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(54) **METHOD AND SYSTEM FOR OVERLOADED ARRAY PROCESSING**

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(52) **U.S. Cl.** **375/341**; 714/792

(58) **Field of Search** 375/341, 262, 375/265, 340; 714/792, 794, 795

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,884,272 A		11/1989	McConnell	371/43
5,406,585 A	*	4/1995	Rohani et al.	375/341
5,862,192 A		1/1999	Huszar et al.	375/347
2002/0044614 A1	*	4/2002	Molnar et al.	375/346

FOREIGN PATENT DOCUMENTS

EP	0 593 404 A1	4/1994	H03M/13/00
WO	WO 99/65160	12/1999	H04B/7/08

OTHER PUBLICATIONS

Fujii, Masaaki, "*Path Diversity Reception Using SMI Steering Vector Arrays and Multi-Trellis Viterbi Equalizer*", Universal Personal Communications, 1998, ICUPC '98, IEEE 1998 International Conference on Florence, Italy Oct. 5–9, 1998, pp. 911–915.

International Search Report dated Mar. 14, 2002 for PCT/US01/15521 filed May 14, 2001.

* cited by examiner

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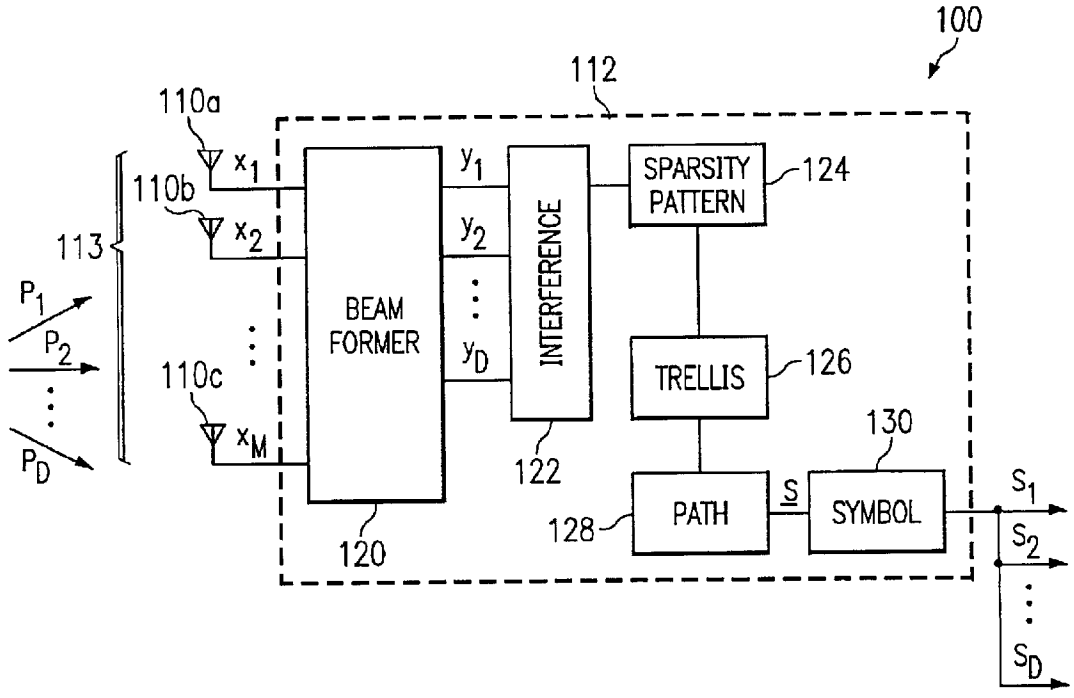
(57) **ABSTRACT**

According to the present invention, a method and system for array processing are disclosed. Signals transmitting a symbol set are received. A dominant signal set for each signal, which includes dominant signals that interfere with the signal, is determined. A trellis, which includes paths that represent possible symbol sets, is constructed from the dominant signal sets. An optimal path from the trellis is selected, and the symbol set represented by the optimal path is determined.

21 Claims, 5 Drawing Sheets



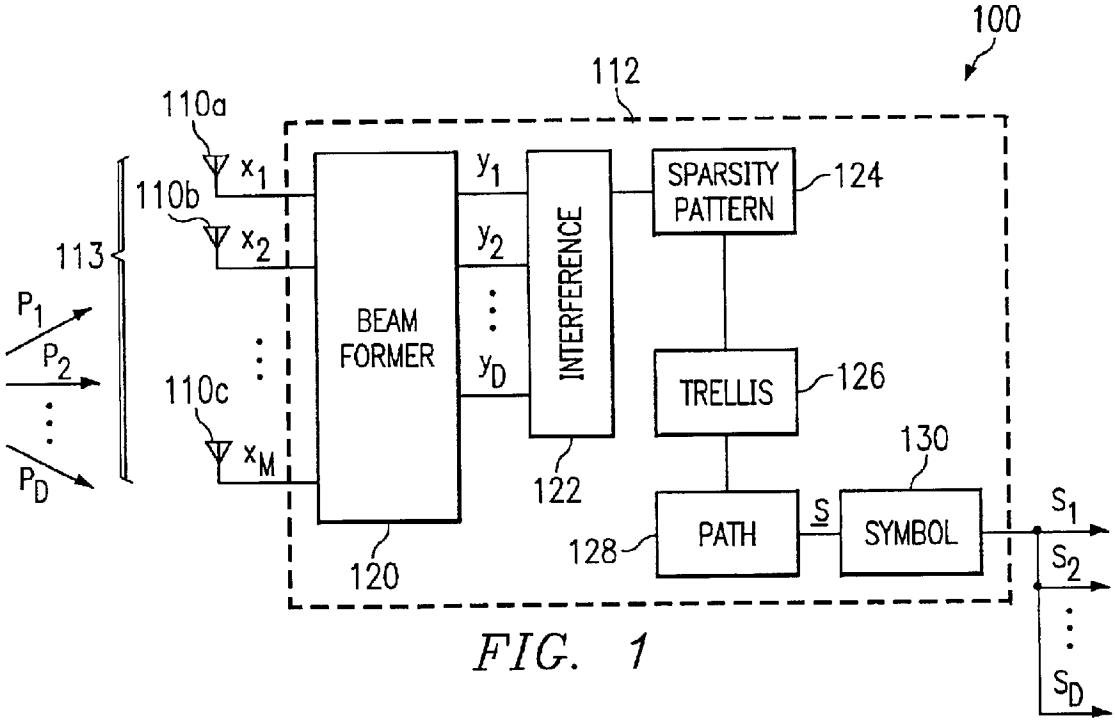

100
112
110a
110b
110c
113
x_1
x_2
x_M
P_1
P_2
P_D
BEAM FORMER
120
y_1
y_2
y_D
INTERFERENCE
122
SPARSITY PATTERN
124
TRELLIS
126
PATH
128
S
SYMBOL
130
S_1
S_2
S_D

