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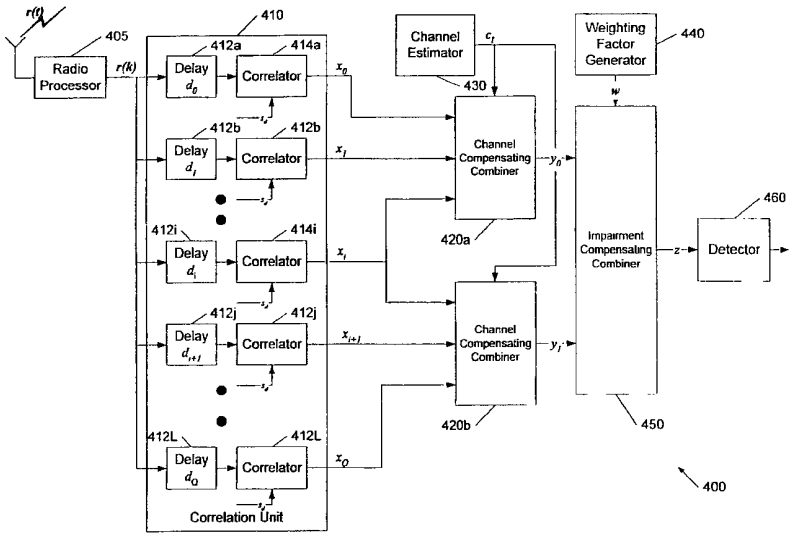
(54) Title: MULTISTEP RAKE COMBINING METHOD AND APPARATUS



(57) Abstract: Information encoded in a spread spectrum signal transmitted in a communications medium is recovered. A composite signal including a spread spectrum signal is received from the communications medium, and correlated with a spreading sequence to generate time-offset correlations. Respective first and second groups of the correlations are combined, e.g., according to estimated channel coefficients, to produce respective first and second combined values. The first and second combined values are then combined in a manner that compensates for correlated impairment in the composite signal to generate an estimate information in the transmitted spread spectrum signal, e.g., using weighting factors generated from an estimated composite channel response and an estimated impairment correlation, or adaptively generated weighting factors.

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MULTISTEP RAKE COMBINING METHOD AND APPARATUS

MULTI-STAGE RAKE COMBINING METHODS AND APPARATUS

Cross-Reference to Related Application

This application is related to Application Serial No. _____, filed concurrently herewith, entitled *Rake Combining Methods and Apparatus Using Weighting Factors Derived from Knowledge of Spread Spectrum Signal Characteristics,* to Wang et al., (Attorney Docket No. 8194-306) assigned to the assignee of the present application. The disclosure of this application is hereby incorporated herein by reference.

Field of the Invention

The present invention relates to communications methods and apparatus, and more particularly, to spread spectrum communications methods and apparatus.

Background of the Invention

Wireless communications systems are commonly employed to provide voice and data communications to subscribers. For example, analog cellular radiotelephone systems, such as those designated AMPS, ETACS, NMT-450, and NMT-900, have long been deployed successfully throughout the world. Digital cellular radiotelephone systems such as those conforming to the North American standard IS-54 and the European standard GSM have been in service since the early 1990's. More recently, a wide variety of wireless digital services broadly labeled as PCS (Personal Communications Services) have been introduced, including advanced digital cellular systems conforming to standards such as IS-136 and IS-95, lower-power systems such as DECT (Digital Enhanced Cordless Telephone) and data communications services such as CDPD (Cellular Digital Packet Data). These and other systems are described in *The Mobile Communications Handbook*, edited by Gibson and published by CRC Press (1996).

Fig. 1 illustrates a typical terrestrial cellular radiotelephone communication system **20**. The cellular radiotelephone system **20** may include one or more radiotelephones (terminals) **22**, communicating with a plurality of cells **24** served by base stations **26** and a mobile telephone switching office (MTSO) **28**. Although only three cells **24** are shown in

Fig. 1, a typical cellular network may include hundreds of cells, may include more than one MTSO, and may serve thousands of radiotelephones.

The cells **24** generally serve as nodes in the communication system **20**, from which links are established between radiotelephones **22** and the MTSO **28**, by way of the base stations **26** serving the cells **24**. Each cell **24** will have allocated to it one or more dedicated control channels and one or more traffic channels. A control channel is a dedicated channel used for transmitting cell identification and paging information. The traffic channels carry the voice and data information. Through the cellular network **20**, a duplex radio communication link may be effected between two mobile terminals **22** or between a mobile terminal **22** and a landline telephone user **32** through a public switched telephone network (PSTN) **34**. The function of a base station **26** is to handle radio communication between a cell **24** and mobile terminals **22**. In this capacity, a base station **26** functions as a relay station for data and voice signals.

As illustrated in Fig. 2, a satellite **42** may be employed to perform similar functions to those performed by a conventional terrestrial base station, for example, to serve areas in which population is sparsely distributed or which have rugged topography that tends to make conventional landline telephone or terrestrial cellular telephone infrastructure technically or economically impractical. A satellite radiotelephone system **40** typically includes one or more satellites **42** that serve as relays or transponders between one or more earth stations **44** and terminals **23**. The satellite conveys radiotelephone communications over duplex links **46** to terminals **23** and an earth station **44**. The earth station **44** may in turn be connected to a public switched telephone network **34**, allowing communications between satellite radiotelephones, and communications between satellite radio telephones and conventional terrestrial cellular radiotelephones or landline telephones. The satellite radiotelephone system **40** may utilize a single antenna beam covering the entire area served by the system, or, as shown, the satellite may be designed such that it produces multiple minimally-overlapping beams **48**, each serving distinct geographical coverage areas **50** in the system's service region. The coverage areas **50** serve a similar function to the cells **24** of the terrestrial cellular system **20** of Fig. 1.

Several types of access techniques are conventionally used to provide wireless services to users of wireless systems such as those illustrated in Figs. 1 and 2. Traditional analog cellular systems generally employ a system referred to as frequency division multiple access (FDMA) to create communications channels, wherein discrete frequency bands serve

as channels over which cellular terminals communicate with cellular base stations. Typically, these bands are reused in geographically separated cells in order to increase system capacity.

Modern digital wireless systems typically utilize different multiple access techniques such as time division multiple access (TDMA) and/or code division multiple access (CDMA) to provide increased spectral efficiency. In TDMA systems, such as those conforming to the GSM or IS-136 standards, carriers are divided into sequential time slots that are assigned to multiple channels such that a plurality of channels may be multiplexed on a single carrier. CDMA systems, such as those conforming to the IS-95 standard, achieve increased channel capacity by using "spread spectrum" techniques wherein a channel is defined by modulating a data-modulated carrier signal by a unique spreading code, *i.e.*, a code that spreads an original data-modulated carrier over a wide portion of the frequency spectrum in which the communications system operates.

Conventional spread-spectrum CDMA communications systems commonly use so-called "direct sequence" spread spectrum modulation. In direct sequence modulation, a data-modulated carrier is directly modulated by a spreading code or sequence before being amplified by a power amplifier and transmitted over a communications medium, *e.g.*, an air interface. The spreading code typically includes a sequence of "chips" occurring at a chip rate that typically is much higher than the bit rate of the data being transmitted.

Typical transmit operations of such a system are illustrated in Fig. 3. Data streams from different users are subjected to various signal processing steps, such as error correction coding or interleaving, and spread using a combination of a user specific spreading code and a group-specific scrambling code. The coded data streams from the users are then combined, subjected to carrier modulation and transmitted as a composite signal in a communications medium.

A so-called RAKE receiver structure is commonly used to recover information corresponding to one of the user data streams. In a typical RAKE receiver, a received composite signal is typically correlated with a particular spreading sequence assigned to the receiver to produce a plurality of time-offset correlations, a respective one of which corresponds to an echo of a transmitted spread spectrum signal. The correlations are then combined in a weighted fashion, i.e., respective correlations are multiplied by respective weighting factors and then summed to produce a decision statistic.

The performance of CDMA systems generally is limited by interference among different user signals. Spreading/despreading provides a degree of interference suppression, but the number of users is generally limited by interference.

Conventional RAKE reception techniques generally treat interference as white noise. More recently proposed techniques provide for a degree of interference cancellation through "whitening" of interference. Examples of such techniques are described in "A Noise Whitening Approach to Multiple Access Noise Rejection-Part I: Theory and Background," by Monk et al., *IEEE Journal on Selected Areas in Communications*, vol. 12, pp., 817-827(June 1994); "A Noise Whitening Approach to Multiple Access Noise Rejection-Part II: Implementation Issues," by Monk et al., *IEEE Journal on Selected Areas in Communications*, vol. 14, pp. 1488-1499 (October 1996); "Data Detection Algorithms Specifically Designed for the Downlink of CDMA Mobile Radio Systems," by Klein, 1997 IEEE Vehicular Technology Conference, Phoenix AZ (May 4-7, 1997); United States Patent No. 5,572,552 to Dent et al. (issued November 5, 1996); and "Optimizing the Rake Receiver for Demodulation of Downlink CDMA Signals," by Bottomley, *Proceedings of the 43rd IEEE Vehicular Technology Conference*, Secaucus NJ (May 18-20, 1993).

Unfortunately, these approaches can be highly complex and difficult to implement in a practical receiver. Whitening approaches tend to provide dramatic gains when the number of RAKE fingers greatly exceeds the number of resolvable multipaths in a received signal, and thus a complex receiver design may be needed in order to obtain performance gains offered by such approaches. This complexity can be amplified in soft-handoff situations, in which a terminal is simultaneously receiving signals from multiple base stations. In addition, wide bandwidth next-generation CDMA systems, such as wideband CDMA (WCDMA) and cdma2000, may require even more complex receiver designs due to increased numbers of multipaths.

Summary of the Invention

In light of the foregoing, it is an object of the present invention to provide improved methods and apparatus for recovering information represented by a spread spectrum signal transmitted in a communications medium.

It is another object of the present invention to provide improved methods and apparatus for recovering information represented by a spread spectrum signal that can compensate for interference from other spread spectrum signals transmitted in the communications medium.

It is another object of the present invention to provide improved methods and apparatus for recovering information from spread spectrum signals that can be implemented

using less complex receiver operations and architectures than conventional interference suppression techniques.

These and other objects, features and advantages can be provided, according to the present invention, by methods and apparatus in which a composite signal including a spread spectrum signal is correlated with a desired spreading sequence, and the resulting correlations are subjected to a multistage combining process in which respective groups of correlations are combined to produced intermediate combined values that are subsequently combined in a manner that compensates for correlated impairment in the composite signal. The first stage of combining preferably is a traditional RAKE combining process in which correlations are combined according to channel estimates. The second stage of combining may use a number of different techniques for canceling multiuser interference and other correlated impairment, including explicit computational techniques, interference rejection combining (IRC), or adaptive techniques. Using a multistage approach allows the number of finger elements combined in more complex interference-canceling combining operations to be reduced, thus offering a potential reduction in complexity. The multistage approach also lends itself to hybrid combining techniques.

In particular, according to aspects of the present invention, information encoded in a spread spectrum signal transmitted in a communications medium is recovered. A composite signal including a spread spectrum signal is received from the communications medium, and correlated with a spreading sequence to generate time-offset correlations. Respective first and second groups of the correlations are combined, e.g., according to estimated channel coefficients, to produce respective first and second combined values. The first and second combined values are then combined in a manner that compensates for correlated impairment in the composite signal to generate an estimate information in the transmitted spread spectrum signal.

According to an embodiment of the present invention, the first and second combined values are combined based on an estimated impairment correlation and on a composite channel response that reflects the preceding combining operations. The composite channel response and impairment correlation may be estimated and used to generate weighting factors that are used to combine the first and second combined values. The weighting factors may also be iteratively generated from an estimated composite channel response, an estimated impairment correlation, and previously determined weighting factors. According to another embodiment of the present invention, the first and second combined values are combined according to weighting factors that are adaptively estimated based on a comparison of

combined values generated by the second combining stage to a reference value, such as a pilot symbol value or a decoded symbol value.

According to another aspect of the present invention, an apparatus for recovering information encoded in a spread spectrum signal included in a composite signal includes a correlation unit operative to correlate the composite signal with a spreading sequence to generate time-offset correlations. A multistage combiner is responsive to the correlation unit and operative to combine respective groups of the correlations to provide respective intermediate combined values, and to combine the intermediate combined values in a manner that compensates for correlated impairment in the composite signal to estimate information in the transmitted spread spectrum signal.

