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CA 2611950 A1 2006/12/28

(21) 2 611 950

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2006/06/15
(87) Date publication PCT/PCT Publication Date: 2006/12/28
(85) Entrée phase nationale/National Entry: 2007/12/12
(86) N° demande PCT/PCT Application No.: US 2006/023515
(87) N° publication PCT/PCT Publication No.: 2006/138582
(30) Priorités/Priorities: 2005/06/16 (US60/691,461); 2005/07/25 (US11/190,106)
(51) Cl.Int./Int.Cl. *H04J 11/00* (2006.01)

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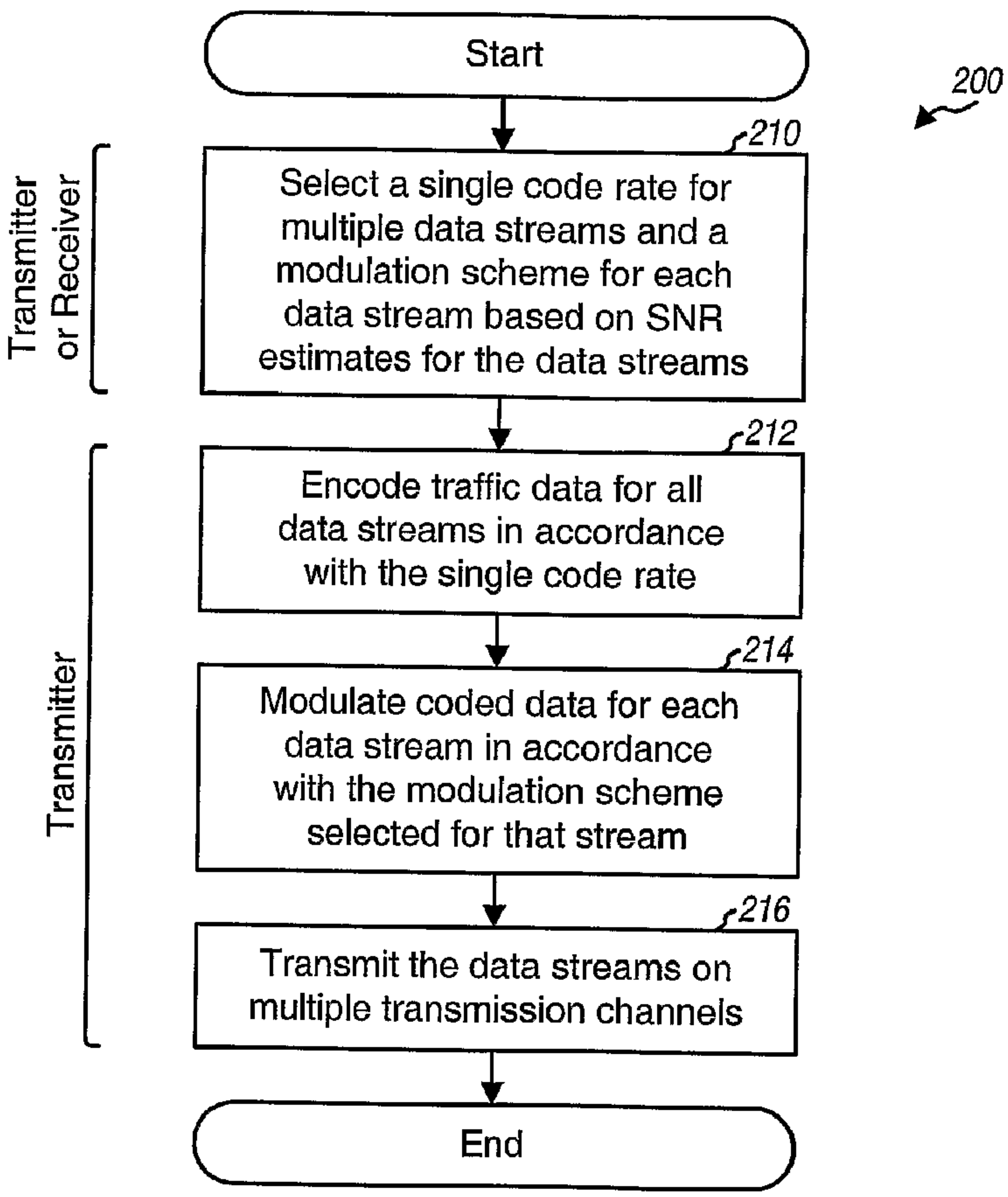
(54) Titre : CODAGE ET MODULATION POUR DE MULTIPLES FLUX DE DONNES DANS UN SYSTEME DE COMMUNICATION
(54) Title: CODING AND MODULATION FOR MULTIPLE DATA STREAMS IN A COMMUNICATION SYSTEM