FIG. 1

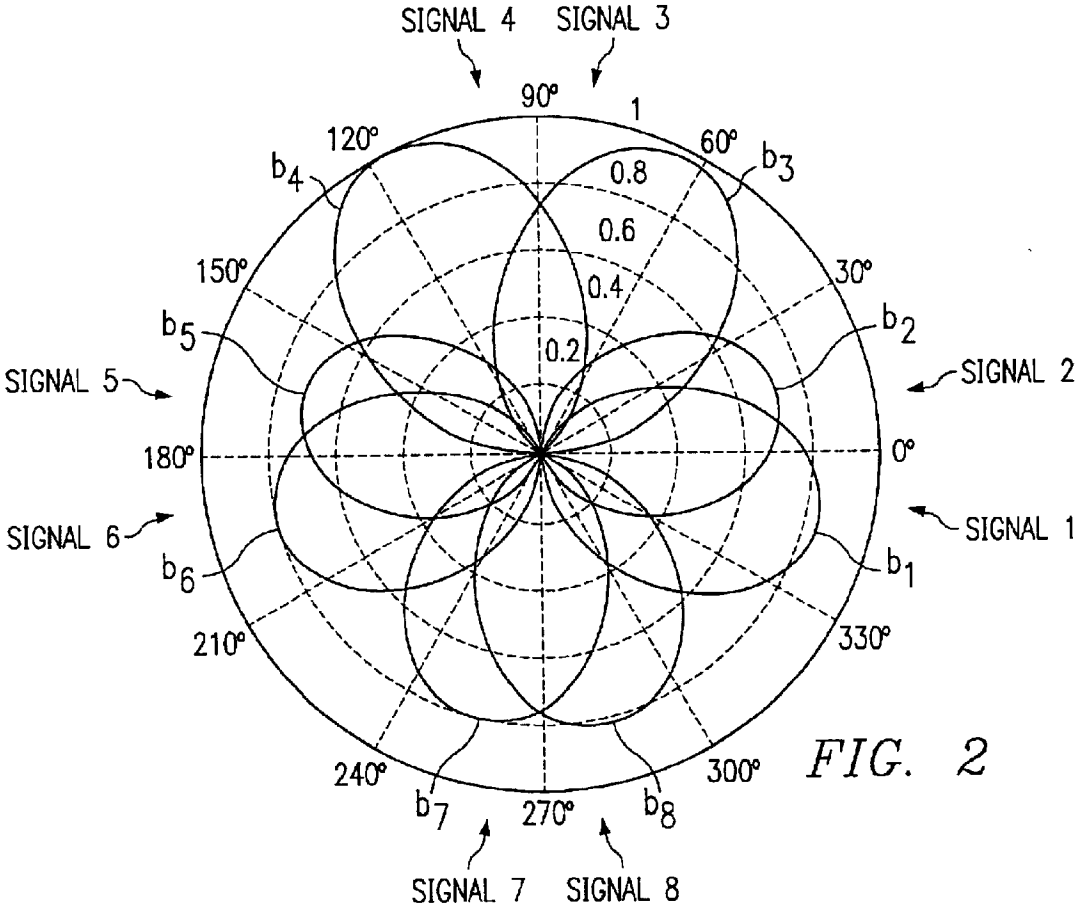

SIGNAL 4
SIGNAL 3
90°
1
120°
60°
b_4
b_3
0.8
0.6
0.4
0.2
150°
30°
b_5
b_2
SIGNAL 5
SIGNAL 2
180°
0°
SIGNAL 6
SIGNAL 1
b_6
b_1
210°
330°
240°
300°
b_7
270°
b_8
SIGNAL 7
SIGNAL 8

FIG. 2

FIG. 3

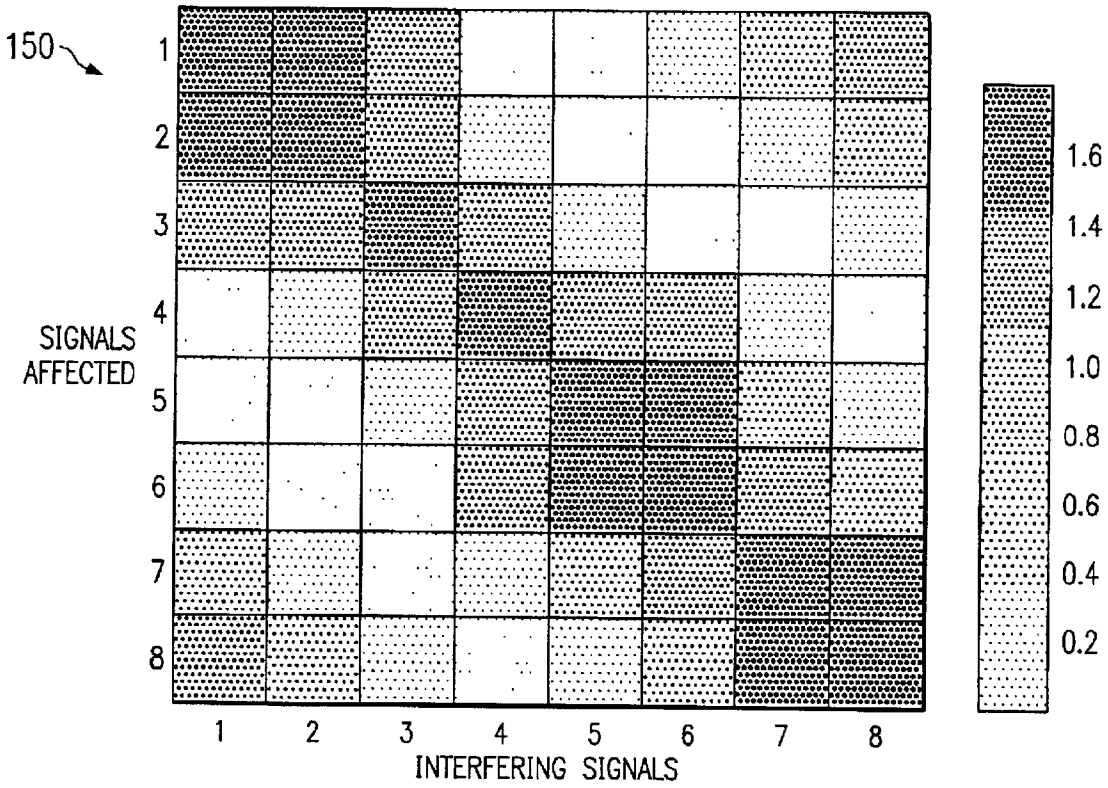
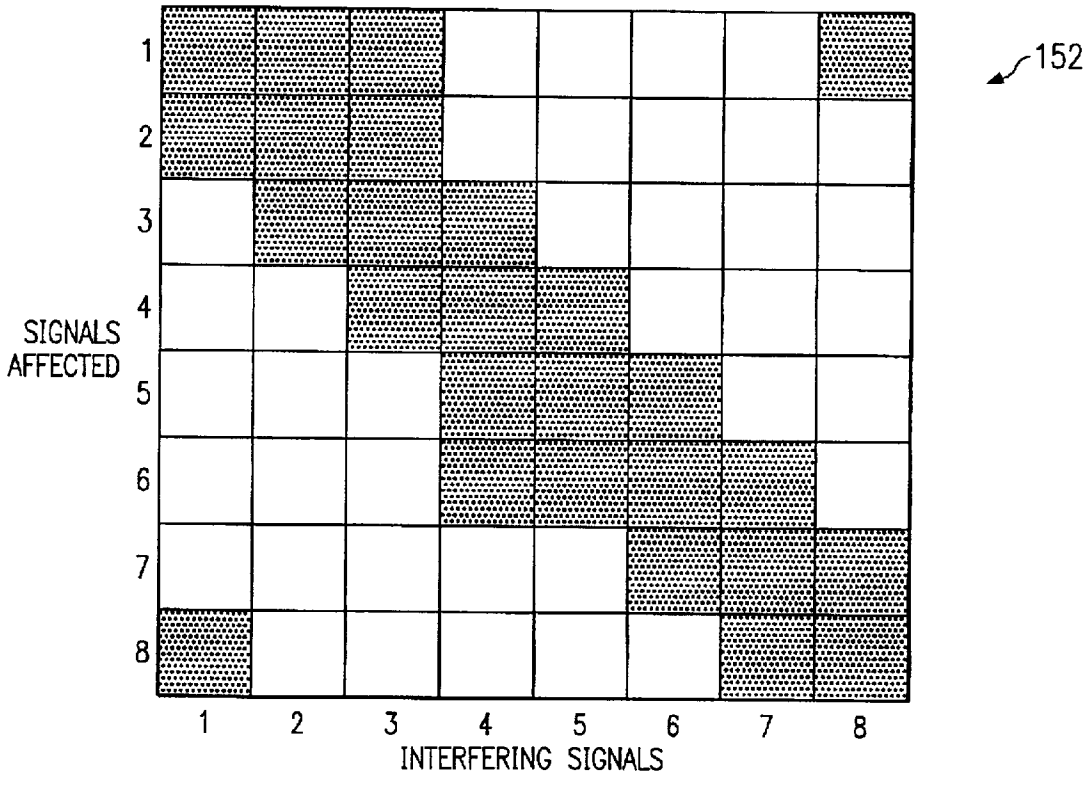