According to one embodiment of the present invention, the multistage combiner includes a first combiner responsive to the correlation unit and operative to combine a first group of the correlations to produce a first combined value. A second combiner is responsive to the correlation unit and operative to combine a second group of the correlations to produce a second combined value. A third combiner is responsive to the first combiner and to the second combiner and operative to combine the first and second combined values in a manner that compensates for correlated impairment in the composite signal to generate an estimate of information in the transmitted spread spectrum signal.

The first and second combiners may combine the first and second groups of correlations in a manner that compensates for effect of a channel over which the spread spectrum signal is received, e.g., using channel coefficient estimates. The third combiner may be operative to combine the first and second values based on an estimated impairment correlation and on a composite channel response that reflects effects of the first and second combiners, e.g., using weighting factors determined from an estimated composite channel response and an estimated impairment correlation. Alternatively, the third combiner may combine the first and second values according to adaptively estimated weighting factors.

Brief Description of the Drawings

Fig. 1 is a schematic diagram illustrating a conventional terrestrial cellular communications system.

Fig. 2 is a schematic diagram illustrating a conventional satellite based wireless communications system.

Fig. 3 is a schematic diagram illustrating a conventional wireless base station.

Fig. 4 is a schematic diagram illustrating a multistage RAKE receiver according to an embodiment of the present invention.

Fig. 5 is a schematic diagram illustrating a weighting factor generator according to an embodiment of the present invention.

Fig. 6 is a schematic diagram illustrating an apparatus for detecting and/or determining power of interfering spread spectrum signals.

Fig. 7 is a schematic diagram illustrating a weighting factor generator according to another embodiment of the present invention.

Fig. 8 is a schematic diagram illustrating a weighting factor generator according to another embodiment of the present invention.

Fig. 9 is a flowchart illustrating exemplary operations for generating an estimate of information represented by a spread spectrum signal according to an embodiment of the present invention.

Fig. 10 is a flowchart illustrating exemplary operation for generating an estimate of information represented by a spread spectrum signal according to another embodiment of the present invention.

Detailed Description of Preferred Embodiments

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like numbers refer to like elements.

The discussion herein relates to wireless communications systems, and more particularly, to wireless code division multiple access (CDMA) systems, for example, systems conforming to the IS-95 standards or to proposed standards for wideband CDMA (WCDMA, CDMA2000, and the like). In such wireless communications systems, one or more antennas radiate electromagnetic waveforms generated by a transmitter located, for example, in a mobile terminal or base station. The waveforms are propagated in a radio propagation environment, and are received by a receiver via one or more antennas. It will be understood that although the description herein refers to a radio environment, apparatus and

methods are applicable to other environments, such as wireline communications and recovery of data from magnetic storage media.

The present invention arises from the realization that interference suppression can be achieved with reduced complexity by using multiple combining stages. In an embodiment of the present invention, groups of correlations are combined according to channel coefficients to produce combined values. The combined values are then combined again in a manner that provides interference suppression, e.g., using weighting factors derived from a composite channel response and an impairment correlation or estimated using adaptive filtering techniques.

Fig. 4 illustrates a multistage RAKE receiver **400** according to an embodiment of the present invention, which recovers information represented by a spread spectrum signal transmitted according to a desired spreading sequence s_d from a composite signal ***r(t)*** received from a communications medium. The receiver **400** includes means for receiving the composite signal ***r(t)***, e.g., a radio processor **405** that performs such operations for example, as amplifying the signal ***r(t)***, mixing, filtering and producing baseband samples ***r(k)*** of the received signal ***r(t)***. A correlation unit **410**, here shown as a bank of delays **412a-412L** linked to a bank of correlators **414a-414L**, correlates delayed versions of the baseband signal ***r(k)*** to the desired spreading sequence s_d. It will be appreciated that the radio processor **405** may perform a variety of other functions, and that the correlation unit **410** may be implemented in other forms, such as by using a sliding correlator or by delaying the desired sequence s_d and placing delays **412a-412L** after the correlators **414a-414L**.

Respective first and second groups of correlations x_0-x_i, x_1-x_Q produced by the correlation unit **410** are combined in respective first and second combiners **420a**, **420b**, here shown as channel compensating combiners that combine the correlations according to channel coefficients c_i estimated by a channel estimator **430**. As used herein, "channel compensating" combining generally refers to combining operations that include the use of channel coefficients, including, but not limited to, operations that match a channel response. It will be appreciated that the channel estimator **430** may estimate channel coefficients in a number of different ways, e.g., by estimation from pilot symbols (e.g., in a pilot or other channel) or recovered data symbols. Such techniques are known to those skilled in the art and will not be described in further detail herein.

First and second combined values y_0, y_1 produced by the first and second combiners **420a**, **420b** are combined in a third combiner **450**, here shown as an correlated impairment compensating combiner that combines the first and second combined values y_0, y_1 according

to weighting factors weighting factors w generated by a weighting factor generator **440**. As will be shown in detail below, the weighting factor generator **440** may generate the weighting factors w in a number of different ways, including by explicit calculation from an estimated composite channel response and an estimated impairment correlation, or by adaptive filtering techniques. The third combiner **450** produces a decision statistic z that may be used by a detector **460** to estimate information represented by the originally transmitted spread spectrum signal corresponding to the desired spreading sequence s_d. The detector 460 may, for example, implement soft decision decoding, such as convolutional decoding or turbo decoding.

It will be appreciated that the receiver **400** of Fig. 4 may be implemented in a number of different ways. Although the description herein refers to employment of the receiver **400** in a mobile or other terminal that is operative to communicate with a base station of a wireless communications system, the receiver **400** can be implemented in a number of other forms including, but not limited to, receivers used in cellular base station transceivers, satellite transceivers, wireline transceivers, and other communications devices. The correlation unit **410**, combiners **420a, 420b, 450**, channel estimator **430**, weighting factor generator **440** and detector **460** may be implemented using, for example, an application-specific integrated circuit (ASIC), digital signal processor (DSP) chip or other processing device configured to perform the described processing functions. It will also be understood that, in general, these and other components of the receiver **400** may be implemented using special-purpose circuitry, software or firmware executing on special or general-purpose data processing devices, or combinations thereof.

In a simplified two-ray example for an IS-95 system, correlations x_0, x_1, x_2 of respective groups of correlations x_0, x_1 and x_1, x_2 produced from a correlation unit, such as the correlation unit **410** of Fig. 4, may be represented as:

$$x_0 = \frac{1}{N}\sum_{k=0}^{N-1} s^*(k)r(k) = \frac{1}{N}\sum_{k=0}^{N-1} W(k)p^*(k)r(k) \qquad (1)$$

$$x_1 = \frac{1}{N}\sum_{k=0}^{N-1} s^*(k)r(k+1) = \frac{1}{N}\sum_{k=0}^{N-1} W(k)p^*(k)r(k+1), \qquad (2)$$

and

$$x_2 = \frac{1}{N}\sum_{k=0}^{N-1} s^*(k)r(k+2) = \frac{1}{N}\sum_{k=0}^{N-1} W(k)p^*(k)r(k+2), \qquad (3)$$

where ***r(k)*** is the baseband version of the received signal, ***s(k)*** is the spreading sequence, ***W(k)*** is the Walsh sequence assigned to the receiver, and ***p(k)*** is the complex scrambling sequence used by the base station. Division by N is included for ease of explanation, though it may be omitted in practice. First and second combiners, along the lines of the first and second combiners **420a**, **420b** of Fig. 4, produce first and second combined outputs y_0, y_1, as given by:

$$y_0 = \hat{c}_0^* x_0 + \hat{c}_1^* x_1 \qquad (4)$$

and

$$y_1 = \hat{c}_0^* x_1 + \hat{c}_1^* x_2, \qquad (5)$$

where $\hat{c}_0$ and $\hat{c}_1$ are complex channel coefficient estimates associated with rays whose timing corresponds to x_0 and x_1. The channel coefficient associated with x_2 is zero. Thus, it may be observed that (4) and (5) can be interpreted as describing a sliding RAKE receiver, in that the same channel coefficients are used in both combiners.

The first and second combined values y_0, y_1 are then combined according to weighting factors w_0, w_1 in a weighted combiner, such as the combiner 450 of Fig. 4, producing a decision statistic z, given by:

$$z = w_0^* y_0 + w_1^* y_1, \text{ or} \qquad (6)$$

$$z = \mathrm{Re}\{w_0^* y_0 + w_1^* y_1\},$$

wherein Re{} denotes the real part of the complex argument. The decision statistic can be used, for example, to determine a bit value (e.g., based on the sign of the decision statistic) or to provide soft values for subsequent decoding.

Determining Weighting Factors Explicitly

According to a first embodiment of the present invention, the weighting factors w generated by the weighting factor generator **440** are determined by first estimating a channel response and power of interfering spread spectrum signals (e.g., signals from the same base station or nearby base stations) and thermal noise. The channel response estimate and statistical properties of the desired spreading sequence s_d are then used to determine a "composite" channel (impulse) response h, which reflects effects of the transmit pulse shape filter and/or other elements on the transmitting end, as well as the effects of the communications medium, radio processing elements, and the first and second combiners **420a, 420b**. The channel response estimate and the power estimates are used to determine an overall impairment correlation R that includes respective components attributable to own-cell interference, other-cell interference and thermal noise, to obtain an overall impairment correlation matrix R. The composite channel response h and the overall impairment correlation R are then used to compute the weighting factors w. The weighting factors w are derived taking into account the statistical properties of the spreading sequences, and more particularly, are explicitly calculated using information related to the spreading sequences and the transmitted spread spectrum signals with which they are associated. Weighting factors w can be intermittently calculated, for example, upon substantial changes in the delays **412a-412L** and the channel estimates.

It can be shown that given a set of first stage combiners (e.g., the combiners **420a, 420b** of Fig. 4), the optimal combining weights to be used in the weighted combiner **450** may be expressed as:

$$w \triangleq (w_0, w_1, \ldots, w_{J-1})^T = R^{-1}h, \qquad (7)$$

where **h** is the composite channel response, including the transmit filter, medium, receive filter and first stage combiner responses, and R is the impairment correlation matrix.

It can be further shown that the composite channel response h is given by:

$$h_i = \frac{1}{N}\sum_{j=0}^{L-1} c_j^* \sum_{l=0}^{L-1} c_l \sum_{m=1-N}^{N-1} C(m) R_p(d_i + mT_c + \tau_j - \tau_l), \quad (8)$$

where c_l and τ_l are related to the medium response $c(t) = \sum_{l=0}^{L-1} c_l \delta(t-\tau_l)$, L is the number of multipaths, N is the spreading factor, T_c is the chip duration, $R_p(t)$ is the autocorrelation function of the chip waveform, and $C(m)$ is the aperiodic autocorrelation function of the spreading sequence defined as:

$$C(m) \equiv \begin{cases} \sum_{n=0}^{N-1-m} s(n)s^*(n+m), 0 \le m \le N-1 \\ \sum_{n=0}^{N-1+m} s(n-m)s^*(n), 1-N \le m < 0 \end{cases} \quad (9)$$

where s(n) is the n-th chip of the spreading sequence.

To reduce complexity, traditional channel estimation can be used to estimate part of equation (8), without necessarily using pulse shape and spreading code information.

The impairment correlation matrix $\boldsymbol{R}$ can be decomposed into three terms.:

$$\boldsymbol{R} = \boldsymbol{R}_{ISI} + \boldsymbol{R}_{MUI} + \boldsymbol{R}_n, \quad (10)$$

where $\boldsymbol{R}_{ISI}$, $\boldsymbol{R}_{MUI}$, and $\boldsymbol{R}_n$ are correlation matrices of the inter-symbol interference, multiuser (e.g., intra-cell) interference, and additive white noise, respectively.