(57) Abrégé/Abstract:
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(57) Abrégé(suite)/Abstract(continued):
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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
28 December 2006 (28.12.2006)

PCT

(10) **International Publication Number**
WO 2006/138582 A3

(51) **International Patent Classification:**
H04J 11/00 (2006.01)

(21) **International Application Number:** PCT/US2006/023515

(22) **International Filing Date:** 15 June 2006 (15.06.2006)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
60/691,461 16 June 2005 (16.06.2005) US
11/190,106 25 July 2005 (25.07.2005) US

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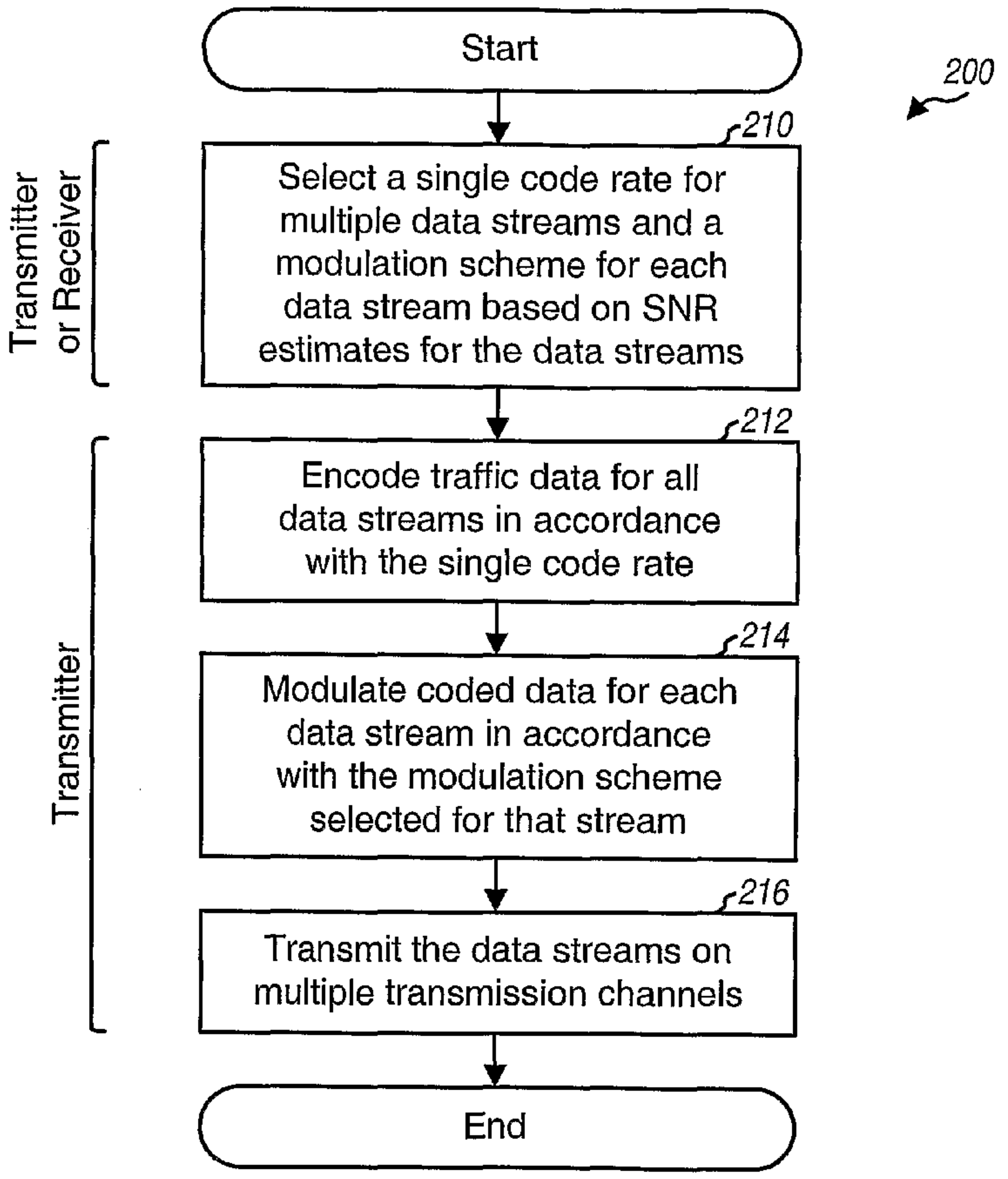
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title:** CODING AND MODULATION FOR MULTIPLE DATA STREAMS IN A COMMUNICATION SYSTEM



