predetermined training sequence and the respective digitized antenna signal for a number of consecutive occurences of the predetermined training sequence. The low pass filters 602 thus calculates low pass filtered quality estimate vectors δ_{LP1}, δ_{LP2}, δ_{LP3} and δ_{LP4} for each respective digitized antenna signal S41-S44.

The low pass filtered quality estimate vectors δ_{LP1}-δ_{LP4} are fed into an evaluator block 603. The evaluator block 603 forms a quality matrix Q from the filtered quality estimate vectors δ_{LP1}-δ_{LP4}. Each row of the matrix corresponds to one of the filtered quality estimate vectors δ_{LP1}-δ_{LP4}, and thus corresponds to one of the digitized antenna signals S41-S44 represented by index a (a=0...3), while each column of the matrix corresponds to one synchronization position/timing offset represented by index p (p=0...p_{max}). The quality matrix Q can be expressed mathematically as

$$Q=\begin{bmatrix} \delta_{a=0,p=0} & \delta_{a=0,p=1} & . & . & \delta_{a=0,p=p_{\max}} \\ \delta_{a=1,p=0} & \delta_{a=1,p=1} & . & . & \delta_{a=1,p=p_{\max}} \\ \delta_{a=2,p=0} & \delta_{a=2,p=1} & . & . & \delta_{a=2,p=p_{\max}} \\ \delta_{a=3,p=0} & \delta_{a=3\ ,p=0} & . & . & \delta_{a=3,p=p_{\max}} \end{bmatrix} \quad (1)$$

After completing the quality matrix Q, the evaluator block 603 forms a plurality of combined quality metrics and determines a maximum combined quality metric q_{max}, i.e. a best combined quality metric, by determining the expression

$$q_{\max} = \underset{a=0..a_{\max-1}}{MAX}\left[\underset{p=0..p_{\max}}{MAX}\left[(\delta_{a,p}+\delta_{a+1,MAX(0,p-w)});...;(\delta_{a,p}+\delta_{a+1,p});...;(\delta_{a,p}+\delta_{a+1,MIN(p+w,p_{\max})})\right]\right] \quad (2)$$

where

w = search window covering possible timing differences between receiver paths, including differences in radio channel characteristics (e.g. multi-path) between receiver antennas and differences in group delay for the different receiver chains. In a TIA/EIA-136 radio communication system with 8 samples per symbol, w=8 is a suitable value, i.e. a window corresponding to one symbol interval.

Expression (2) implies that when forming the plurality of combined quality metrics, a priori knowledge of which geographical areas the different antenna lobes L1-L4 covers is used to determine from which at least two digitized antenna signals S41-S44 quality estimates may be combined to form a combined quality estimate. More in particular, only quality estimates of digitized antenna signals associated with adjacent antenna lobes, i.e L1 and L2, L2 and L3, L3 and L4, which partly overlap each other are combined. Furthermore, expression (2) implies that only quality estimates for synchronization positions within a predetermined distance in time of each other are combined when forming a combined quality estimate. More in particular, the predetermined distance in time corresponds to one symbol interval.

The evaluator block 603 selects a subset of the first set of digitized antenna signals S41-S44 by selecting the two digitized antenna signals to which the quality estimates forming the best combined quality metric belongs. The evaluator block 603 also determines the synchronization positions of the two selected digitized antenna signals as being the respective position of the quality estimates forming the best combined quality metric.

Thus the evaluator block 603 performs a plurality of functions including acting as combining means for forming the combined quality metrics and acting as evaluating means for selecting the two digitized antenna signals to which the quality estimates forming the best combined quality metric belongs.

A multiplexor 604 receives a control signal S61 from the evaluator 603 informing the multiplexor 604 of which two digitized antenna signals constitutes the subset 506 of digitized antenna signals selected by the evaluator 603 and the determined synchronization positions of said selected signals. The multiplexor 605 also receives the first set 405 of digitized antenna signals S41-S44 and provides as output from the preprocessor block 501 the selected two digitized antenna signals, while the remaining two digitized antenna signals are discarded.

Apart from the exemplary embodiments of the invention disclosed above, there are several ways of providing rearrangements, modifications and substitutions resulting in additional embodiments of the invention.

In order to reduce the processing capacity consumed by the preprocessor block 501, the preprocessor block 501 can be adapted to intially operate in a first mode using an extensive quality matrix as disclosed above. After receiving a number of consecutive uplink bursts, e.g. 5 bursts, from the first mobile station MS1 in the same antenna group and with approximately the same timing (+/- 1 symbol interval), the connection with the first mobile station MS1 can be regarded as established and the preprocessor block 501 may enter a second mode in which it operates using a much smaller quality matrix in terms of the number of columns (corresponding to the number of different possible synchronization positions considered) and/or the number of rows (corresponding to the number of digitized antenna signals considered for selection). In this second mode the number of columns of the used quality matrix can be reduced to correspond to a search window corresponding to e.g. +/- 3 symbols which results in 48 columns instead of the original 240 columns. In a receiver where the first set of digitized antenna signals only includes 4 digitized antenna signals, the quality matrix used in the second mode would still typically contain quality estimates of all 4 digitized antenna signals.