These components of $\boldsymbol{R}$ can be computed by the following expressions:

$$R_{ISI}(d_1, d_2) = \frac{1}{N^2} \sum_{l=0}^{L-1} \sum_{j=0}^{L-1} \sum_{p=0}^{L-1} \sum_{q=0}^{L-1} \sum_{i=-\infty, i\neq 0}^{\infty} c_l c_j^* c_p^* c_q \sum_{m=1-N}^{N-1} (N-|m|) \times R_p(d_1 + mT_c + \tau_j - iT - \tau_l) R_p^*(d_2 + mT_c + \tau_q - iT - \tau_p) \quad (11)$$

$$R_{MUI}(d_1, d_2) = \frac{\gamma_I}{N^2} \sum_{j=0}^{L-1} \sum_{p=0}^{L-1} \sum_{i=-\infty}^{\infty} \sum_{l=0}^{L-1} \sum_{q=0}^{L-1} c_l c_j^* c_p^* c_q \sum_{m=1-N}^{N-1} (N-|m|) \times R_p(d_1 + mT_c + \tau_j - iT - \tau_l) R_p^*(d_2 + mT_c + \tau_q - iT - \tau_p)(1 - \alpha\delta(m)\delta(i)) \quad (12)$$

and

$$R_n(d_1, d_2) = \frac{\gamma_N}{N} \sum_{l=0}^{L-1} \sum_{j=0}^{L-1} \sum_{m=1-N}^{N-1} c_l c_j^* C(m) R_p(d_1 - d_2 + mT_c + \tau_j - \tau_l) \quad (13)$$

where γ_I is the multiuser interference to signal power ratio, and γ_N is the noise to signal power ratio. The variable α in (12) takes values on {1, 0}; if orthogonal spreading is used, $\alpha = 1$, whereas if pseudo random spreading is used, $\alpha = 0$. By considering various combinations (including combinations other than d_1, d_2), all elements of the impairment correlation matrix R can be obtained (the infinite summation in i can be truncated to include only significant terms, e.g., i=-1, 0, 1). From the above equations, if the receiver has the knowledge of (1) the channel impulse response $c(t)$, (2) the autocorrelation function of the chip waveform $R_p(t)$, (3) the interference to signal ratio (γ_I), (4) the noise to signal ratio γ_N, and (5) the aperiodic autocorrelation function of the spreading sequence $C(m)$, the weighting factors w can be computed explicitly.

In many applications, multiuser interference is much stronger than inter-symbol interference. Accordingly, the impairment correlation R matrix can be approximated by:

$$R \approx R_{MUI} + R_n \qquad (14)$$

In this case, these terms include a common scaling factor, a signal power S in the ratios γ_I, γ_N. This term can be omitted, so that only the interference power I and noise power need be estimated. Alternatively, signal power can be estimated and used to estimate the ratios γ_I, γ_N.

Furthermore, in practice it may be cumbersome to calculate the aperiodic autocorrelation function $C(m)$, as such a function typically varies from symbol to symbol. To reduce the complexity of weight calculation, an average aperiodic autocorrelation function $\overline{C}(m)$ can be used instead, as given by:

$$\overline{C}(m) = N\delta(m) \qquad (15)$$

Using equations (14) and (15), equations (11) - (13) can be greatly simplified.

In handoff scenarios, the interference as a result of multiuser signals from each base station typically is colored in its own way by the channel response, and the multiuser interference component R_{MUI} can be calculated by:

$$R_{MUI}(d_1,d_2)=\sum_{k=1}^{K}\left\{\begin{array}{l}\frac{\gamma_l^{(k)}}{N^2}\sum_{l=0}^{L-1}\sum_{j=0}^{L-1}\sum_{p=0}^{L-1}\sum_{i=-\infty}^{\infty}\sum_{q=0}^{L-1}c_l^{(k)}(c_j^{(k)})^*(c_p^{(k)})^*c_q^{(k)}\sum_{m=1-N}^{N-1}(N-|m|)\times \\ R_p(d_1+mT_c+\tau_j^{(k)}-iN-\tau_l^{(k)})R_p^*(d_2+mT_c+\tau_q^{(k)}-iN-\tau_p^{(k)})(1-\alpha_k\delta(m)\delta(i))\end{array}\right\} \quad (16)$$

where superscript k is used for indexing base stations, and $k = 1$ corresponds to the base station transmitting the desired spread spectrum signal. Typically, when orthogonal spreading is used, $\alpha_1 = 1$ while $\alpha_k = 0$, for $k \neq 1$. Such an approach may also be used with transmitter diversity, in which the two transmitted signals originate from the same site, but from multiple spatially and/or polarization diverse antennas.

Fig. 5 illustrates an exemplary weighting factor generator **440′** according to an embodiment of the present invention. The weighting factor generator **440′** includes an aperiodic autocorrelation calculator **520** that determines a value of the aperiodic autocorrelation function $C(m)$. Channel tap coefficients c_l provided by channel estimator **430** and the value of the periodic autocorrelation function $C(m)$ are supplied to a composite channel response calculator **530** that calculates the composite channel response $\boldsymbol{h}$ based on the statistical properties of the desired spreading sequence, i.e., the autocorrelation $R_p(t)$ of the desired spreading sequence, using equation (8).

The weighting factor generator **440′** also includes an impairment correlation calculator **540** that computes an impairment correlation $\boldsymbol{R}$ according to equation (10) or (14). The impairment correlation calculator **540** includes a power estimator **542** that supplies respective power ratio estimates γ_1, γ_N that are supplied to respective multiuser interference correlation and noise correlation calculators **546, 548** that compute multiuser interference correlation and noise correlation components $\boldsymbol{R_{MUI}}$, $\boldsymbol{R_N}$, respectively, according to equations (12) and (13). An intersymbol interference correlation calculator **544** calculates an intersymbol interference correlation component $\boldsymbol{R_{ISI}}$. The intersymbol interference impairment correlation, multiuser interference correlation and noise correlation components $\boldsymbol{R_{MUI}}$, $\boldsymbol{R_N}$, $\boldsymbol{R_{ISI}}$ are summed by a summer **549** to produce the impairment correlation R, which is used, along with the composite channel response $\boldsymbol{h}$, to generate weighting factors w in a weighting factor calculator **550**.

It will be understood that the apparatus illustrated in Fig. 5 may be modified along the lines suggested above. For example, the aperiodic autocorrelation calculator **520** may be eliminated, with the average aperiodic autocorrelation $\overline{C}(m)$ being substituted for the calculated aperiodic autocorrelation C(m), as described above in reference to equations (15),

(13) and (8). The intersymbol interference impairment correlation calculator **544** may also be eliminated, along the lines described in reference to equation (14).

Further simplification in determining weighting factors w can be achieved by using an iterative approach that obviates the need to compute the inverse R^{-1} of the impairment correlation R to determine the weighting factors w. The weighting factors w, impairment correlation matrix R, and the composite channel response h form a linear system of the form:

$$Ax=b, \qquad (17)$$

where $A = R$, $x = w$, and $b = h$.

As equation (17) describes a linear system, any of a number of techniques for solving linear systems may be used to find the weights. Preferably, an iterative technique that can compute new weighting factors from already existing weights without requiring matrix inversion is utilized. For example, an iterative Gauss-Seidel technique may be used, where weighting factors w are calculated by:

$$w_i(k+1) = \left(h_i - \sum_{j=0}^{i-1} r_{ij} w_j(k+1) - \sum_{j=i+1}^{n-1} r_{ij} x_j(k) \right) / r_{ii}, \qquad (13)$$

where n is the dimension of the vectors **w** and **h**, r_{ij} is the (i, j)th element of the impairment correlation matrix R, and k is the stage of iteration. Initially, the weighting factor corresponding to a traditional RAKE combined value can be set to one, and other weighting factors set to zero. If the initial guess (the values of **w** in the previous iteration or previous symbol period) are close to the correct solution, the iteration should converge after only one or a few iterations. Convergence can be accelerated by modifying the calculated $w_i(k + 1)$ to:

$$w_i(k + 1) = \lambda w_i(k + 1) + (1 - \lambda) w_i(k), \qquad (14)$$

where λ is a relaxation parameter. For $1 < \lambda \leq 2$, faster convergence may be obtained for already convergent systems, and if normal iteration is not convergent, $\lambda \leq 1$ may be used to obtain convergence. These and other techniques for iterative solution of linear systems are described in the *Handbook of Mathematics and Computer Science*, by Harris et al., published by Springer-Verlag (New York, 1998), at pp. 456-457.

Referring again to Fig. 5, power estimator **542** estimates interference to signal and noise to signal ratios γ_I, γ_N, which are used in computing the weighting factors w. As the inter-symbol interference impairment correlation component R_{ISI} can be neglected, as described above, it may suffice to determine a ratio γ_I/γ_N of the interference to signal and noise to signal ratios to perform computation of the weighting factors **w**, setting γ_N to some nominal number, such as 1 (equivalent to estimating a ratio of interference power to noise power).

In a wireless cellular communications system, a base station (BS) may inform a mobile or other terminal of power levels of all the spread spectrum signals being transmitted. The terminal may then simply compute its received power using conventional means, and use the base station information to determine the relative received power of the interference. Using these interference power estimates and an estimate of the total received power (which also may be obtained using conventional means), an estimate of the noise power (i.e., power of other interference and thermal noise) may then be obtained.

If a base station does not transmit power level information, however, it still may inform the terminal of which spreading codes are currently being used. Using such information, power information for the interfering signals can be determined using an apparatus such as the power estimator **542** illustrated in Fig. 6. Baseband samples ***r(k)*** of a received composite signal are passed through banks of delays **610a-610L**, with each of the delayed versions of the baseband signal ***r(k)*** being descrambled by a descrambler **620a-620L** and processed by a fast Walsh transformer **630a-630L**. The resulting correlation information is then combined by a maximal ratio combiner **640**, the combined values indicating the energy in each code dimension. An interference power estimator **650** calculates the energy in dimensions spanned by the active codes (other than the desired code), and a noise power estimator **660** calculates energy in dimensions spanned by inactive codes.

If the information on the active codes is not provided to the terminal, then the apparatus of Fig. 6 may be modified to detect which codes are active by, for example, thresholding the magnitude squared of the outputs of the maximal ratio combiner **640**. Smoothing the magnitude square of the output of the maximal ratio combiner for inactive codes can provide an estimate of the white noise power. There may be a slight bias from the interference and desired signal echoes, which can be removed. Smoothing the magnitude squared of the output of the maximal ratio combiner **640** for the active codes, estimates of $I_i + N$ can be obtained, where I_i is the interference power of the ith user and N is the white

noise power. Using the estimate of N, estimates of I_i can be obtained and summed to obtain an estimate of the overall interference power. Exemplary techniques for detecting spreading sequences and estimating power associated with particular spreading codes are described in United States Patent Application Serial Number 09/235,470 to Wang et al., filed January 22, 1999, assigned to the assignee of the present invention, and incorporated herein by reference in its entirety.

The above-described operations for explicitly determining weighting factors are similar to operations described in a United States Patent Application entitled "RAKE Combining Methods and Apparatus using Weighting Factors Derived From Knowledge of Spread Spectrum Signal Characteristics" (Application Serial No. _____) (Attorney Docket No. 8194-306), by Bottomley et al., assigned to the assignee of the present invention, filed concurrently herewith, and incorporated herein by reference in its entirety.

Determining Weighting Factors by Interference Rejection Combining (IRC)

According to a second embodiment of the present invention, the weighting factors w generated by the weighting factor generator **440** are determined by determining a post-combining composite channel response and generating an error vector therefrom that is used to estimate an impairment correlation.

Referring to Fig. 7, a weighting factor generator **440''** includes a post-combining channel response estimator **710** that computes a channel response h that reflects the first stage of combining performed by the first and second combiners **420a**, **420b** of Fig. 4 (the post-combining channel response estimator **710** may operate in the same manner as the composite channel response calculator **530** shown in Fig. 5). The post-combining channel response h is subtracted from the combined values produced by the first combining stages to generate an error vector e, that is in turn provided to an impairment correlation estimator **720** that estimates an impairment correlation R. The post-combining channel response h and the impairment correlation R are provided to a weighting factor estimator **730** that estimates weighting factors w.

Returning to the two-ray example discussed with respect to equations (1)-(6), the post-combining channel response h can be expressed as the channel coefficient response convolved with itself, such that:

$$h_0 = \hat{c}_0^* \hat{c}_0 + \hat{c}_1^* \hat{c}_1 = |\hat{c}_0|^2 + |\hat{c}_1|^2 \qquad (16)$$

and

$$h_1 = \hat{c}_0^* \hat{c}_1, \qquad (17)$$

where h_0, h_1 are components of the post-combining channel response $\boldsymbol{h}$. For known or detected symbol $\hat{b}$, components e_0, e_1 of the error vector e are thus:

$$e_0 = y_0 - \hat{b}h_0 = y_0 - h_0 \qquad (18)$$

and

$$e_1 = y_1 - \hat{b}h_1 = y_1 - h_1. \qquad (19)$$

The symbol $\hat{b}$ may be known (pilot) or estimated; here it is assumed that the IS-95 pilot channel is used, wherein $\hat{b}=1$.

The impairment correlation matrix $\boldsymbol{R}$ may be updated using the expression:

$$\boldsymbol{R}(k) = \lambda \boldsymbol{R}(k-1) + e(k)e^H(k), \qquad (20)$$

wherein H denotes a conjugate transpose. Because $\boldsymbol{R}$ is Hermitian, only the diagonal and one of the off-diagonal triangles of $\boldsymbol{R}$ need be determined. The above-described techniques for determining a channel response $\boldsymbol{h}$ and an impairment correlation $\boldsymbol{R}$ for a system with single-stage combining is described in detail in United States Patent Application Serial Number 09/165,647, by Bottomley, filed October 2, 1998, assigned to the assignee of the present invention and incorporated by reference herein in its entirety. As with the explicit approach described above, weighting factors w can be determined from $\boldsymbol{h}$ and $\boldsymbol{R}$ by inverting $\boldsymbol{R}$ and multiplying it by $\boldsymbol{h}$, or by using iterative techniques which obviate the need to invert the impairment correlation matrix R.