(57) **Abstract:** Techniques for transmitting multiple data streams to a single receiver using a single code rate and different modulation schemes are described. Channel estimates are determined for the multiple data streams and used to select a single code rate and multiple modulation schemes for the multiple data streams. The system may support a set of code rates, and each code rate may be associated with a respective set of modulation schemes that may be used with that code rate. The single code rate for all data streams is selected from among the set of supported code rates, and the modulation scheme for each data stream is selected from among the set of modulation schemes associated with the single code rate. The multiple data streams are encoded in accordance with the single code rate. Each data stream is further modulated in accordance with the modulation scheme selected for that stream.

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WO 2006/138582 A3

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(88) Date of publication of the international search report:
22 February 2007

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

CODING AND MODULATION FOR MULTIPLE DATA STREAMS IN A COMMUNICATION SYSTEM

I. Claim of Priority under 35 U.S.C. §119

[0001] The present Application for Patent claims priority to Provisional Application Serial No. 60/691,461, entitled "Coding and Modulation for Multiple Data Streams in a Communication System," filed June 16, 2005, assigned to the assignee hereof, and expressly incorporated herein by reference.

BACKGROUND

I. Field

[0002] The present disclosure relates generally to communication, and more specifically to techniques for transmitting multiple data streams in a communication system.

II. Background

[0003] In a communication system, a transmitter may transmit multiple data streams via multiple transmission channels to a receiver. The transmitter typically encodes and modulates (or symbol maps) the data for each stream prior to transmission in order to combat deleterious channel conditions. The receiver performs the complementary demodulation and decoding to recover the data sent by the transmitter. The coding and modulation performed by the transmitter have a large impact on the performance of the data transmission.

[0004] Rate selection refers to the selection of an appropriate coding and modulation scheme for each data stream to achieve a specified level of performance, which may be quantified by a target packet error rate (PER). Rate selection is challenging because the transmission channels may experience different channel conditions (e.g., different fading, multipath, and interference effects) and may achieve different signal-to-noise-and-interference ratios (SNRs). The SNR of a transmission channel determines its transmission capability, which is typically quantified by a particular data rate that may be reliably sent on the transmission channel. If the SNR varies from transmission channel to transmission channel, then the supported data rate would also vary from channel to channel. Furthermore, if the channel conditions vary with time, then the data rates supported by the transmission channels would also vary with time.

[0005] There is therefore a need in the art for techniques to perform coding and modulation for multiple data streams in a manner to achieve good performance and to simplify rate selection.

SUMMARY

[0006] Techniques for transmitting multiple data streams to a single receiver using a single code rate and different modulation schemes are described herein. These techniques may simplify encoding and decoding, may simplify rate selection and/or reduce the amount of rate information to send, and may improve performance.

[0007] According to an embodiment of the disclosure, an apparatus is described which includes a controller and a processor. The controller obtains a selection of a single code rate and multiple modulation schemes for multiple data streams to be sent to a single receiver. The processor encodes the multiple data streams in accordance with the single code rate and modulates the multiple data streams in accordance with the multiple modulation schemes.

[0008] According to another embodiment, an apparatus is described which includes a processor and a controller. The processor determines channel estimates for multiple data streams to be sent to a single receiver. The controller selects a single code rate and multiple modulation schemes for the multiple data streams based on the channel estimates.

[0009] Various aspects and embodiments of the disclosure are described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 shows a block diagram of a transmitter and a receiver in a multi-channel communication system according to an embodiment.

[0011] FIG. 2 shows a process for transmitting multiple data streams to a single receiver using a single code rate and different modulation schemes according to an embodiment.

[0012] FIG. 3 shows a process for selecting the rates for the multiple data streams with independent rate per stream according to an embodiment.

[0013] FIG. 4 shows a process for selecting the rates for the multiple data streams with a vector-quantized rate set according to an embodiment.

[0014] FIG. 5 shows a block diagram of a transmit (TX) data processor according to an embodiment.