150
1
2
3
4
5
6
7
8
SIGNALS AFFECTED
1 2 3 4 5 6 7 8
INTERFERING SIGNALS
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2

FIG. 4


152
1
2
3
4
5
6
7
8
SIGNALS AFFECTED
1 2 3 4 5 6 7 8
INTERFERING SIGNALS

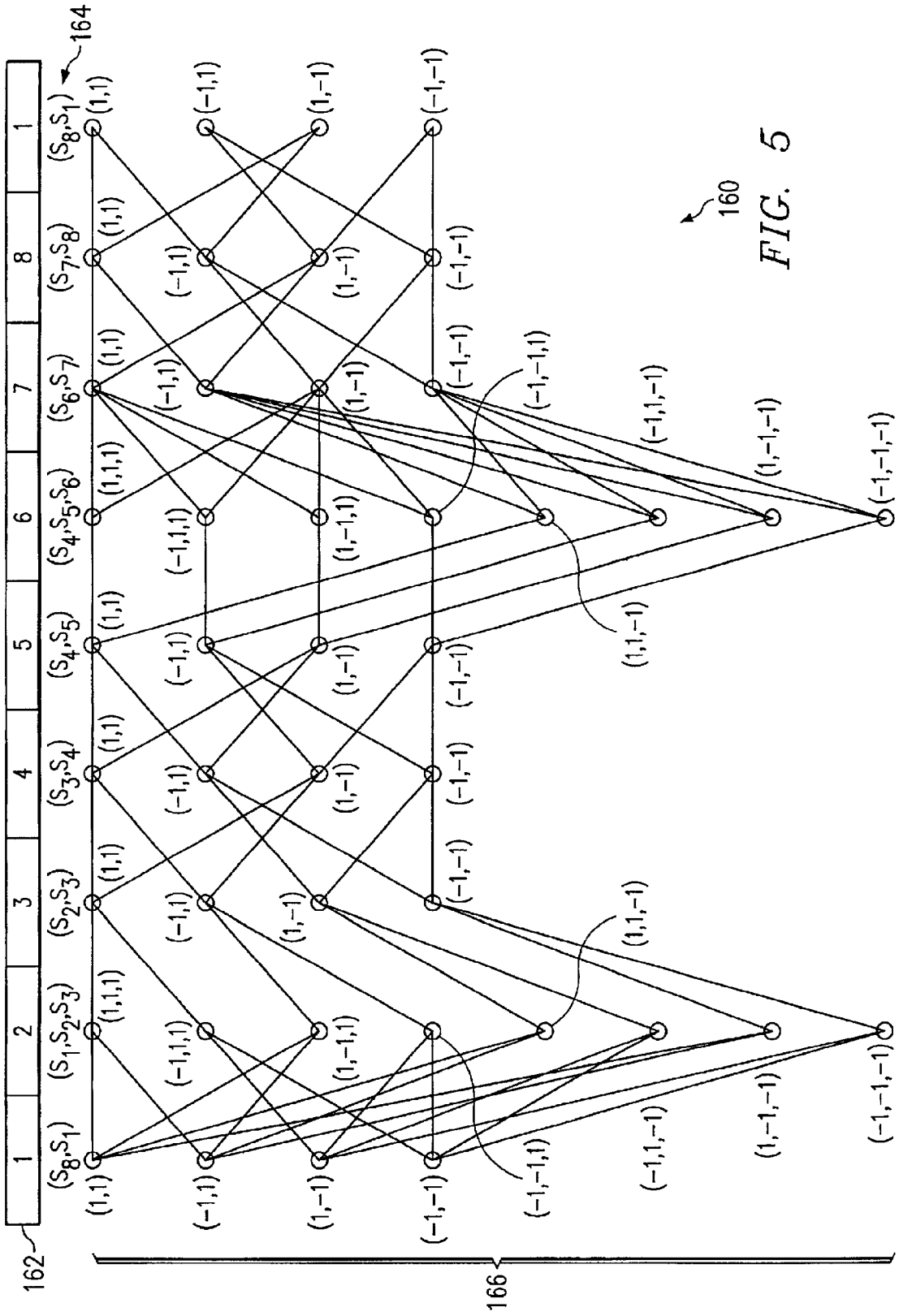

164
160
162
166
1
2
3
4
5
6
7
8
(S_8,S_1)
(S_1,S_2,S_3)
(S_2,S_3)
(S_3,S_4)
(S_4,S_5)
(S_4,S_5,S_6)
(S_6,S_7)
(S_7,S_8)
(1,1)
(-1,1)
(1,-1)
(-1,-1)
(1,1,1)
(-1,1,1)
(1,-1,1)
(-1,-1,1)
(1,1,-1)
(-1,1,-1)
(1,-1,-1)
(-1,-1,-1)