As multipath components appear and disappear due to movement of the terminal or due to movement of objects in the terminal's environment, sudden changes may occur in the impairment correlation matrix corresponding to the outputs of the first combining stage. To

track such changes, it may be desirable to estimate a large impairment matrix correlation associated with the outputs of the correlators, before the first stage of combining, as described in the aforementioned Patent Application Serial Number 09/165,647, to Bottomley, filed October 2, 1998. This larger impairment correlation matrix may be used, along with the first stage combining weighting factors (typically channel estimates), to determine the impairment correlation matrix after the first step of combining. Basically, the elements in the impairment correlation matrix needed for the second stage of combining would be a weighted sum of the elements in the impairment correlation matrix associated with the correlator outputs. The weighting factors would be products of the first stage combining weighting factors.

Determining Weighting Factors by Adaptive Filtering

Alternatively, the combining weighting factors w may be "learned" using adaptive filtering techniques. Starting with an initial set of weighting factors, post-combining (the combining performed by the third combiner **430** of Fig. 4) would be applied to combined values produced from pilot channel correlations, and compared to the known pilot channel values. An error thus generated may then be used to produce updated weighting factors using a variety of known adaptive filtering approaches, such as Least Mean Squares (LMS) and Recursive Least Squares (RLS) techniques.

As illustrated in Fig. 8, according to an embodiment of the present invention, a weighting factor generator **400'''** includes an adaptive weighting factor estimator **810** that adaptively estimates weighting factors w based on inputs y to the second stage combiner **430** of Fig. 4 and an error e generated from a comparison of outputs z of the combiner with a desired response. Generally, the values y, z are generated from received data corresponding to a known or estimated symbol, e.g., a pilot symbol or a decoded symbol, with the desired response representing the known or estimated symbol. The adaptive weighting factor estimator **400'''** may use, for example, an LMS algorithm, whereby the weighting factors w are updated as:

$$w(k) = w(k-1) + \mu y(k) e^{*}(k), \qquad (21)$$

where μ is an adaptive step size, the value of which can be determined through trial and error.

Optimal Finger Placement

Referring again to Fig. 4, for the above described embodiments, it is preferable that optimal finger locations (i.e., delay values) be used in the correlation unit **410** and weighting factor generator **440**. Various delay optimization techniques and criteria may be used. A preferred optimization metric can be expressed as:

$$M=h^H w \text{ or} \qquad (15)$$
$$M=h^H R^{-1} h,$$

wherein optimization is achieved by selecting delays that maximize M.

Exemplary Multistage Combining Operations

Figs. 9-10 are flowchart illustrations of exemplary operations according to various aspects of the present invention. It will be understood that blocks of these flowcharts, and combinations of blocks in these flowcharts, can be implemented by computer program instructions which may be loaded and executed on a computer or other programmable data processing apparatus, such as a microcomputer, microprocessor, ASIC, DSP chip or other processing circuitry used to implement the receiver **400** of Fig. 4, to produce a machine such that the instructions which execute on the computer or other programmable data processing apparatus create means for implementing the functions specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block or blocks.

Accordingly, blocks of the flowcharts of Figs. 9-10 support combinations of means for performing the specified functions and combinations of steps for performing the specified functions. It will also be understood that each block of the flowcharts of Figs. 9-10, and combinations of blocks therein, can be implemented by special purpose hardware-based computer systems which perform the specified functions or steps, or combinations of special purpose hardware and computer instructions.

Fig. 9 illustrates exemplary operations **900** for estimating information encoded in a spread spectrum signal transmitted in a communications medium according to an aspect of

the present invention. A composite signal including the spread spectrum signal is received from a communications medium (Block **910**). The composite signal is correlated with the desired spreading sequence associate with the spread spectrum signal to produce a plurality of time-offset correlations (Block **920**). Respective first and second groups of the correlations are combined, e.g., according to estimated channel coefficients, to produce respective first and second combined values that are compensated for effects of a channel over which the spread spectrum signal is received (Block **930**). The first and second combined values are then combined in manner that compensates for correlated impairment (interference plus noise) in the composite signal, producing an estimate of information in the spread spectrum signal (Block **940**).

Fig. 10 illustrates exemplary operations **1000** for recovering information encoded in a spread spectrum signal transmitted in a communications medium, according to another aspect of the present invention. A composite signal including the spread spectrum signal is received from a communications medium (Block **1010**). The composite signal is correlated with the desired spreading sequence associated with the spread spectrum signal to produce a plurality of time-offset correlations (Block **1020**). Channel coefficient estimates are generated from the correlations (Block **1030**). Respective first and second groups of the correlations are combined according to the estimated channel coefficients to produce respective first and second combined values (Block **1040**). Weighting factors are generated from an estimated composite channel response and impairment correlation, or are adaptively generated as described above (Block **1050**). The first and second combined values are then combined according to the weighting factors to estimate information in the spread spectrum signal (Block **1060**).

It will be appreciated that a number of variations to the above-described exemplary embodiments and operations may be utilized according to the present invention. For example, a variety of configurations of the correlation unit **410** of Fig. 4 may be utilized, including respective banks of integrate-and-dump correlators, a single bank of such correlators, a sliding correlator or a selectively inhibited correlator as described in the aforementioned United States Patent Application Serial Number 09/165,647 (Bottomley). A variety of other weighting factor computation techniques can also be used, including a number of known antenna array processing techniques. For example, an impairment correlation estimate may be replaced by a despread correlation estimate in which the error vector e is replaced with a correlation values vector x when forming the impairment

correlation estimate. This approach can cancel interference, but the soft decision statistic produced by such an approach may not work as well in subsequent processing steps.

A variety of channel tracking approaches may be used with the present invention, including LMS techniques, KLMS techniques as described in "Adaptive MLSE Performance on the D-AMPS 1900 Channel," by Jamal et al., *IEEE Transactions on Vehicular Technology*, vol. 46, pp. 634-641 (Aug. 1997), RLS techniques and Kalman tracking techniques. Although chip-spaced rays are described herein, rays may generally have arbitrary spacing, including fractional spacing. Channel estimation can also be performed using interpolation between pilot symbols. A variety of impairment correlation estimation techniques may be used as well. For example, impairment correlation may be tracked or interpolated between pilot symbols.

Channel estimation may also include automatic frequency correction (AFC). Feedforward AFC can be applied to each correlator associated with a signal echo, with the resulting phase estimate being used to forming weighting factors by rotating channel estimates, as described in United States Patent Application Serial Number 08/991,770, to Bottomley et al., filed December 16, 1997, assigned to the assignee of the present invention and incorporated by reference herein in its entirety. Feedback correction of a voltage controlled oscillator could be based on a combination of the frequency error estimates.

It will also be appreciated that other combining strategies may also be used within the scope of the present invention. For example, the impairment-compensating second combining stage may itself be implemented in multiple stages, e.g., a first combining stage based on an impairment correlation estimate and a second combining stage based on a composite (post-combining) channel response. Multiple receive antennas may also be used.

A modified approach may also be followed in which the impairment correlation used is a combination of an impairment correlation estimate and a fixed value. This can provide a graceful mechanism for switching between conventional combining approaches (wherein the fixed value is the correlation matrix associated with the combiner response), and combining techniques according to the present invention. Such a mixed approach can also be used to switch between an adaptive estimate and a known structure. For example, if the interference in the composite signal is non-dispersive, i.e., the impairment is only colored by the receive structure, the fixed component of the impairment correlation can be a matrix of pulse shape autocorrelation values, possibly scaled by an estimate of noise power. The "fixed" component can also be adaptive, using a pulse shape autocorrelation matrix scaled by an adaptive noise power estimate. The interference cancellation may be "softly" turned on or

off, by weighting the "normal" RAKE combiner output more and the added "slides" less, using a fixed or adaptive scaling factor.

A multipass approach to parameter estimation may also be used with the present invention. Despread values corresponding to a frame can be stored. In a post-combining process, error detection and/or correction coding can be used to detect errors, and successfully detected symbols can be used as reference values for channel estimation, weighting factor estimation, and the like. Multipass techniques are generally described in United States Patent Number 5,673,291 to Dent.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

THAT WHICH IS CLAIMED:

1. A method of recovering information encoded in a spread spectrum signal transmitted in a communications medium, the method comprising the steps of:

receiving a composite signal including a spread spectrum signal from the communications medium;

correlating the received composite signal with a spreading sequence to generate time-offset correlations;

combining a first group of the correlations to produce a first combined value;

combining a second group of the correlations to produce a second combined value; and

combining the first and second combined values in a manner that compensates for correlated impairment in the composite signal to generate an estimate of information in the transmitted spread spectrum signal.

2. A method according to Claim 1:

wherein said step of combining a first group of the correlations comprises the step of combining the first group of correlations in a manner that compensates for effect of a channel over which the spread spectrum signal is received; and

wherein said step of combining a second group of the correlations comprises the step of combining the second group of correlations in a manner that compensates for effect of a channel over which the spread spectrum signal is received.

3. A method according to Claim 2:

wherein said step of combining a first group of the correlations comprises the step of combining the first group of correlations according to estimated channel coefficients; and

wherein said step of combining a second group of the correlations comprises the step of combining the second group of correlations according to estimated channel coefficients.

4. A method according to Claim 3, wherein said step of combining a first group and said step of combining a second group are preceded by the step of generating the channel coefficient estimates.

5. A method according to Claim 4, wherein said step of generating the channel coefficient estimates comprises the step of generating the channel coefficient estimates from at least one of a pilot channel, a pilot symbol or a decoded symbol.

6. A method according to Claim 1, wherein said step of combining the first and second combined values comprises the step of combining the first and second values based on an estimated impairment correlation and on a composite channel response that reflects said step of combining the first group correlations and said step of combining the second group of correlations.

7. A method according to Claim 6:

wherein said step of combining the first and second combined values is preceded by the steps of:

estimating the composite channel response;

estimating the impairment correlation; and

generating weighting factors from the estimated composite channel response and the estimated impairment correlation; and

wherein said step of combining the first and second combined values comprises the step of combining the first and second combined values according to the generated weighting factors.

8. A method according to Claim 7, wherein said step of generating weighting factors comprises the step of iteratively generating weighting factors from the estimated composite channel response, the estimated impairment correlation, and previously determined weighting factors.

9. A method according to Claim 1, wherein said step of combining the first and second combined values comprises the step of combining the first and second values according to weighting factors to generate a third combined value, wherein the weighting factors are adaptively estimated based on comparison of the third combined value to a reference value.

10. A method according to Claim 1, wherein said step of correlating comprises the step of correlating using at least one of a plurality of integrate and dump correlators, a sliding correlator, or a selectively inhibited sliding correlator.

11. A method according to Claim 6, wherein said step of correlating comprises the step of correlating using a set of time delays that optimizes a metric that is proportional to a product of the weighting factors and the composite channel response.

12. A method of recovering information encoded in a spread spectrum signal transmitted in a communications medium, the method comprising the steps of:

receiving a composite signal including a spread spectrum signal from the communications medium;

correlating the received composite signal with a spreading sequence to generate a plurality of time-offset correlations;

combining a first group of the correlations according to a channel estimate to produce a first combined value;

combining a second group of the correlations according to a channel estimate to produce a second combined value; and

combining the first and second combined values according to weighting factors that compensate for correlated impairment in the composite signal to generate an estimate information in the transmitted spread spectrum signal.

13. A method according to Claim 12, wherein said step of combining the first and second combined values comprises the step of combining the first and second combined values based on an estimated impairment correlation and on a composite channel response that reflects said step of combining the first group of correlations and said step of combining the second group of correlations.

14. A method according to Claim 13:

wherein said step of combining the first and second combined values is preceded by the steps of:

estimating the composite channel response;

estimating the impairment correlation; and

generating weighting factors from the estimated composite channel response and the estimated impairment correlation; and

wherein said step of combining the first and second combined values comprises the step of combining the first and second combined values according to the generated weighting factors.

15. A method according to Claim 14, wherein said step of generating weighting factors comprises the step of iteratively generating weighting factors from the estimated composite channel response, the estimated impairment correlations, and previously determined weighting factors.

16. A method according to Claim 12, wherein said step of combining the first and second combined values comprises the step of combining the first and second values to generate a third combined value, wherein the weighting factors are adaptively estimated based on comparison of the third combined value to a reference value.