In another alternative embodiment of the preprocessor block 501, the number of quality estimates calculated per symbol interval may be reduced e.g. to a single quality estimate per symbol interval. Thus the number of columns of the quality matrix would be reduced from 240 to 30. Once the selection of digitized antenna signals and a coarse synchronization of the selected digital antenna signals have been performed using the quality matrix, fine synchronization of the selected digitized antenna signals are performed. The fine synchronization is performed based on a tighter sampling, e.g. 8 samples per symbol, as compared to the coarse synchronization but using a small synchronization window, e.g. +/- 3 symbols and may be performed on each selected branch seperately.

Yet another way of reducing the processing capacity consumed by the preprocessor block 501 when intially establishing communication with the first mobile station MS1 would be to use a priori information reflecting the whereabouts of the first mobile station MS1 and its transmission timing to reduce the required initial size of the quality matrix. Said information may e.g. be provided by a previous base station in a handoff situation or by dedicated measurement devices. To what extent the quality matrix can be reduced depends on the precision of the whereabouts and transmission timing of the first mobile station MS1 offered by said information.

There are alternative ways of forming quality estimates for a digitized antenna signal which reflects the degree of match between the predetermined training sequence and the digitized antenna signal for different possible synchronization positions of the digitized antenna signal. One such alternative would be to form quality estimates in similar ways as disclosed in U.S. patent 5,199,047 by, for different possible synchronization positions of the digitized antenna signal, estimating a channel impulse response and comparing the digitized antenna signal to a version of the predetermined training sequence which has been modified by the estimated channel impulse response.

A multitude of different antenna system configurations may be used in connection with the invention apart from the exemplary antenna configuration of the base station BS1 disclosed in Fig. 1. In a preferred embodiment of the invention, the antenna system configuration provides at least three different antenna lobes pointing in different directions and/or having different polarisations. In order to fully utilise the performance enhancement of the invention, the antenna lobes should be arranged in such a way that in all, or at least most, of the coverage area, there are at least two antenna lobes providing radio coverage. This can be achieved in a first embodiment of an antenna system by selecting the antenna lobe directions such that sufficient overlap is achieved between adjacent antenna lobes. In a second embodiment of an antenna system using antennas with two polarisation branches, typically +45 and -45 degrees from the vertical plane, pairs of antenna lobes covering the same area but having different polarisation can be provided to ensure that there are at least two antenna lobes providing radio coverage anywhere in the coverage area.

The antenna lobe directions of adjacent antenna lobe pairs in the antenna system according to the second embodiment can be dispersed further as compared to the antenna lobe directions of adjacent antenna lobes in the first embodiment while retaining radio coverage of at least two antenna lobes in most of the coverage area.

A priori knowledge of which geographical areas different antenna lobes cover is preferably used when determining how quality estimates of digital antenna signals associated with different antenna lobes should be combined to form combined quality metrics. Preferably only quality estimates of digitized antenna signals associated with antenna lobes which at least partly overlaps each other are combined.

Thus, according to the exemplary embodiment disclosed in Fig. 4-6, only quality estimates of digitized antenna signals associated with antenna lobes adapted to have a substantial mutual overlap are considered for combination when forming combined quality metric. As an example, antenna lobes L1 and L2 in Fig. 1 are adapted to have a substantial mutual overlap while antenna lobes L1 and L4 are adapted to have essentially no overlap. Digitized antenna signals S41, S42 and S44 are associated with antenna lobes L1, L2 and L4 respectively (see Fig. 4). In this exemplary embodiment, quality estimates of the digitized antenna signal S41 are combined with quality estimates of the digitized antenna signal S42 but not with quality estimates of the digitized antenna signal S44 to provide combined quality metrics.

Yet another example of how a priori knowledge of which geographical areas different antenna lobes cover may be used to determine from which digitized antenna signals quality estimates may be combined can be found in another exemplary embodiment of the invention, wherein a first set of digitized antenna signals includes a first digitized antenna signal associated with a first antenna lobe and a second digitized antenna signal associated with a second antenna lobe and wherein the first and second antenna lobes have different polarisation and are adapted to have a substantial mutual overlap. According to this exemplary embodiment of the invention, quality estimates of the first digitized antenna signal are combined with quality estimates of the second digitized antenna signal to provide combined quality metrics.

It is of course possible to select a true subset containing more than two digitized antenna signals. The number of digitized antenna signals selected to generate an estimate of the transmitted digital sequence is typically determined as a trade off between an expected improvement in the reliability of the estimate by using an increased number of digitized antenna signals as a basis for the estimate and the increase in the complexity of the estimation process caused by using an increased number of digitized antenna signals. In preferred embodiments of the invention, the number of quality estimates combined to form each combined quality metric equals the number of digitized antenna signals included in the selected subset.

In the exemplary embodiment of a receiver apparatus disclosed in Fig. 4-6, interference rejection diversity combining is performed on the subset 506 of digitized antenna signals selected by the preprocessor 501. In other embodiments of the invention other forms of diversity combining may be used when processing the selected subset of digitized antenna signals. Examples of such other diversity combining methods are maximum ratio combining (MRC) and equal-gain combining which are both well known to a person skilled in the art.

The invention is in no way limited in its application to only TIA/EIA-136 compliant radio communication systems, but is on the contrary applicable to radio communication systems conforming to a multitude of different air interface specifications such as e.g. the Global System for Mobile communication (GSM) standard and the Personal Digital Cellular (PDC) standard. Generally, as long as a digital symbol sequence transmitted by radio includes at least one occurence of a predetermined training sequence, i.e. a known symbol sequence, the invention may be applied when receiving said digital symbol sequence.