FIG. 5

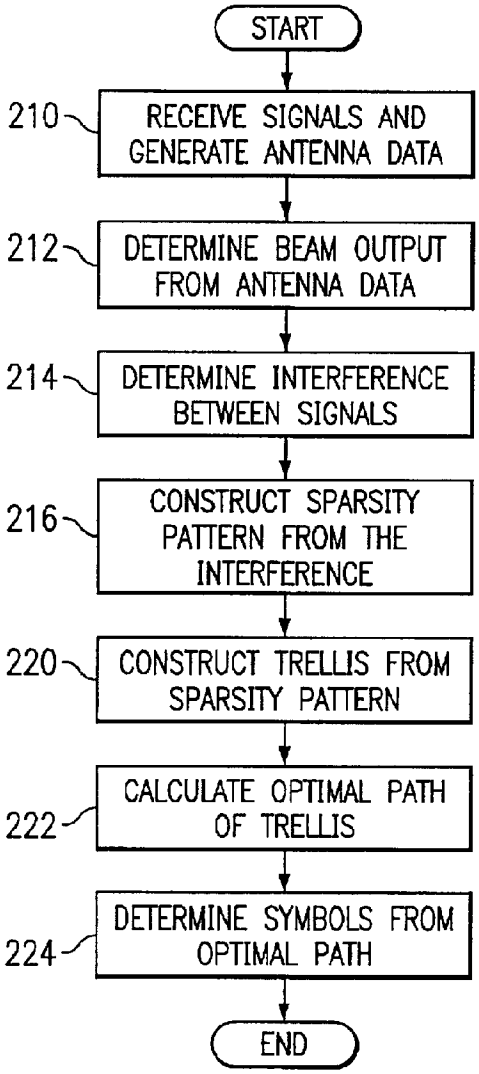

START
210
RECEIVE SIGNALS AND GENERATE ANTENNA DATA
212
DETERMINE BEAM OUTPUT FROM ANTENNA DATA
214
DETERMINE INTERFERENCE BETWEEN SIGNALS
216
CONSTRUCT SPARSITY PATTERN FROM THE INTERFERENCE
220
CONSTRUCT TRELLIS FROM SPARSITY PATTERN
222
CALCULATE OPTIMAL PATH OF TRELLIS
224
DETERMINE SYMBOLS FROM OPTIMAL PATH
END

FIG. 6

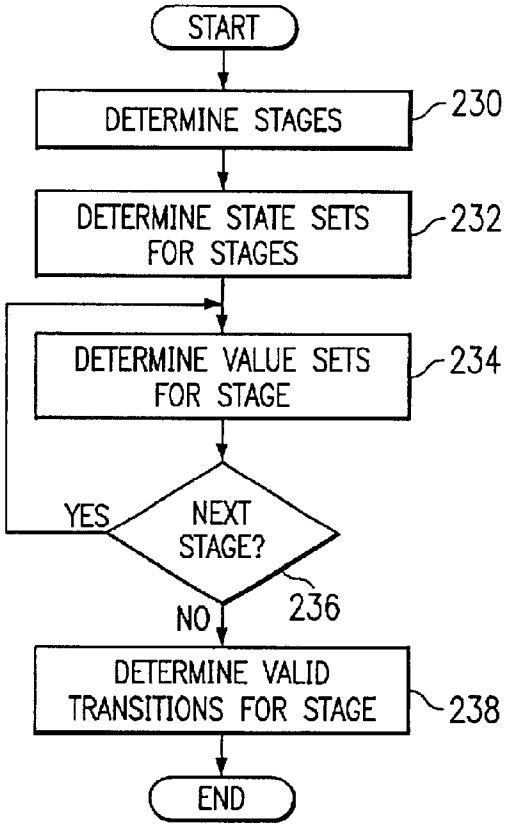

START
DETERMINE STAGES
230
DETERMINE STATE SETS FOR STAGES
232
DETERMINE VALUE SETS FOR STAGE
234
YES
NEXT STAGE?
236
NO
DETERMINE VALID TRANSITIONS FOR STAGE
238
END

FIG. 7

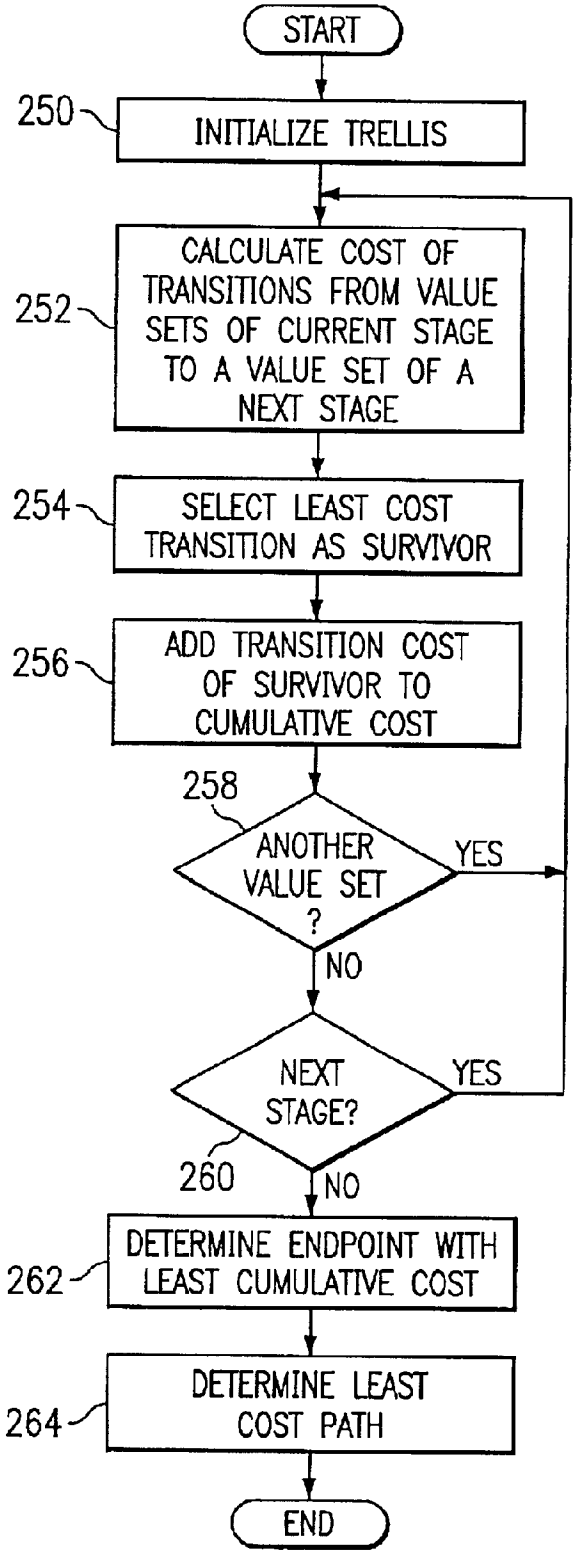

START
250
INITIALIZE TRELLIS
252
CALCULATE COST OF TRANSITIONS FROM VALUE SETS OF CURRENT STAGE TO A VALUE SET OF A NEXT STAGE
254
SELECT LEAST COST TRANSITION AS SURVIVOR
256
ADD TRANSITION COST OF SURVIVOR TO CUMULATIVE COST
258
ANOTHER VALUE SET ?
YES
NO
NEXT STAGE?
YES
260
NO
262
DETERMINE ENDPOINT WITH LEAST CUMULATIVE COST
264
DETERMINE LEAST COST PATH
END

FIG. 8

METHOD AND SYSTEM FOR OVERLOADED ARRAY PROCESSING

RELATED APPLICATION

This application claims the benefit of U.S. provisional application Ser. No. 60/204,117, filed May 15, 2000, entitled *SPATIALLY REDUCED SEARCH JOINT DETECTION FOR OVERLOADED ARRAY PROCESSING.*

TECHNICAL FIELD OF THE INVENTION

This invention relates generally to the field of wireless communications and more specifically to a method and system for overloaded array processing.