17. A method according to Claim 12, wherein said steps of combining a first group and said step of combining a second group are preceded by the step of generating the channel estimate.

18. A method according to Claim 12, wherein said step of generating a channel estimate comprises the step of generating the channel estimate from at least one of a pilot channel, a pilot symbol or a decoded symbol.

19. A method according to Claim 18, wherein said step of correlating comprises the step of correlating using at least one of a plurality of integrate and dump correlators, a sliding correlator, or a selectively inhibited sliding correlator.

20. A method according to Claim 13, wherein said step of correlating comprises the step of correlating using a set of time delays that optimizes a metric that is proportional to a product of the weighting factors and the composite channel response

21. An apparatus for recovering information encoded in a spread spectrum signal included in a composite signal, the apparatus comprising:

a correlation unit operative to correlate the composite signal with a spreading sequence to generate time-offset correlations; and

a multistage combiner responsive to said correlation unit and operative to combine respective groups of the correlations to provide respective intermediate combined values, and to combine the intermediate combined values in a manner that compensates for correlated impairment in the composite signal to estimate information in the transmitted spread spectrum signal.

22. An apparatus according to Claim 21, wherein said multistage combiner comprises:

a first combiner responsive to said correlation unit and operative to combine a first group of the correlations to produce a first combined value;

a second combiner responsive to said correlation unit and operative to combine a second group of the correlations to produce a second combined value; and

a third combiner responsive to said first combiner and to said second combiner and operative to combine the first and second combined values in a manner that compensates for correlated impairment in the composite signal to generate an estimate information in the transmitted spread spectrum signal.

23. An apparatus according to Claim 22:

wherein said first combiner is operative to combine the first group of correlations in a manner that compensates for effect of a channel over which the spread spectrum signal is received; and

wherein said second combiner is operative to combine the second group of correlations in a manner that compensates for effect of a channel over which the spread spectrum signal is received.

24. An apparatus according to Claim 23:

wherein said first combiner is operative to combine the first group of correlations according to estimated channel coefficients; and

wherein said second combiner is operative to combine the second group of correlations according to estimated channel coefficients.

25. An apparatus according to Claim 24, further comprising a channel estimator operative to generate the channel coefficient estimates.

26. An apparatus according to Claim 25, wherein said channel estimator is operative to generate the channel coefficient estimates from at least one of a pilot channel, a pilot symbol or a decoded symbol.

27. An apparatus according to Claim 22, wherein said third combiner is operative to combine the first and second values based on an estimated impairment correlation and on a composite channel response that reflects effects of said first and second combiners.

28. An apparatus according to Claim 27, further comprising:

a composite channel response estimator operative to estimate the composite channel response;

an impairment correlation estimator operative to estimate the impairment correlation; and

a weighting factor estimator responsive to said composite channel response estimator and to said impairment correlation estimator and operative to generate weighting factors from the estimated composite channel response and the estimated impairment correlation; and

wherein said third combiner is operative to combine the first and second combined values according to the generated weighting factors.

29. An apparatus according to Claim 28, wherein said weighting factor estimator is operative to iteratively generate weighting factors from the estimated composite channel response, the estimated impairment correlation, and previously determined weighting factors.

30. An apparatus according to Claim 22, wherein said third combiner is operative to combine the first and second values according to weighting factors to generate a third combined value, and further comprising an adaptive weighting factor estimator operative to adaptively estimate weighting factors based on comparison of the third combined value to a reference value.

31. An apparatus according to Claim 22, wherein said correlation unit comprises at least one of a plurality of integrate and dump correlators, a sliding correlator, or a selectively inhibited sliding correlator.

32. An apparatus according to Claim 27, wherein said correlation unit is operative to correlate the composite signal with the spreading sequence using a set of time delays that optimizes a metric that is proportional to a product of the weighting factors and the composite channel response.

33. An apparatus for recovering information encoded in a spread spectrum signal transmitted in a communications medium, the apparatus comprising:

means for receiving a composite signal including a spread spectrum signal from the communications medium;

means, responsive to said means for receiving, for correlating the composite signal with a spreading sequence to generate time-offset correlations;

means, responsive to said means for correlating, for combining a first group of the correlations to produce a first combined value;

means, responsive to said means for correlating, for combining a second group of the correlations to produce a second combined value; and

means, responsive to said means for combining a first group and to said means for combining a second group, for combining the first and second combined values in a manner that compensates for correlated impairment in the composite signal to generate an estimate information in the transmitted spread spectrum signal.

34. An apparatus according to Claim 33:

wherein said means for combining a first group of the correlations comprises means for combining the first group of correlations in a manner that compensates for effect of a channel over which the spread spectrum signal is received; and

wherein said means for combining a second group of the correlations comprises means for combining the second group of correlations in a manner that compensates for effect of a channel over which the spread spectrum signal is received.

35. An apparatus according to Claim 34:

wherein said means for combining a first group of the correlations comprises means for combining the first group of correlations according to estimated channel coefficients; and

wherein said means for combing a second group of the correlations comprises means for combining the second group of correlations according to estimated channel coefficients.

36. An apparatus according to Claim 35, further comprising means for generating the channel coefficient estimates.

37. An apparatus according to Claim 36, wherein said means for generating the channel coefficient estimates comprises means for generating the channel coefficient estimates from at least one of a pilot channel, a pilot symbol or a decoded symbol.

38. An apparatus according to Claim 33, wherein said means for combining the first and second combined values comprises means for combining the first and second values based on an estimated impairment correlation and on a composite channel response that reflects said means for combining the first group correlations and said means for combining the second group of correlations.

39. An apparatus according to Claim 38, further comprising:

means for estimating the composite channel response;

means for estimating the impairment correlation; and

means for generating weighting factors from the estimated composite channel response and the estimated impairment correlation; and

wherein said means for combining the first and second combined values comprises means for combining the first and second combined values according to the generated weighting factors.

40. An apparatus according to Claim 39, wherein said means for generating weighting factors comprises means for iteratively generating weighting factors from the estimated composite channel response, the estimated impairment correlation, and previously determined weighting factors.

41. An apparatus according to Claim 33, wherein said means for combining the first and second combined values comprises means for combining the first and second values

according to weighting factors to generate a third combined value, and further comprising means for adaptively estimating weighting factors based on comparison of the third combined value to a reference value.

42. An apparatus according to Claim 33, wherein said means for correlating comprises at least one of a plurality of integrate and dump correlators, a sliding correlator, or a selectively inhibited sliding correlator.

43. An apparatus according to Claim 38, wherein said means for correlating comprises means for correlating using a set of time delays that optimizes a metric that is proportional to a product of the weighting factors and the composite channel response.

44. An apparatus for recovering information encoded in a spread spectrum signal transmitted in a communications medium, the apparatus comprising:

means for receiving a composite signal including a spread spectrum signal from the communications medium;

means, responsive to said means for receiving, for correlating the received composite signal with a spreading sequence to generate a plurality of time-offset correlations;

means, responsive to said means for correlating, for combining a first group of the correlations according to a channel estimate to produce a first combined value;

means, responsive to said means for correlating, for combining a second group of the correlations according to a channel estimate to produce a second combined value; and

means, responsive to said means for combining a first group and to said means for combining a second group, for combining the first and second combined values according to weighting factors that compensate for correlated impairment in the composite signal to generate an estimate of information in the transmitted spread spectrum signal.

45. An apparatus according to Claim 44, wherein said means for combining the first and second combined values comprises means for combining the first and second combined values based on an estimated impairment correlation and on a composite channel response that reflects said means for combining the first group of correlations and said means for combining the second group of correlations.

46. An apparatus according to Claim 45, further comprising:

means for estimating the composite channel response;

means for estimating the impairment correlation; and

means for generating weighting factors from the estimated composite channel response and the estimated impairment correlation; and

wherein said means for combining the first and second combined values comprises means for combining the first and second combined values according to the generated weighting factors.

47. An apparatus according to Claim 46, wherein said means for generating weighting factors comprises means for iteratively generating weighting factors from the estimated composite channel response, the estimated impairment correlation, and previously determined weighting factors.

48. An apparatus according to Claim 44, wherein said means for combining the first and second combined values comprises means for combining the first and second values to generate a third combined value, and further comprising means for adaptively estimating weighting factors based on comparison of the third combined value to a reference value.

49. An apparatus according to Claim 44, further comprising means for generating the channel estimate.

50. An apparatus according to Claim 44, wherein said means for generating a channel estimate comprises means for generating the channel estimate from at least one of a pilot channel, a pilot symbol or a decoded symbol.

51. An apparatus according to Claim 50, wherein said means for correlating comprises at least one of a plurality of integrate and dump correlators, a sliding correlator, or a selectively inhibited sliding correlator.

52. An apparatus according to Claim 45, wherein said means for correlating comprises means for correlating using a set of time delays that optimizes a metric that is proportional to a product of the weighting factors and the composite channel response.

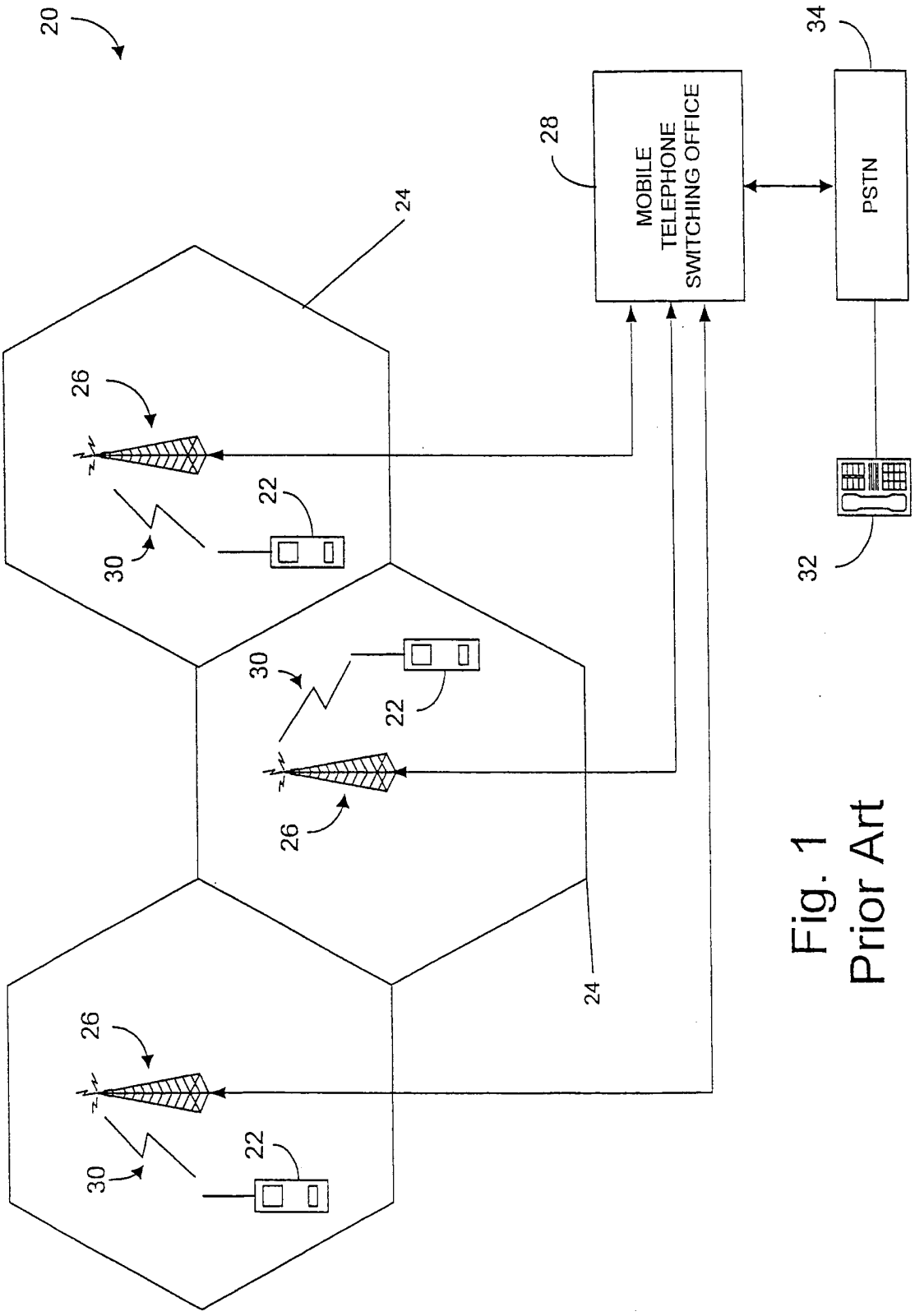
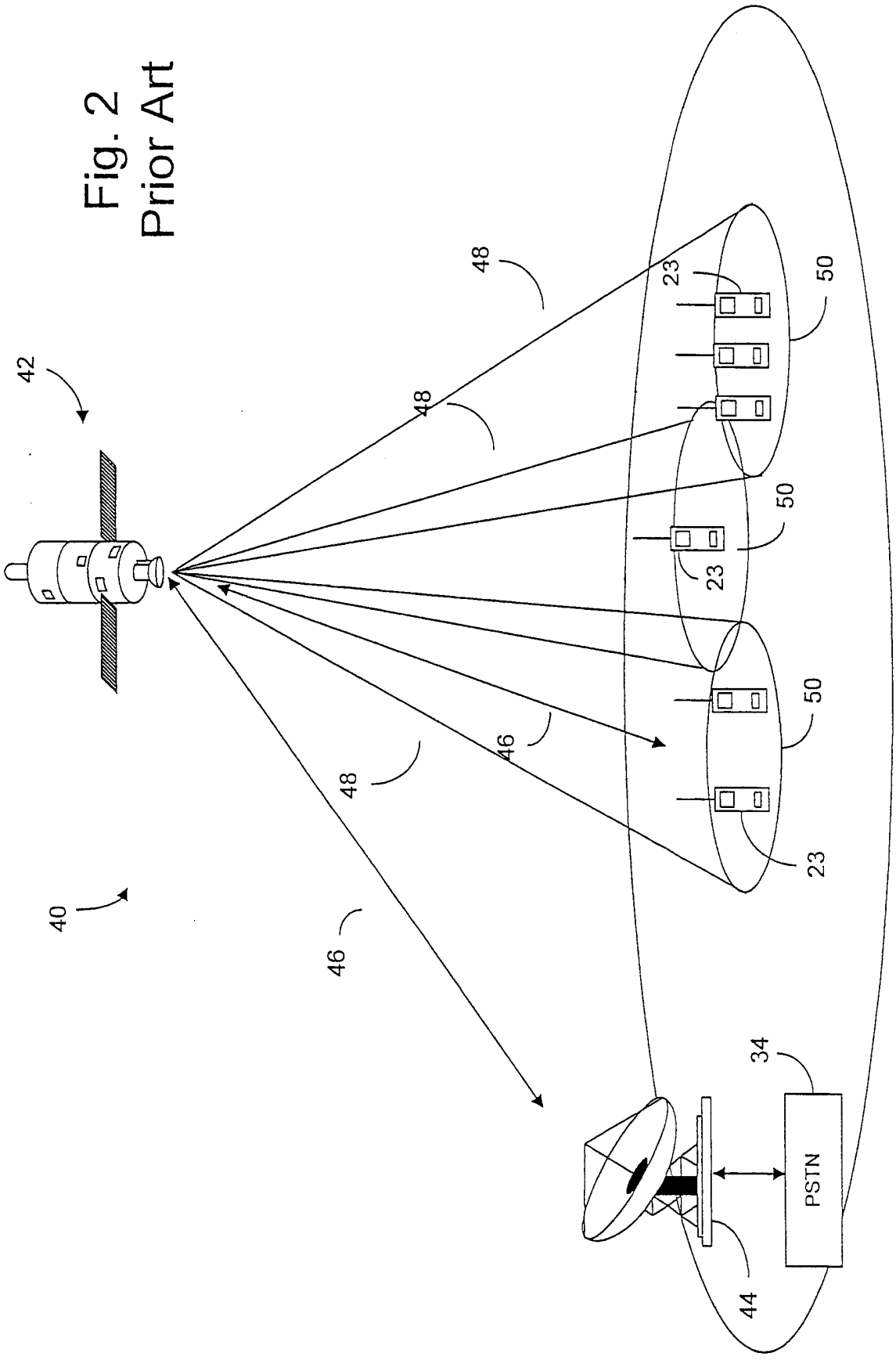