CLAIMS

1. A method for receiving a digital symbol sequence (S) transmitted by radio, said digital symbol sequence (S) including at least one occurence of a predetermined training sequence (211), the method comprising the steps of:

generating (301) a first set (405) of digitized antenna signals comprising at least three digitized antenna signals (S41-S44) by receiving and digitizing a plurality of radio signals representing the transmitted digital symbol sequence (S);

selecting (302-304) from the first set (405) a true subset (506) of digitized antenna signals containing fewer digitized antenna signals than the first set (405);

processing (305) the selected subset (506) of digitized antenna signals to generate an estimate (S_{EST}) of the transmitted digital symbol sequence (S),

c h a r a c t e r i z e d in that the selecting step involves the substeps of:

forming (302) a plurality of quality estimates (δ_{LP1}-δ_{LP4}) for each of the digitized antenna signals (S41-S44) in the first set (405), the quality estimates of each digitized antenna signal (S41-S44) reflecting the degree of match between the predetermined training sequence (211) and the digitized antenna signal for different possible synchronization positions of the digitized antenna signal;

forming (303) a plurality of combined quality metrics, each combined quality metric being formed by combining at least two quality estimates of different digitized antenna signals in the first set (405);

selecting (304) the true subset (506) of digitized antenna signals based on an analysis of the combined quality metrics.

2. A method according to claim 1, wherein the first set (405) of digitized antenna signals (S41-S44) includes digitized antenna signals associated with different antenna lobes (L1-L4) and wherein, when forming the plurality of combined quality metrics, a priori knowledge of which geographical areas the different antenna lobes (L1-L4) cover is used to determine from which at least two digitized antenna signals (S41-S44) quality estimates may be combined to form a combined quality metric.

3. A method according to any one of claims 1-2, wherein only quality estimates of digitized antenna signals associated with antenna lobes which at least partly overlap each other are considered for combination when forming a combined quality metric.

4. A method according to any one of claims 1-3, wherein only quality estimates of digitized antenna signals associated with antenna lobes adapted to have a substantial mutual overlap are considered for combination when forming a combined quality metric.

5. A method according to any one of claims 1-4, wherein said first set of at least three digitized antenna signals includes a first digitized antenna signal associated with a first antenna lobe and a second digitized antenna signal associated with a second antenna lobe, the first and the second antenna lobes have different polarisation and are adapted to have a substantial mutual overlap and wherein quality estimates of the first digitized antenna signal are combined with quality estimates of the second digitized antenna signal to provide combined quality metrics.

6. A method according to claim 5, wherein the first and the second antenna lobes essentially covers the same geographical area.

7. A method according to any one of claims 1-4, wherein the first set of digitized antenna signals includes a first digitized antenna signal (S41) associated with a first antenna lobe (L1), a second digitized antenna signal (S42) associated with a second antenna lobe (L2) and a third digitized antenna signal (S44) associated with a third antenna lobe (L4), the first antenna lobe (L1) and the second antenna lobe (L2) are adapted to have a substantial mutual overlap while the first antenna lobe (L1) and the third antenna lobe (L4) are adapted to have essentially no overlap and wherein quality estimates of the first digitized antenna signal (S41) are combined with quality estimates of the second digitized antenna signal (S42) but not with quality estimates of the third digitized antenna signal (S44) to provide combined quality metrics.

8. A method according to any one of claims 1-7, wherein only quality estimates for synchronization positions within a predetermined distance in time of each other are considered for combination when forming a combined quality metric.

9. A method according to claim 8, wherein the predetermined distance in time corresponds to one symbol period.

10. A method according to claim 8, wherein the predetermined distance in time is selected in dependence of an estimated maximum timing difference between the digitized antenna signals caused by differences in radio channel characteristics and differences in group delay of circuitry generating the respective digitized antenna signal.

11. A method according to any one of claims 1-10, wherein the number of quality estimates combined to form each combined quality metric equals the number of digitized antenna signals included in the selected subset.

12. A method according to claim 11, wherein selecting the subset of antenna signals based on the combined quality metrics includes the substeps of:

determining a best combined quality metric among the formed plurality of combined quality metrics;

selecting the subset of digitized antenna signals to consist of the digitized antenna signals to which the quality estimates forming the best combined quality metric belongs.

13. A method according to any one of claims 1-12, wherein each of the combined quality metrics are formed by combining quality estimates of two different digitized antenna signals.

14. A method according to any one of claims 1-13, wherein the digital symbol sequence (S) includes repeated occurences of the predetermined training sequence (211) and the quality estimates of each digitized antenna signal (S41-S44) in the first set (405) is averaged or low pass filtered to account for the degree of match between the predetermined training sequence and the digitized antenna signal for a number of consecutive occurences of the predetermined training sequence.