BACKGROUND OF THE INVENTION

Many antenna arrays such as airborne antenna arrays have a limited number of antenna elements due to size and weight restrictions, but receive multiple signals due to their high altitude and resulting large field of view. An antenna array becomes overloaded when the number of signals received by the array exceeds the number of antenna elements of the array. Techniques for overloaded array processing, however, require a large amount of computational power and time. Consequently, overloaded array processing has posed challenges in the field of wireless communications.

SUMMARY OF THE INVENTION

While known approaches have provided improvements over prior approaches, the challenges in the field of wireless communications have continued to increase with demands for more and better techniques having greater effectiveness. Therefore, a need has arisen for a new method and system for overloaded array processing.

In accordance with the present invention, a method and system for overloaded array processing are provided that substantially eliminate or reduce the disadvantages and problems associated with previously developed systems and methods.

According to one embodiment of the present invention, a method for array processing is disclosed. Signals transmitting a symbol set are received. A dominant signal set for each signal is determined. The dominant signal set for a signal includes dominant signals that interfere with the signal. A trellis is constructed from the dominant signal sets. The trellis includes paths that represent possible symbol sets. An optimal path from the trellis is selected, and the symbol set represented by the optimal path is determined.

Certain embodiments of the invention may provide numerous technical advantages. A technical advantage of one embodiment is that a spatial-trellis is used to describe possible symbol sets transmitted by spatially diverse signals. The trellis may significantly reduce the required search with little performance degradation over the optimal solution. Another technical advantage of one embodiment is that a sparsity pattern is used to identify signals that produce dominant interference and to eliminate the rest of the signals. The sparsity pattern may provide an efficient method for constructing a trellis of reduced complexity, thus decreasing computational time and power. Another technical advantage of one embodiment is that an efficient search process is used to locate an approximate least cost path through the trellis. The least cost path identifies an optimal symbol set.

Other technical advantages are readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and for further features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a block diagram illustrating a system for array processing;

FIG. **2** illustrates beams formed from eight signals impinging on five antenna elements;

FIG. **3** is an interference diagram illustrating interference that each signal of FIG. **2** experiences from the other signals;

FIG. **4** is a sparsity pattern for the interference diagram of FIG. **3**;

FIG. **5** is a trellis generated from the sparsity pattern of FIG. **4**;

FIG. **6** is a flowchart illustrating a method for array processing;

FIG. **7** is a flowchart illustrating a method for constructing the trellis of FIG. **5** from the sparsity pattern of FIG. **4**; and

FIG. **8** is a flow chart illustrating one method for determining an optimal path of the trellis of FIG. **5**.

DETAILED DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention and its advantages are best understood by referring to FIGS. **1** through **8** of the drawings, like numerals being used for like and corresponding parts of the various drawings.

FIG. **1** is a block diagram illustrating a system **100** for array processing. System **100** includes an antenna array **113** of radius R that has antenna elements **110** that receive signals $p_1, p_2, \ldots, p_D$. Signals p_d transmit symbols to system **100**, which processes the signals p_d to extract the symbols. Signals p_d may be, for example, co-channel, complex pulse-amplitude modulated (PAM) signals that are symbol-synchronous, or have perfectly aligned symbols. The number D of signals p_d received by antenna elements **110** may be greater than the number M of antenna elements **110** such that antenna array **113** is overloaded. Antenna elements **110** generate antenna data $x_1, x_2, \ldots, x_m, \ldots, x_M$ in response to detecting signals p_d.

The relationship between the antenna data and symbols for system **100** is described by Equation (1):

$$\underline{x}[n]=A\underline{s}[n]+\underline{z}[n] \tag{1}$$

where vector $\underline{s}[n]=[s_1[n]\ s_2[n] \ldots s_D[n]]^T$ is a D×1 vector of the nth symbol set transmitted by the signals, and $s_d[n]$ is the symbol set transmitted by signal p_d. Each $s_d[n]$ is independent and drawn equally likely from an alphabet of symbols. Vector $\underline{x}[n]=[x_1[n]\ x_2[n] \ldots x_M[n]]$ is an M×1 vector of antenna data generated in response to the nth received signals. Matrix A is the composite array response for the signals, where the dth column of matrix A is the steering vector for the dth signal. If signals p_d are at zero elevation. If the array has a circular geometry then the steering vector for antenna array **113** is given by Equation (2):

$$\underline{a}(\theta_d) = [\alpha_1 \ \ldots \ \alpha_M]^T,\ \alpha_m = \exp\left(-jK_R \sin\left(\theta_d - \frac{2\pi(m-1)}{M}\right)\right) \tag{2}$$

where the constant $K_R=2\pi R/\lambda$, angle θ_d is the azimuthal angle of arrival, λ is the wavelength of the carrier frequency, and T represents vector transpose. Vector $\underline{z}[n]$ is an M×1 vector representing temporally uncorrelated noise with zero

mean and autocorrelation $\Phi_{\underline{z}\underline{z}}=E[\underline{z}[n]\underline{z}[n]^H]$, where H represents the Hermetian transpose, or the conjugate-transpose, of a matrix.

System **100** utilizes a modified form of a joint maximum likelihood (JML) criterion to identify the most likely symbol set transmitted by signals p_d. The modified form represents a cost function, which is optimized to determine the most likely symbol set. If no inter-symbol interference is present, a joint maximum likelihood (JML) criterion for detecting signals p_d impinging on antenna array **113** is described by Equation (3):

$$\hat{\underline{s}}[n] = \underset{\underline{s}\in A^{D_u}}{\operatorname{argmin}} (\underline{x}[n] - A\underline{s})^H \Phi_{\underline{z}\underline{z}}^{-1} (\underline{x}[n] - A\underline{s}) \tag{3}$$

The JML criterion is modified to produce a cost function. Equation (3) is simplified by expanding products and dropping terms independent of the optimization to yield Equation (4):

$$\hat{\underline{s}}[n] = \operatorname{argmin}\left\{\underline{s}^H A^H \Phi_{\underline{z}\underline{z}}^{-1} A\underline{s} - 2Re\left\{(\Phi_{\underline{z}\underline{z}}^{-1} A\underline{s})^H \underline{x}\right\}\right\} \tag{4}$$

where Re represents the real part of a number. A D×D matrix H and D×1 vector $\underline{y}$ are defined by Equations (5):

$$\begin{aligned} H^H H &= A^H \Phi_{\underline{z}\underline{z}}^{-1} A, \\ H^H \underline{y} &= A^H \Phi_{\underline{z}\underline{z}}^{-1} \underline{x} \end{aligned} \tag{5}$$

Matrix H may be written as a spectral square root described by Equation (6):

$$H = (A^H \Phi_{\underline{z}\underline{z}}^{-1} A)^{(1/2)} \tag{6}$$

Matrix H may be used as an interference matrix that describes the energy that one signal receives from other signals. Matrix H may be selected such that the interference represented by each row of matrix H is concentrated.