Fig. 1
Prior Art

Fig. 2
Prior Art



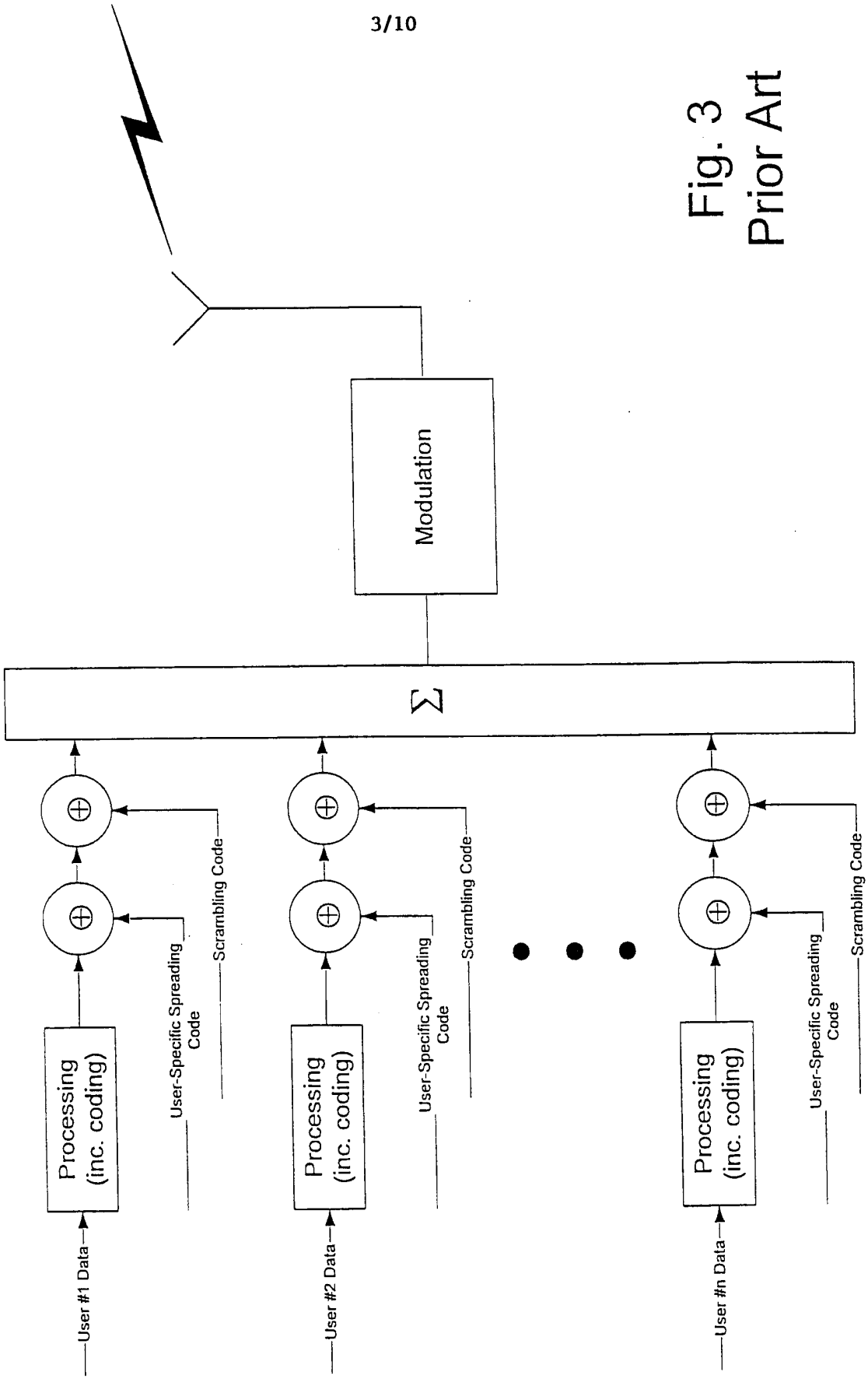


Fig. 3
Prior Art

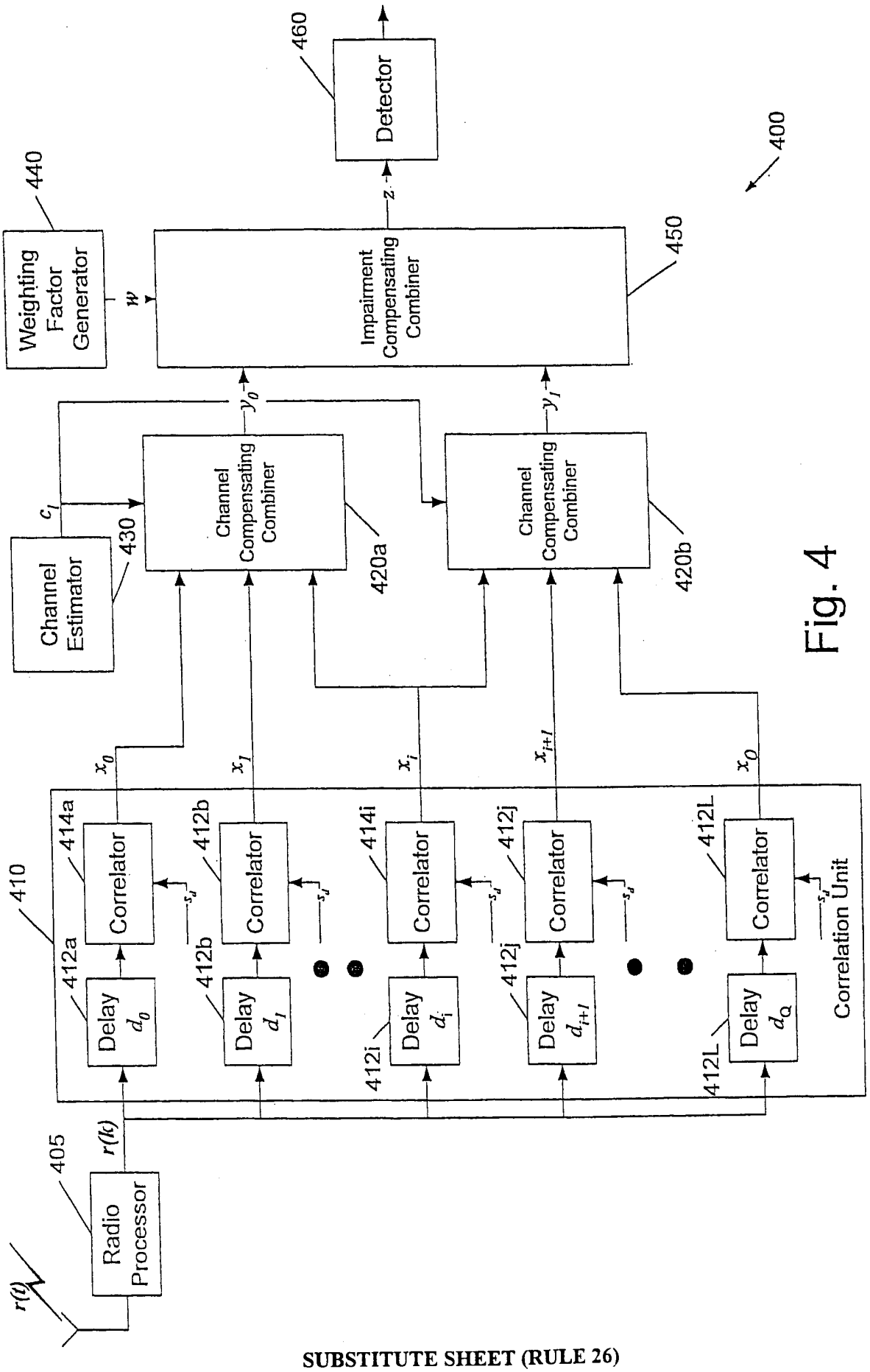

400
460
Detector
z
440
Weighting Factor Generator
w
Impairment Compensating Combiner
450
y_0
y_1
c_l
Channel Estimator
430
Channel Compensating Combiner
420a
Channel Compensating Combiner
420b
x_0
x_1
x_i
x_{i+1}
x_Q
410
414a
Correlator
412b
Correlator
414i
Correlator
412j
Correlator
412L
Correlator
s_d
412a
Delay d_0
412b
Delay d_1
412i
Delay d_i
412j
Delay d_{i+1}
412L
Delay d_Q
Correlation Unit
r(k)
405
Radio Processor
r(t)