15. A receiving apparatus (BS1) for receiving a digital symbol sequence (S) transmitted by radio, said digital symbol sequence (S) including at least one occurence of a predetermined training sequence (211), the receiving apparatus (BS1) comprising:

receiving means (401, 402, 403) for generating a first set (405) of digitized antenna signals comprising at least three digitized antenna signals (S41-S44) by receiving and digitizing a plurality of radio signals representing the transmitted digital symbol sequence (S);

selecting means (501) for selecting from the first set (405) a true subset (506) of digitized antenna signals containing fewer digitized antenna signals than the first set (405);

estimating means (502a, 502b, 503, 504, 505) for processing the selected subset (506) of digitized antenna signals to generate an estimate (S_{EST}) of the transmitted digital symbol sequence (S), c h a r a c t e r i z e d in that the selecting means (501) includes:

signal quality estimating means (601, 602) adapted to form a plurality of quality estimates (δ_{LP1}-δ_{LP4}) for each of the digitized antenna signals (S41-S44) in the first set (405), the quality estimates of each digitized antenna signal (S41-S44) reflecting the degree of match between the predetermined training sequence (211) and the digitized antenna signal for different possible synchronization position of the digitized antenna signal;

combining means (603) adapted to form a plurality of combined quality metrics, each combined quality metric being formed by combining at least two quality estimates of different digitized antenna signals in the first set; and

evaluating means (603) adapted to select the true subset (506) of digitized antenna signals based on an analysis of the combined quality metrics.

16. A receiving apparatus (BS1) according to claim 15, wherein the receiving means (401, 402, 403) are adapted to generate the first set (405) of digitized antenna signals (S41-S44) to include digitized antenna signals associated with different antenna lobes (L1-L4) and wherein the combining means (603) are adapted to use a priori knowledge of which geographical areas the different antenna lobes (L1-L4) cover to determine from which at least two digitized antenna signals (S41-S44) quality estimates may be combined to form a combined quality metric.

17. A receiving apparatus (BS1) according to any one of claims 15-16, wherein the combining means (603) are adapted to only combine quality estimates of digitized antenna signals

associated with antenna lobes which at least partly overlap each other when forming a combined quality metric.

18. A receiving apparatus (BS1) according to any one of claims 15-17, wherein the combining means (603) are adapted to only combine quality estimates of digitized antenna signals associated with antenna lobes adapted to have a substantial mutual overlap when forming a combined quality metric.

19. A receiving apparatus (BS1) according to any one of claims 15-18, wherein the combining means (603) are adapted to only combine estimates for synchronization positions within a predetermined distance in time of each other when forming a combined quality metric.

20. A receiving apparatus (BS1) according to claim 19, wherein the predetermined distance in time corresponds to one symbol period.

21. A receiving apparatus (BS1) according to claim 19, wherein the predetermined distance in time is selected in dependence of an estimated maximum timing difference between the digitized antenna signals caused by differences in radio channel characteristics and differences in group delay of circuitry generating the respective digitized antenna signal.

22. A receiving apparatus (BS1) according to any one of claims 15-21, wherein the number of quality estimates combined by the combining means (603) to form each combined quality metric equals the number of digitized antenna signals included in the subset (506) of digitized antenna signals selected by the evaluating means (603).

23. A receiving apparatus (BS1) according to claim 22, wherein the evaluating means (603) are adapted to select the subset of digitized antenna signals by determining a best combined quality metric among the formed plurality of combined quality metrics and selecting the subset of digitized antenna signals to consist

of the digitized antenna signals to which the quality estimates forming the best combined quality metric belongs.

24. A receiving apparatus (BS1) according to any one of claims 15-23, wherein the combining means (603) are adapted to form each combined quality metrics by combining quality estimates of two different digitized antenna signals.

25. A receiving apparatus (BS1) according to any one of claims 15-24, wherein the digital symbol sequence (S) includes repeated occurences of the predetermined training sequence (211) and the signal quality estimating means (601, 602) are adapted to form quality estimates accounting for the degree of match between the predetermined training sequence and the digitized antenna signal for a number of consecutive occurences of the predetermined training sequence by performing averaging or low pass filtering of the quality estimates of each digitized antenna signal (S41-S44) in the first set (405).