Equation (4) is rewritten as a cost function as defined by Equation (7):

$$\begin{aligned} \hat{\underline{s}}[n] &= \arg_{\underline{s}}\min \|\underline{y} - H\underline{s}\|^2 \\ &= \arg_{\underline{s}}\min \sum_{d=1}^{D_s} |y[d] - \hat{y}[d]|^2 \end{aligned} \tag{7}$$

where $\underline{h}[d]$ is the dth row of H, and $y[d]=\underline{h}[d]\underline{s}$.

Vector $\underline{y}$ is selected to complete the square of the cost function as described by Equation (7) such that when the quantities on the right side of Equation (7) and the matrix H are known, for example, vector $\underline{y}$ may be defined by Equation (8):

$$\underline{y} = ((H^H)^{\mp} A^H \Phi_{\underline{z}\underline{z}}^{-1})\underline{x} = W\underline{x} \tag{8}$$

where $\mp$ represents the penrose psuedo-inverse of a matrix.

A module set **112** uses Equations (5) through (8) to process antenna data x_m to identify the symbol sets $\underline{s}[n]$ that are communicated by the signals p_d. The modules of module set **112** may include hardware, software, or any suitable configuration of hardware and software. Module set **112** includes a beam former module **120**, an interference module **122**, a sparsity pattern module **124**, a trellis module **126**, a path module **128**, and a symbol module **130**. Beam former module **120** applies a beam former matrix W, as defined by Equation (8), to antenna data x_m to yield beam outputs y_d. Matrix W is a multi-input, multi-output (MIMO) beamformer matrix since each row of matrix W performs an implicit beamforming operation and all rows together preserve the maximum-likelihood criterion. For certain antenna arrays, matrix W focuses the dth beam on the dth user such that every user has dominant energy in at least one beam, thus reducing the complexity of overloaded array processing. A representation of the beams is illustrated in FIG. **2**. FIG. **2** illustrates beams $b_1, b_2, \ldots, b_8$ formed from eight signals p_d impinging on five antenna elements **110**. The angles of arrival for signals $p_1, p_2, \ldots, p_8$ are 12°, 64°, 115°, 171°, 186°, 261°, 278°, and 353°, respectively.

Interference module **122** uses interference matrix H, as defined by Equation (5), and beam outputs y_k to determine interference among signals p_d. FIG. **3** is an interference diagram **150** constructed from matrix H, which illustrates interference that each signal p_d of FIG. **2** experiences from the other signals. The rows of interference diagram **150** represent the energy that an affected signal receives from interfering signals, and the columns represent the interfering signals. For example, the first row represents the energy that signal p_1 receives from signals $p_1, p_2, \ldots, p_8$. Interference diagram **150** indicates that signal p_1 receives the most energy from itself and from neighboring signals p_2 and p_8.

Sparsity pattern module **124** generates a sparsity pattern from interference diagram **150**. The sparsity pattern is a matrix of ones and zeros, where the ones represent dominant signals, or signals that produce interference with high levels of energy, and the zeros represent nondominant signals. The rows of the sparsity pattern represent the signals affected by the interfering signals, and the columns represent the interfering signals. The dominant signals from an affected signal form a dominant signal set U for that signal.

An example of a sparsity pattern **152** for interference diagram **150** is illustrated in FIG. **4**. The rows of sparsity pattern **152** correspond to the rows of interference diagram **150**, and the columns of sparsity pattern **152** correspond to the columns of interference diagram **150**. The dominant signal set U for signal p_1, according to sparsity pattern **152**, is $U=\{s_1, s_2, s_3, s_8\}$. Dark squares represent ones, and white squares represent zeros. For each signal, the sparsity pattern selects the dominant signals that interfere most with the signal, and eliminates the nondominant signals. Thus, the sparsity pattern reduces complexity, allowing for more efficient array processing.

If an optimal sparsity pattern cannot be readily determined, a sub-optimal sparsity pattern may be calculated according to a ratio RP of a desired signal's power in the beam former output y[d] to the power of the signals outside the dominant signal set. The ratio RP may be defined by Equation (9):

$$RP = \frac{E[|h[d,d]s[d]|^2]}{E\left[\left|\sum_{u\in U[d]} h[d,u]s[u]\right|^2\right]} = \frac{|h[d,d]|^2}{\sum_{u\in U[d]} |h[d,u]|^2} \tag{9}$$

where E represents the expected value. The sparsity pattern is generated by selecting the smallest number of contiguous signals that satisfy a predetermined ratio RP for each affected signal.

Trellis module **126** generates a trellis from the sparsity pattern. A trellis represents possible symbol sets. FIG. **5** illustrates a spatial trellis **160** generated from sparsity pat-

tern **152**. A method for generating trellis **160** from sparsity pattern **152** is described in more detail in connection with FIG. **7**. Path module **128** searches trellis **160** to determine an optimal path of trellis **160** that optimizes the cost function as defined by Equation (7). The optimal path of trellis **160** represents a most likely symbol set s[n] transmitted by signals p_d. Symbol module **130** extracts the symbol set s[n] from the optimal path. A method for determining the optimal path and extracting the symbol set is described in more detail in connection with FIGS. **6** through **8**.

FIG. **6** is a flowchart illustrating a method for array processing. The method generates a trellis that represents the possible symbol sets s[n] transmitted by signals p_d. A search is performed on the trellis in order to determine the symbol set s[n] that satisfies the maximum likelihood criterion as defined by Equation (3).

The method begins at step **210**, where antenna elements **110** receive signals p_d and output antenna data x_m. At step **212**, beam former **120** determines beam output y_d from antenna data x_m using beam former matrix W as defined by Equation (8). FIG. **2** illustrates beams described by beam outputs y_d. At step **214**, the interference between beams is determined. Interference module **122** determines the interference by applying matrix H as defined by Equation (5) to beam output y_d. Interference diagram **150** of FIG. **3** illustrates the interference among beams. At step **216**, sparsity pattern **152** of FIG. **4** is constructed from interference matrix H. Sparsity pattern **152** represents the dominant signals.

A trellis is constructed using from sparsity pattern **152** at step **220**. A method for constructing a trellis is described in connection with FIG. **7**.

FIG. **7** is a flowchart illustrating a method for constructing trellis **160** from sparsity pattern **152**. The method begins at step **230** to determine stages **162** of trellis **160**. A stage **162** represents a signal affected by interfering signals, and corresponds to a row of sparsity pattern **152**. Stages **1**, **2**, . . . , **8** represent signals p_1, p_2, . . . , p_8, respectively, affected by interference from interfering signals.