Fig. 4

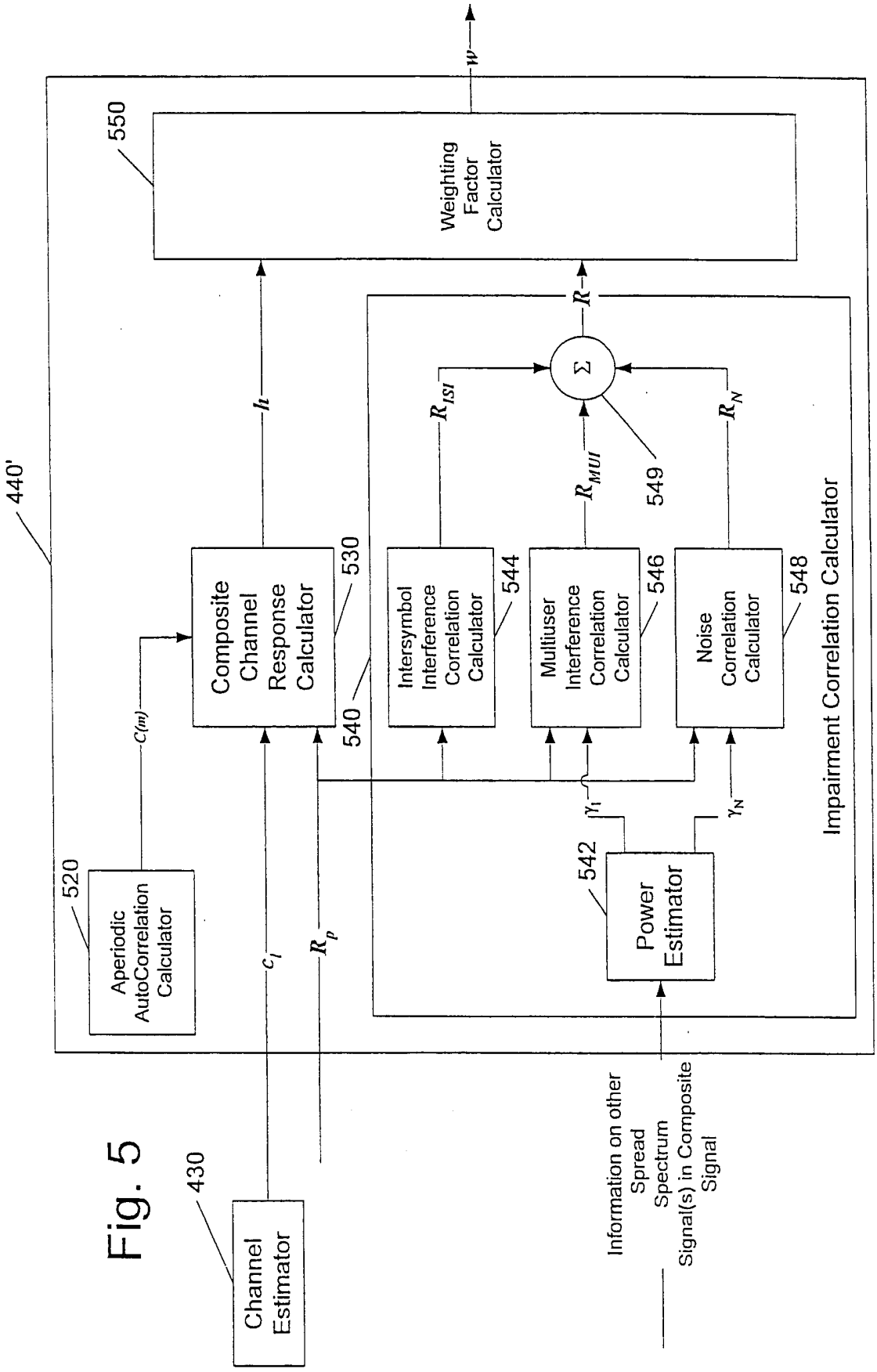

440'
550
Weighting Factor Calculator
w
h
R
Σ
549
R_{ISI}
R_{MUI}
R_N
530
Composite Channel Response Calculator
540
544
Intersymbol Interference Correlation Calculator
546
Multiuser Interference Correlation Calculator
548
Noise Correlation Calculator
Impairment Correlation Calculator
520
Aperiodic AutoCorrelation Calculator
c(m)
c_l
R_p
γ_1
γ_N
542
Power Estimator
430
Channel Estimator
Information on other Spread Spectrum Signal(s) in Composite Signal

Fig. 5

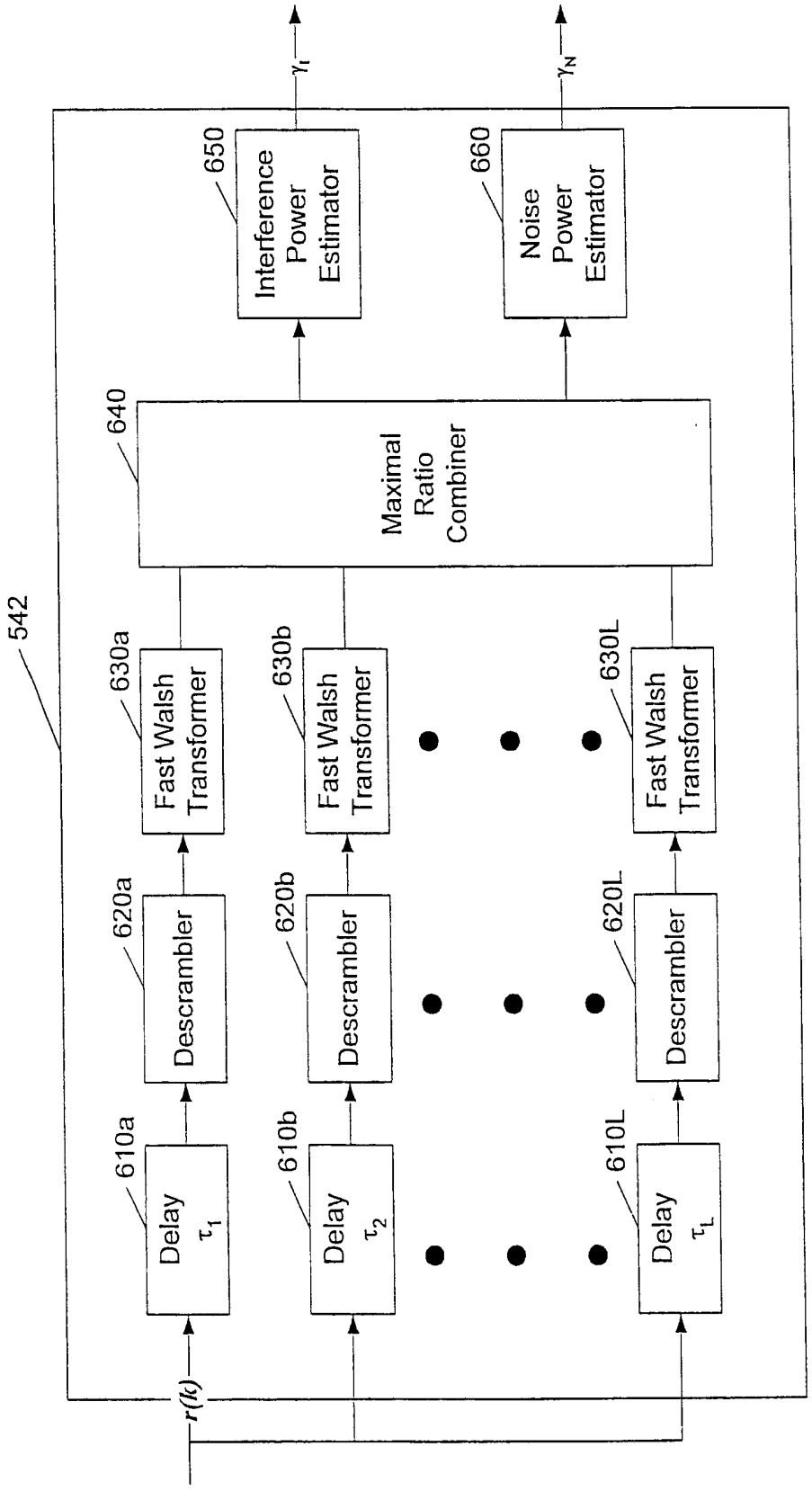

542
r(k)
610a
Delay
τ_1
610b
Delay
τ_2
610L
Delay
τ_L
620a
Descrambler
620b
Descrambler
620L
Descrambler
630a
Fast Walsh Transformer
630b
Fast Walsh Transformer
630L
Fast Walsh Transformer
640
Maximal Ratio Combiner
650
Interference Power Estimator
660
Noise Power Estimator
γ_I
γ_N

Fig. 6

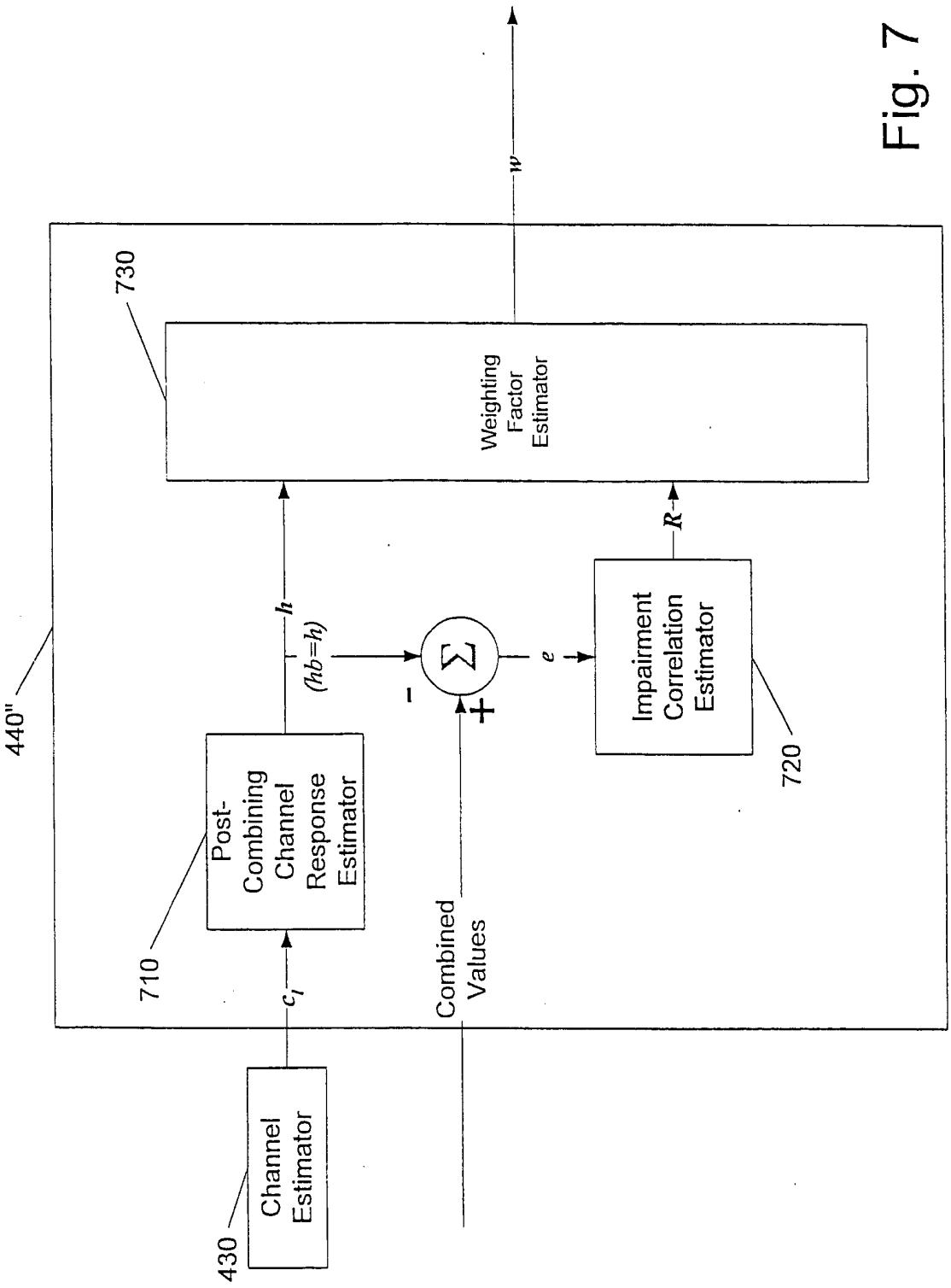

w
730
Weighting Factor Estimator
440"
h
(hb=h)
Σ
-
+
e
R
Impairment Correlation Estimator
720
Post-Combining Channel Response Estimator
710
c_i
Combined Values
Channel Estimator
430