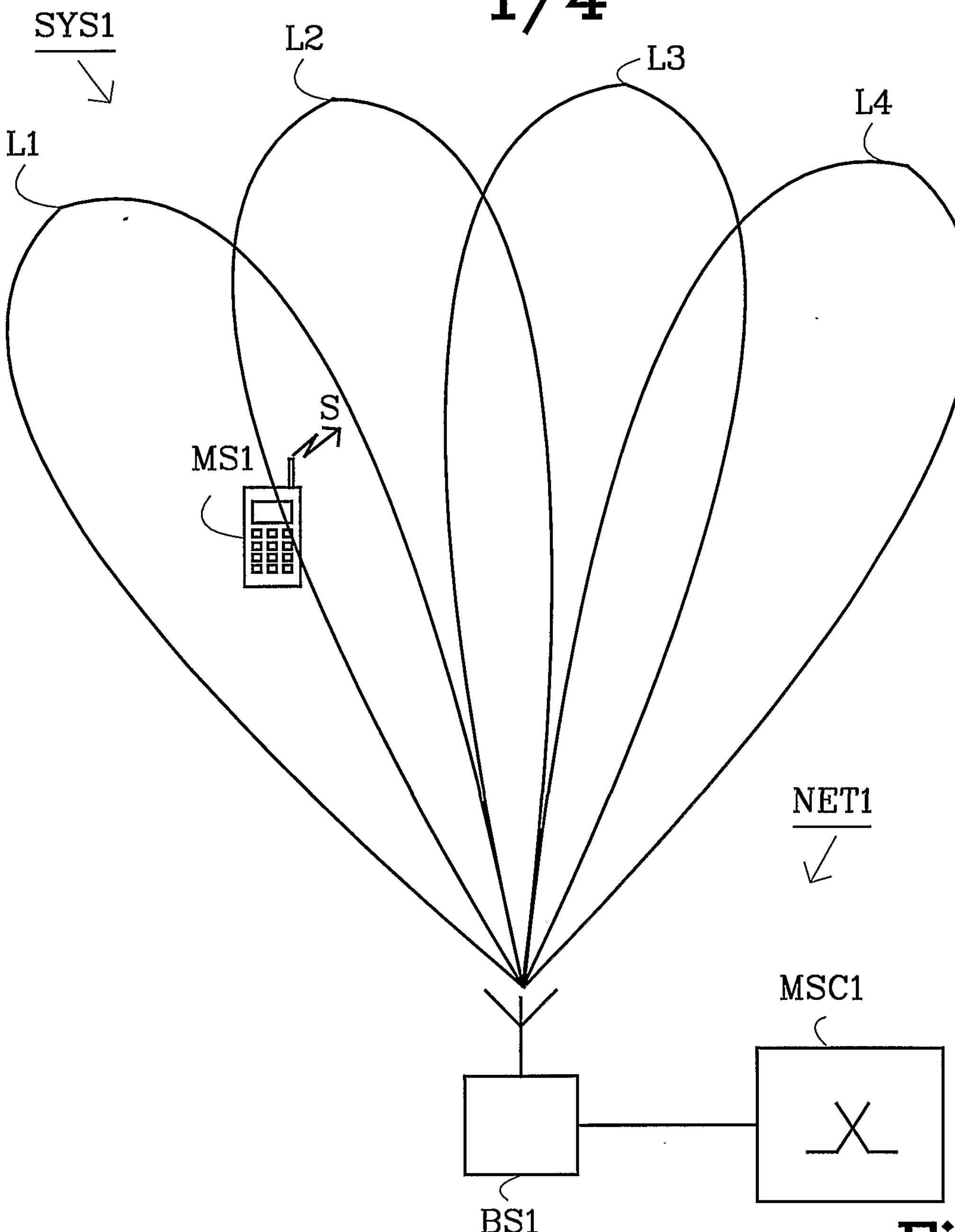

SYS1
L1
L2
L3
L4
S
MS1
NET1
MSC1
BS1

Fig. 1