At step **232**, state sets **164** for stages **162** are determined. A state set **164** for a stage **162** (see FIG. **5**) represents selected dominant signals interfering with the signal represented by the stage **162**. State sets **164** are selected from the dominant signal sets U of sparsity pattern **152**. If the dominant signal sets U of sparsity pattern **152** satisfy $U_e[d] \subseteq U_e[d-1] \cup U_e[d+1]$ with modulo-D indexing, the resulting trellis **160** is called a "tail-biting trellis." State sets $\sigma[d]$ for the dth state may be determined from the dominant signal sets U using Equation (10):

$$\sigma[d]=\{s_u | u \epsilon U[d-1] \cap U[d]\} \tag{10}$$

That is, the dth stage of trellis **160**, is described by Equation (11):

$$\sigma[d] \cup \sigma[d+1]=(U[d-1] \cap U[d]) \cup (U[d] \cap U[d+1])=U[d] \tag{11}$$

For example, state set (s_8, s_1) is determined for stage **1**. At step **234**, value sets **166** for a stage **162** are determined. Value sets **166** of stage **162** include all possible values that the signals, or states, of a state set of the stage **162** may have. For example, values (1,1), (−1,1), (1,−1), and (−1,−1) are determined for state (s_8, s_1).

At step **236**, the method determines whether there is a next stage. If there is a next stage, the method returns to step **234** to determine the value sets for the stage. If there is no next stage, the method proceeds to step **238** to determine the valid transitions for a stage. Valid transitions are transitions between stages for which the corresponding states have the same value. For example, a transition from state set (s_8, s_1) with values (1,1) to state sets (s_1, s_2, s_3) with values (1,1,1) is valid, because state s_1 has the same value 1 at both stages. The transition from state set (s_8, s_1) with values (1,1) to state set (s_1, s_2, s_3) with values (−1,1,1) is not valid because s_1 has value 1 at stage **1** and value −1 at stage **2**. After determining the valid transitions, the method terminates.

Returning to FIG. **6**, at step **222**, an optimal path of trellis **160** is calculated. The optimal path is the least cost path for the cost function defined by Equation (7). A method for calculating the optimal path is described in connection with FIG. **8**.

FIG. **8** is a flow chart illustrating one method for determining an optimal path of trellis **160**. The method selects an optimal path by calculating a cumulative cost for each path through the stages of trellis **160**.

The method begins at step **250**, where trellis **160** is initialized. Trellis **160** is initialized by selecting a starting stage as a current stage, for example, stage **1**, and setting the cumulative costs for all value sets at zero. At step **452**, the costs of transitions from value sets of the current stage to one value set of a next stage are calculated using Equation (7). For example, the costs of transitions from (1,1) at stage **1** to (1,1,1) at stage **2** and from (−1,1) at stage **1** to (−1,1,1) at stage **2** are calculated. The least cost transition is selected as a survivor at step **254**. For example, the transition from (−1,1) to (1,1,1) is selected as the survivor. At step **256**, the transition cost of the survivor is added to the cumulative cost of the value set at the next stage. For example, the transition cost is added to the cumulative cost of (1,1,1) at stage **2**.

At step **258**, the method determines whether there is another value set of the next stage. If there is another value set, the method returns to step **252** in order to calculate the cost of the transitions from the value sets of the current stage to the value set of the next stage. For example, the costs of the transitions from (1,1) to (−1,1,1) and from (−1,−1) to (−1,1,1) are calculated.

If there is not another value set at step **258**, the method proceeds to step **260** to determine whether there is a next stage. Since trellis **160** is a tail-biting trellis, the method may proceed around the trellis through any number of stages. For example, the method may process stages **1** through **8**, and then process stages **1** through **8** again. As more stages are processed, the accuracy of the search increases. The number of stages to be processed may be determined according to the desired accuracy and available computational power and time. If there is a next stage, the method returns to step **252** to calculate the transition costs at the next stage. If there is no next stage at step **260**, the method proceeds to step **262** to determine the least cumulative cost. For example, a path ending at stage **8** with an endpoint value set (1,−1) has the least cumulative cost.

The least cost path is determined at step **264**. The least cost path is determined by tracing back from the endpoint value set with the least cumulative cost through the survivors. For example, a path with value sets for stages **1** through **8** is represented by [(1,1) (1,−1,1) (1,1) (1,−1) (−1,1) (1,1,−) (1,−1) (−1,1) (1,−1)]. After determining the least cost path, the method terminates.

Returning to FIG. **6**, the symbols are determined from the least cost path at step **224**. The least cost path lists the symbols of the symbol set, for example, [(1,1) (1,−1,1) (1,1) (1,−1) (−1,1) (1,1,−1) (1,−1) (−1,1) (1,−1)]. Thus, the method identifies a symbol set that satisfies the maximum likelihood criterion as defined by Equation (3). After determining the symbols, the method terminates.

Certain embodiments of the invention may provide numerous technical advantages. A technical advantage of

one embodiment is that a trellis is used to describe possible symbol sets transmitted by spatially diverse signals. The trellis is searched to efficiently identify an optimal symbol set. Another technical advantage of one embodiment is that a sparsity pattern is used to identify signals that produce dominant interference and to eliminate the rest of the signals. The sparsity pattern reduces the complexity of the array processing, thus decreasing computational time and power. Another technical advantage of one embodiment is that an efficient search process is used to locate a least cost path of the trellis. The least cost path identifies an optimal symbol set.

Although an embodiment of the invention and its advantages are described in detail, a person skilled in the art could make various alterations, additions, and omissions without departing from the spirit and scope of the present invention as defined by the appended claims.

What is claimed is:

1. A method for array processing, the method comprising:

receiving a plurality of signals transmitting a symbol set;

determining a dominant signal set for each signal, the dominant signal set for a signal comprising a set of dominant signals that interfere with the signal;

constructing a trellis from the dominant signal sets, the trellis comprising a plurality of paths, each path representing a possible symbol set;

selecting an optimal path from the trellis; and

determining the symbol set represented by the optimal path.

2. The method of claim **1**, wherein determining the dominant signal set for each signal comprises:

determining energy that each signal receives from the other signals;

constructing a sparsity pattern from the energy; and

selecting the dominant signal sets from the sparsity pattern.

3. The method of claim **1**, wherein constructing the trellis from the dominant signal sets comprises:

associating a stage of the trellis with each signal;

selecting a state set for each stage, the state set selected from the dominant signal set of the signal associated with the stage;

determining a plurality of value sets for each state set, each value set comprising a set of values for the state set; and

determining a plurality of transitions between the value sets, the paths of the trellis comprising at least some of the transitions.

4. The method of claim **1**, wherein constructing the trellis from the dominant signal sets comprises:

associating a state set with each signal, the state set selected from the dominant signal set of the signal;

determining a value set for each state set, the value set comprising a set of values for the state set; and

determining the paths of the trellis from the value sets.

5. The method of claim **1**, wherein selecting the optimal path from the trellis comprises determining an optimal path according to an approximation of a maximum likelihood criterion.