Fig. 7

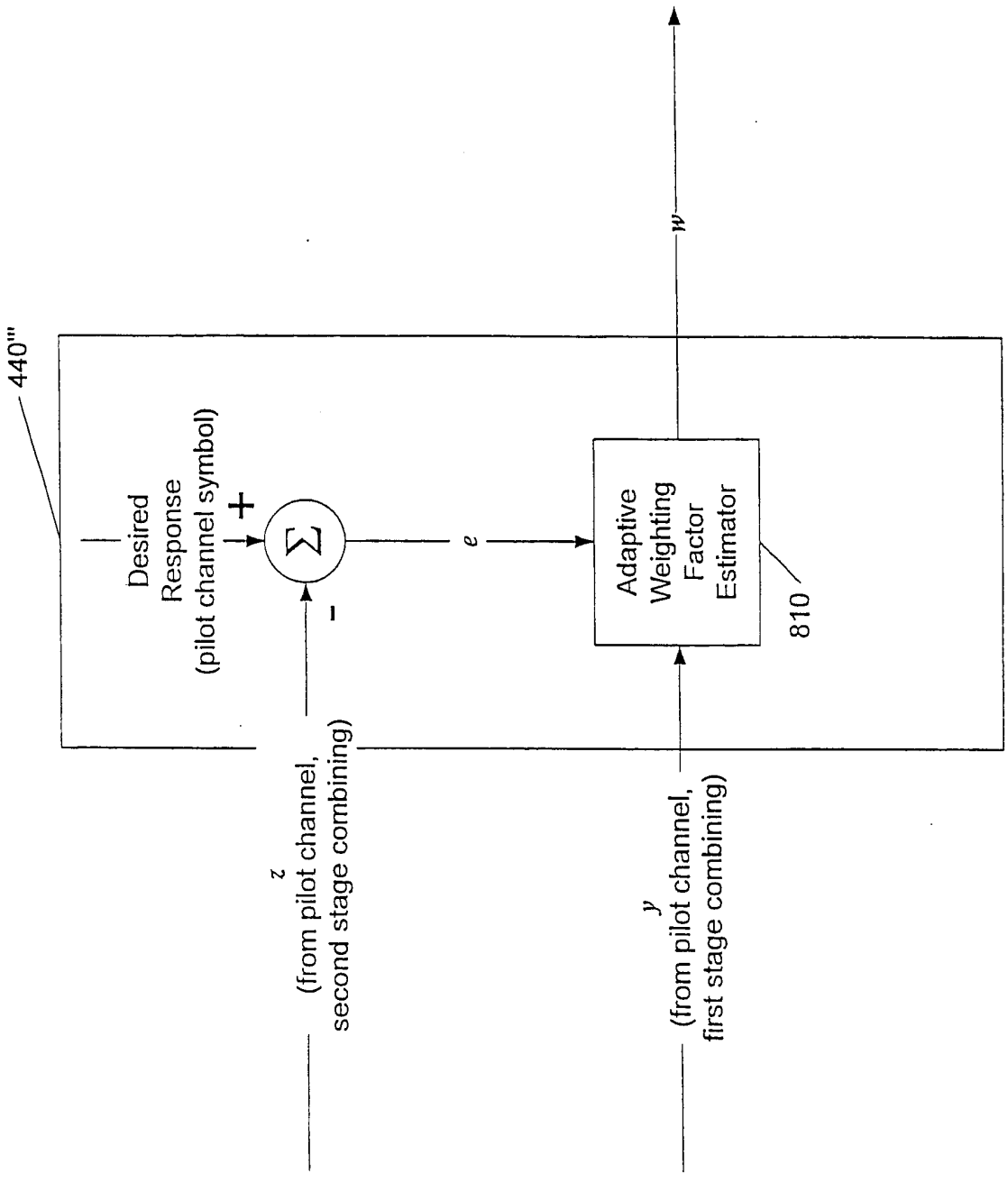

440'''
Desired
Response
(pilot channel symbol)
+
Σ
-
e
Adaptive
Weighting
Factor
Estimator
810
w
z
(from pilot channel,
second stage combining)
y
(from pilot channel,
first stage combining)

Fig. 8

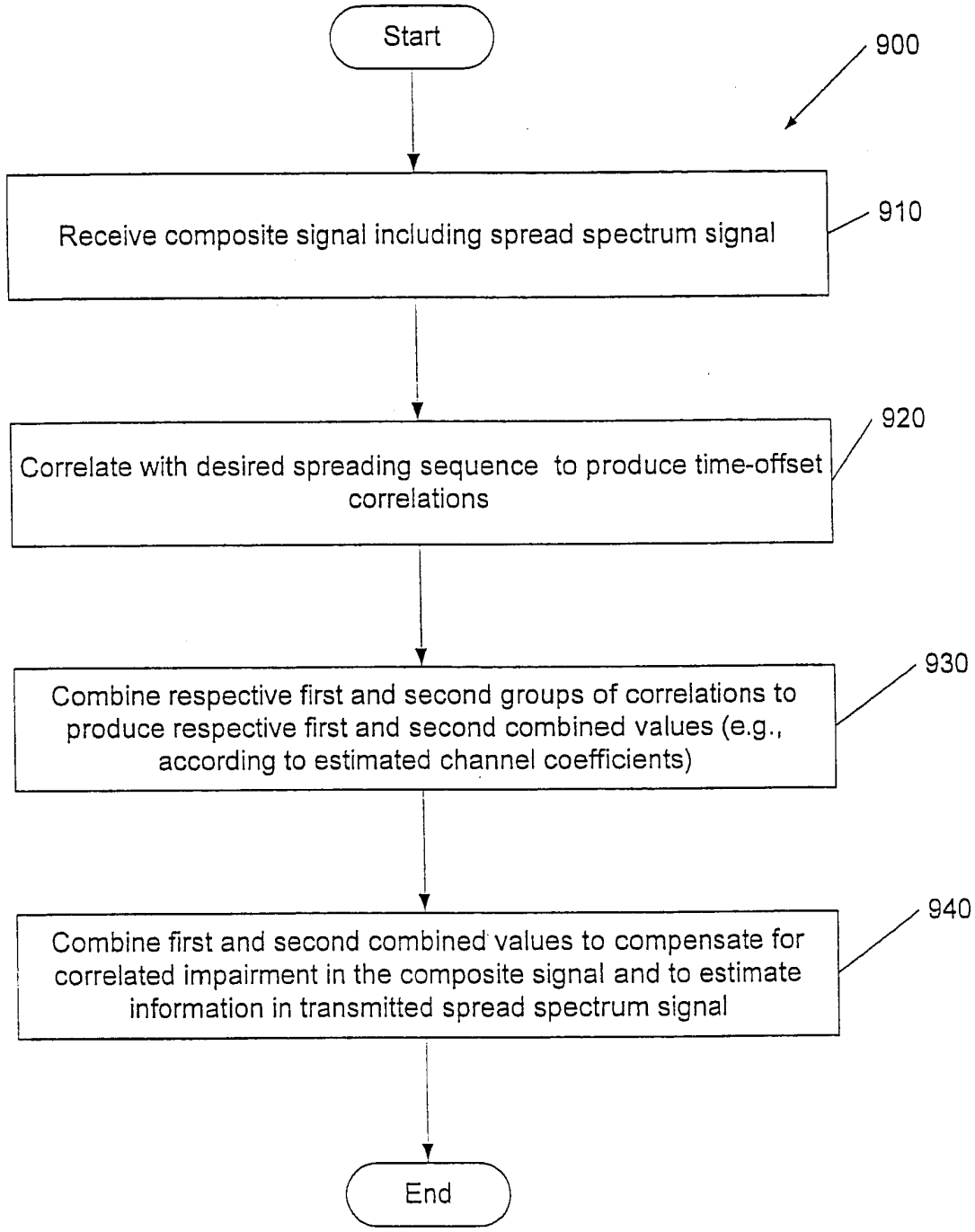

Start
900
Receive composite signal including spread spectrum signal
910
Correlate with desired spreading sequence to produce time-offset correlations
920
Combine respective first and second groups of correlations to produce respective first and second combined values (e.g., according to estimated channel coefficients)
930
Combine first and second combined values to compensate for correlated impairment in the composite signal and to estimate information in transmitted spread spectrum signal
940
End

Fig. 9

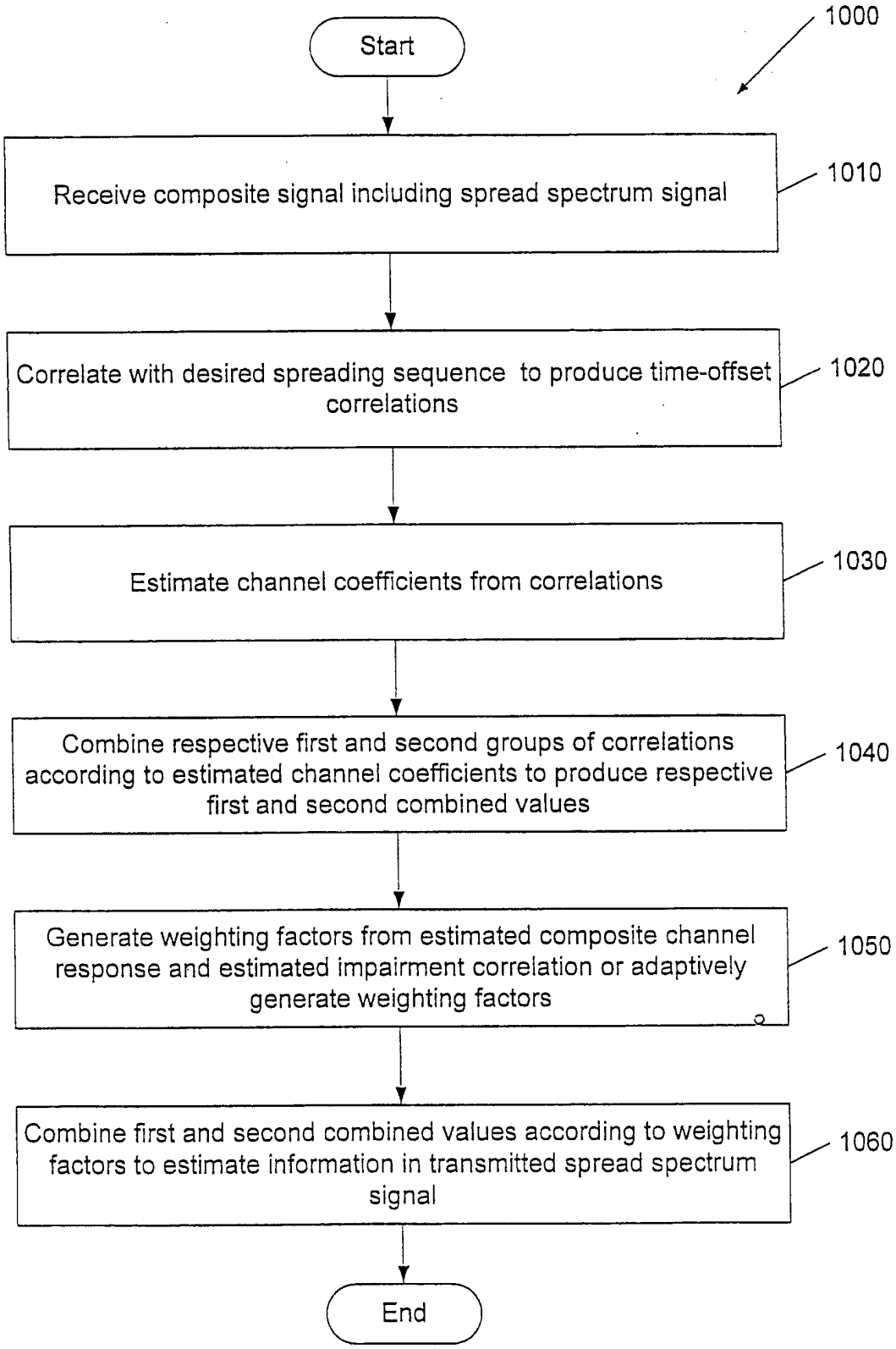

Start
1000
Receive composite signal including spread spectrum signal
1010
Correlate with desired spreading sequence to produce time-offset correlations
1020
Estimate channel coefficients from correlations
1030
Combine respective first and second groups of correlations according to estimated channel coefficients to produce respective first and second combined values
1040
Generate weighting factors from estimated composite channel response and estimated impairment correlation or adaptively generate weighting factors
1050
Combine first and second combined values according to weighting factors to estimate information in transmitted spread spectrum signal
1060
End

Fig. 10

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/12670

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B1/707

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)
IPC 7 H04B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 574 747 A (LOMP GARY R) 12 November 1996 (1996-11-12) column 6, line 13 -column 8, line 43 column 10, line 42 -column 14, line 11	1-52
X	EP 0 825 727 A (NTT MOBILE COMMUNICATIONS NETWORK INC.) 25 February 1998 (1998-02-25) column 4, line 16 -column 8, line 39	1-52

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 August 2000	01/09/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Behringer, L.V.

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Ir ational Application No
PCT/US 00/12670

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