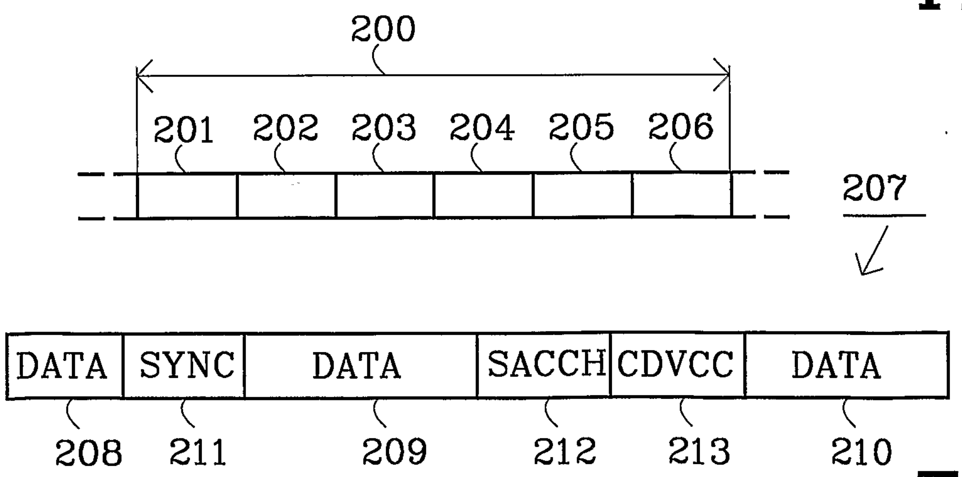
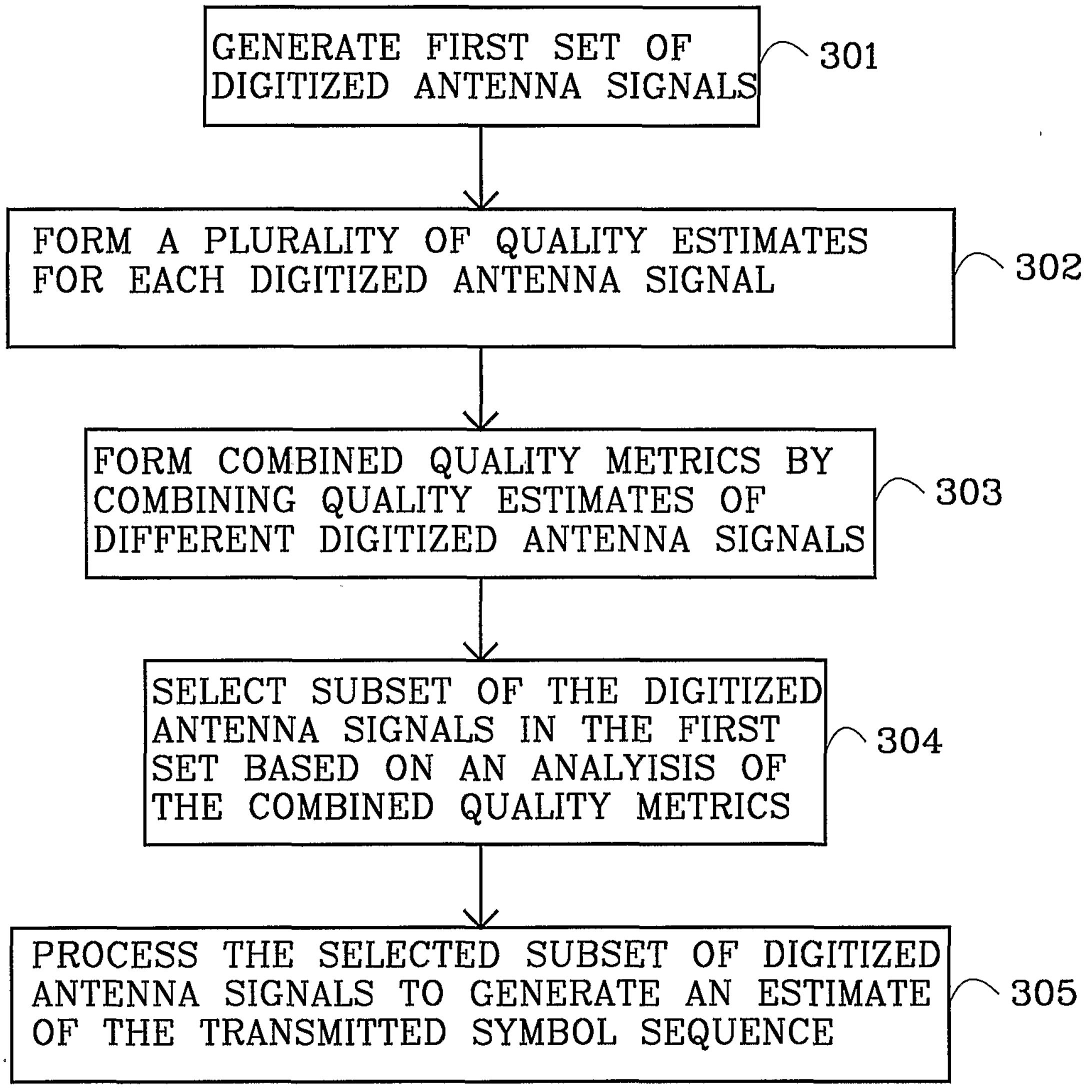