6. The method of claim **1**, wherein selecting the optimal path from the trellis comprises:

associating each path with a cumulative cost; and

determining the path with the lowest cumulative cost.

7. The method of claim **1**, wherein:

each path of the trellis comprises a plurality of transitions; and

selecting the optimal path from the trellis comprises:

calculating a transition cost for each transition; and

determining the path comprising the transitions with the lowest total transition cost.

8. A method for array processing, the method comprising:

receiving a plurality of signals transmitting a symbol set;

determining a dominant signal set for each signal, the dominant signal set for a signal comprising a set of dominant signals that interfere with the signal;

constructing a trellis from the dominant signal sets, comprising:

constructing a plurality of paths, each path representing a possible symbol set;

constructing a plurality of stages, each stage corresponding to a signal;

constructing a plurality of value sets associated with each stage; and

constructing a plurality of transitions, each transition going from a current value set to a next value set, each path of the trellis comprising at least some of the transitions;

selecting an optimal path from the trellis; and

determining the symbol set represented by the optimal path.

9. The method of claim **8**, wherein selecting the optimal path from the trellis comprises:

determining a set of survivor transitions for each stage;

calculating a transition cost for each survivor transition;

adding the transition cost of each survivor transition to a cumulative cost associated with the survivor transition; and

determining the optimal path from a survivor transition of a last stage corresponding to the lowest cumulative cost.

10. The method of claim **8**, wherein selecting the optimal path from the trellis comprises:

determining a set of survivor transitions for each stage by:

calculating a transition cost for each transition from the value sets of a current stage to a value set of a next stage;

determining a survivor transition with the lowest transition cost;

adding the transition cost of each survivor transition to a cumulative cost associated with the survivor transition; and

determining the optimal path from a survivor transition of a last stage corresponding to the lowest cumulative cost.

11. A system for array processing, the system comprising:

a plurality of antenna elements receiving a plurality of signals transmitting a symbol set;

a module set coupled to the antenna elements, the module set:

determining a dominant signal set for each signal, the dominant signal set for a signal comprising a set of dominant signals that interfere with the signal;

constructing a trellis from the dominant signal sets, the trellis comprising a plurality of paths, each path representing a possible symbol set;

selecting an optimal path from the trellis; and

determining the symbol set represented by the optimal path.

12. The system of claim 11, wherein the module set determines the dominant signal set for each signal by:
- determining energy that each signal receives from the other signals;
- constructing a sparsity pattern from the energy; and
- selecting the dominant signal sets from the sparsity pattern.

13. The system of claim 11, wherein the module set constructs the trellis from the dominant signal sets by:
- associating a stage of the trellis with each signal;
- selecting a state set for each stage, the state set selected from the dominant signal set of the signal associated with the stage;
- determining a plurality of value sets for each state set, each value set comprising a set of values for the state set; and
- determining a plurality of transitions between the value sets, the paths of the trellis comprising at least some of the transitions.

14. The system of claim 11, wherein the module set constructs the trellis from the dominant signal sets by:
- associating a state set with each signal, the state set selected from the dominant signal set of the signal;
- determining a value set for each state set, the value set comprising a set of values for the state set; and
- determining the paths of the trellis from the value sets.

15. The system of claim 11, wherein the module set selects the optimal path from the trellis by determining an optimal path according to an approximation of a maximum likelihood criterion.

16. The system of claim 11, wherein the module set selects the optimal path from the trellis by:
- associating each path with a cumulative cost; and
- determining the path with the lowest cumulative cost.

17. The system of claim 11, wherein:
- each path of the trellis comprises a plurality of transitions; and
- the module set selects the optimal path from the trellis by:
  - calculating a transition cost for each transition; and
  - determining the path comprising the transitions with the lowest total transition cost.

18. A system for array processing, the system comprising:
- a plurality of antenna elements receiving a plurality of signals transmitting a symbol set;
- a module set coupled to the antenna elements, the module set:
  - determining a dominant signal set for each signal, the dominant signal set for a signal comprising a set of dominant signals that interfere with the signal;
  - constructing a trellis from the dominant signal sets, the trellis comprising:
    - a plurality of paths, each path representing a possible symbol set;
    - a plurality of stages, each stage corresponding to a signal;
    - a plurality of value sets associated with each stage; and
    - a plurality of transitions, each transition going from a current value set to a next value set, each path of the trellis comprising at least some of the transitions;
  - selecting an optimal path from the trellis; and
  - determining the symbol set represented by the optimal path.

19. The system of claim 18, wherein the module set selects the optimal path from the trellis by:
- determining a set of survivor transitions for each stage;
- calculating a transition cost for each survivor transition;
- adding the transition cost of each survivor transition to a cumulative cost associated with the survivor transition; and
- determining the optimal path from a survivor transition of a last stage corresponding to the lowest cumulative cost.

20. The system of claim 18, wherein the module set selects the optimal path from the trellis by:
- determining a set of survivor transitions for each stage by:
  - calculating a transition cost for each transition from the value sets of a current stage to a value set of a next stage;
  - determining a survivor transition with the lowest transition cost;
- adding the transition cost of each survivor transition to a cumulative cost associated with the survivor transition; and
- determining the optimal path from a survivor transition of a last stage corresponding to the lowest cumulative cost.

21. A method for array processing, the method comprising:
- receiving a plurality of signals transmitting a symbol set;
- determining a dominant signal set for each signal by:
  - determining energy that each signal receives from the other signals;
  - constructing a sparsity pattern from the energy; and
  - selecting the dominant signal sets from the sparsity pattern;
- constructing a trellis comprising a plurality of paths from the dominant signal sets by:
  - associating a state set with each signal, the state set selected from the dominant signal set of the signal;
  - determining a value set for each state set, the value set comprising a set of values for the state set; and
  - determining the paths of the trellis from the value sets, each path representing a possible symbol set;
- selecting an optimal path from the trellis by:
  - determining a set of survivor transitions for each stage;
  - calculating a transition cost for each survivor transition;
  - adding the transition cost of each survivor transition to a cumulative cost associated with the survivor transition; and
  - determining the optimal path from a survivor transition of a last stage corresponding to the lowest cumulative cost; and
- determining the symbol set represented by the optimal path.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,868,133 B2
APPLICATION NO. : 09/858316
DATED : March 15, 2005
INVENTOR(S) : Hicks et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 2, Line 34, after "p_2, ...,", delete "p_D", and insert -- p_d --.
Column 3, Line 21, after "{$\underline{s}^H A^H$", delete "Φ_{zz}^{-1}", and insert -- $\Phi_{\underline{zz}}^{-1}$ --.
Column 3, Line 21, after "2Re{(", delete "Φ_{zz}^{-1}", and insert -- $\Phi_{\underline{zz}}^{-1}$ --.

Column 3, Lines 45-47, after "min" delete "$\sum_{d=1}^{Ds}$", and insert -- $\sum_{d=1}^{Du}$ --.

Column 6, Line 57, after "(-1,1)", delete "(1, 1, -)", and insert -- (1, 1, -1) --.

Signed and Sealed this

Thirteenth Day of February, 2007

JON W. DUDAS
Director of the United States Patent and Trademark Office