200
201
202
203
204
205
206
207
DATA
SYNC
DATA
SACCH
CDVCC
DATA
208
211
209
212
213
210

Fig. 2



GENERATE FIRST SET OF DIGITIZED ANTENNA SIGNALS
301
FORM A PLURALITY OF QUALITY ESTIMATES FOR EACH DIGITIZED ANTENNA SIGNAL
302
FORM COMBINED QUALITY METRICS BY COMBINING QUALITY ESTIMATES OF DIFFERENT DIGITIZED ANTENNA SIGNALS
303
SELECT SUBSET OF THE DIGITIZED ANTENNA SIGNALS IN THE FIRST SET BASED ON AN ANALYISIS OF THE COMBINED QUALITY METRICS
304
PROCESS THE SELECTED SUBSET OF DIGITIZED ANTENNA SIGNALS TO GENERATE AN ESTIMATE OF THE TRANSMITTED SYMBOL SEQUENCE
305

Fig. 3

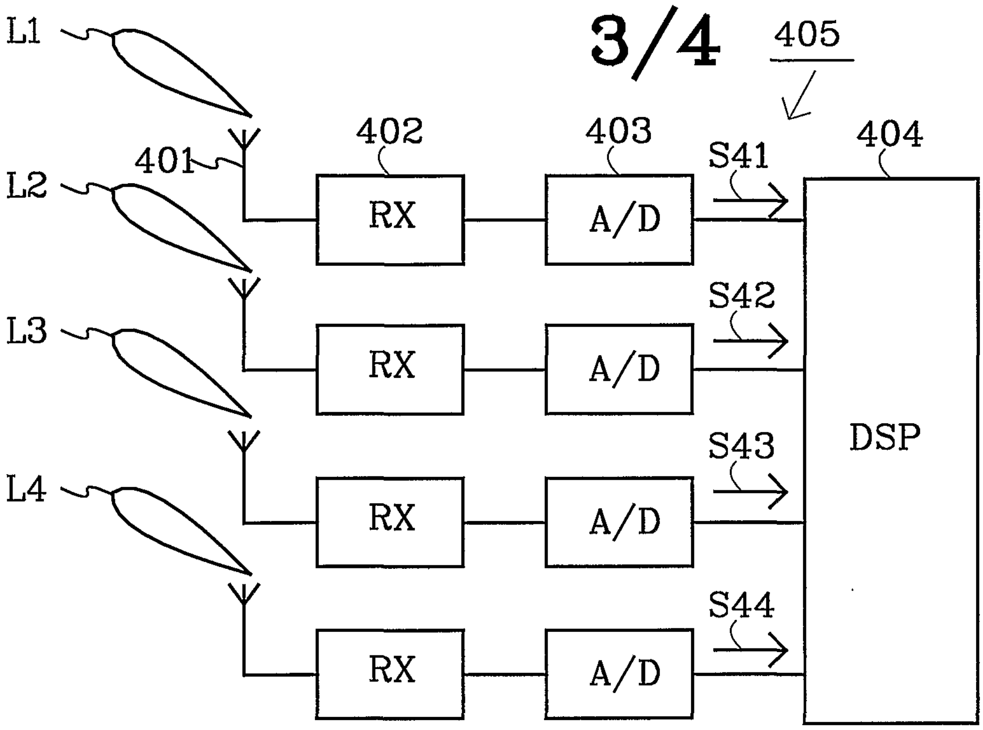

405
L1
L2
L3
L4
401
402
403
404
RX
RX
RX
RX
A/D
A/D
A/D
A/D
S41
S42
S43
S44
DSP

Fig. 4

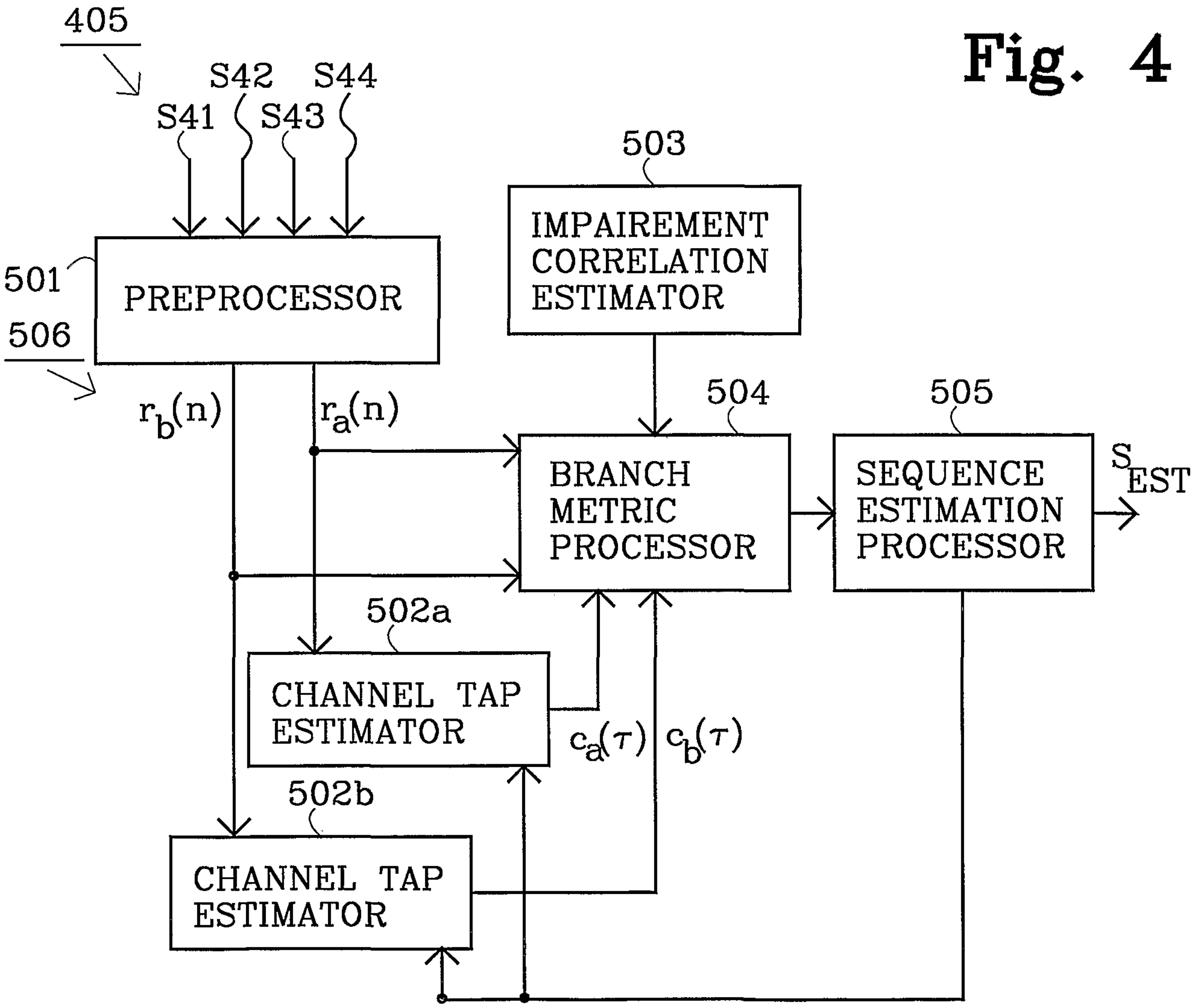

405
S41
S42
S43
S44
501
506
PREPROCESSOR
503
IMPAIREMENT
CORRELATION
ESTIMATOR
504
505
$r_b(n)$
$r_a(n)$
BRANCH
METRIC
PROCESSOR
SEQUENCE
ESTIMATION
PROCESSOR
S_{EST}
502a
CHANNEL TAP
ESTIMATOR
$c_a(\tau)$
$c_b(\tau)$
502b
CHANNEL TAP
ESTIMATOR

Fig. 5

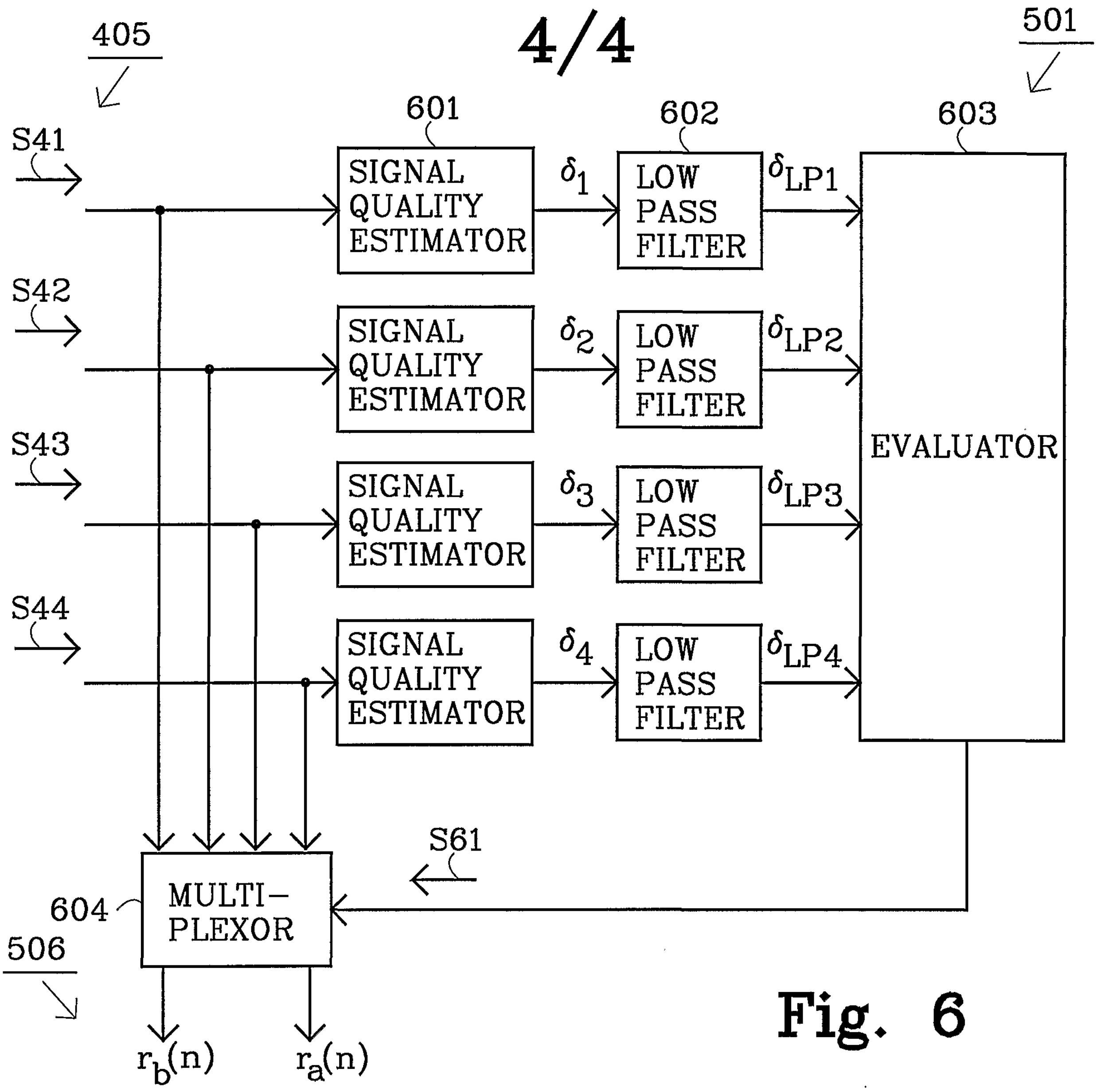

405
501
601
602
603
S41
S42
S43
S44
SIGNAL QUALITY ESTIMATOR
SIGNAL QUALITY ESTIMATOR
SIGNAL QUALITY ESTIMATOR
SIGNAL QUALITY ESTIMATOR
δ_1
δ_2
δ_3
δ_4
LOW PASS FILTER
LOW PASS FILTER
LOW PASS FILTER
LOW PASS FILTER
δ_{LP1}
δ_{LP2}
δ_{LP3}
δ_{LP4}
EVALUATOR
S61
604
MULTI–PLEXOR
506
$r_b(n)$
$r_a(n)$

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/01587

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04B 7/08

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)

IPC7: H04B

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

SE,DK,FI,NO classes as above

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 9740588 A1 (ERICSSON INC.), 30 October 1997 (30.10.97), see the whole document. Cited in the application --	1-25
A	IEICE TRANS. COMMUN., Volume E77-B, No 5, May 1994, Hidekazu Murata, Susumu Yoshida and Tsutomu Takeuchi, "Adaptive Receiver Consisting of MLSE and Sector-Antenna Diversity for Mobile Radio Communications" page 573 - page 579 --	1-25

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 October 2001	19 -10- 2001
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Bo Gustavsson/AE Telephone No. +46 8 782 25 00

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/01587

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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