DETAILED DESCRIPTION

[0015] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

[0016] The data transmission and rate selection techniques described herein may be used for various multi-channel communication systems with multiple transmission channels. For example, these techniques may be used for a multiple-input multiple-output (MIMO) system, an orthogonal frequency division multiplex (OFDM) system, a MIMO system that utilizes OFDM (which is called a MIMO-OFDM system), a time division multiplex (TDM) system, a frequency division multiplex (FDM) system, a code division multiplex (CDM) system, and so on.

[0017] A MIMO system employs multiple (T) transmit antennas at a transmitter and multiple (R) receive antennas at a receiver for data transmission. A MIMO channel formed by the T transmit antennas and the R receive antennas may be decomposed into S spatial channels, where $S \leq \min\{T,\ R\}$. S transmission channels may be formed with the S spatial channels.

[0018] An OFDM system partitions the overall system bandwidth into multiple (K) orthogonal subbands, which are also called tones, subcarriers, bins, and frequency channels. Each subband is associated with a respective carrier that may be modulated with data. Up to K transmission channels may be formed with the K subbands. A MIMO-OFDM system has S spatial channels for each of the K subbands. Up to $S \cdot K$ transmission channels may be formed with the spatial channels of the K subbands in the MIMO-OFDM system.

[0019] In general, multiple transmission channels may be formed in the spatial, frequency, time, and/or code domains. For example, the multiple transmission channels may correspond to different spatial channels in a MIMO system, different wideband spatial channels in a MIMO-OFDM system, different subbands in an OFDM or FDM system, different time slots in a TDM system, different code channels in a CDM system, and so on. A transmission channel may also be called a physical channel, a traffic channel, a data channel, a parallel channel, or some other terminology. For clarity, portions of the following description are for a MIMO-OFDM system.

[0020] **FIG. 1** shows a block diagram of a transmitter 110 and a receiver 150 in a multi-channel communication system 100 according to an embodiment. At transmitter 110, a TX data processor 120 receives traffic/packet data, processes (e.g., encodes, interleaves, and symbol maps) the traffic data in accordance with M rates from a main controller 140, and generates M streams of data symbols, where $M > 1$. As used herein, a data symbol is a modulation symbol for traffic data, a pilot symbol is a modulation symbol for pilot (which is data that is known *a priori* by both the transmitter and receiver), a modulation symbol is a complex value for a point in a signal constellation for a modulation scheme (e.g., PSK or QAM), a transmit symbol is a symbol to be sent from one transmit antenna on one subband in one symbol period, and a symbol is a complex value. A TX spatial processor 130 multiplexes the M data symbol streams with pilot symbols, performs spatial processing on the data and pilot symbols (e.g., for eigensteering, no steering, or spatial spreading, which are described below), and provides T streams of transmit symbols, where $T \geq M$. The M data symbol streams are for M data streams. The T transmit symbol streams are generated such that the M data streams are sent on M transmission channels.

[0021] A transmitter unit (TMTR) 132 processes the T transmit symbol streams (e.g., for OFDM) and generates T modulated signals, which are transmitted from T antennas and via a first communication link 148. Communication link 148 distorts the modulated signals with a channel response and further degrades the modulated signals with additive white Gaussian noise (AWGN) and possibly interference from other transmitters.

[0022] At receiver 150, R antennas receive the transmitted signals and provide R received signals to a receiver unit (RCVR) 160. Receiver unit 160 conditions and digitizes the R received signals and further processes the samples in a manner complementary to the processing performed by transmitter unit 132. Receiver unit 160 provides received pilot symbols to a channel estimator/processor 172 and R streams of received data symbols to a receive (RX) spatial processor 170. Channel estimator 172 derives channel estimates for communication link 148 and provides the channel estimates to RX spatial processor 170. RX spatial processor 170 performs receiver spatial processing on the R received data symbol streams with the channel estimates (e.g., using a full-CSI, CCMI, or MMSE technique, as described below) and provides M detected symbol streams, which are estimates of the M data symbol streams sent by transmitter 110. An RX data processor 180 processes (e.g., symbol demaps, deinterleaves, and decodes) the M detected symbol streams in accordance with the M rates selected for these streams and provides decoded data, which is an estimate of the traffic data sent by transmitter 110. RX data processor 180 may further provide decoding results (e.g., the status of each packet) to a rate selector/controller 182.

[0023] Main controllers 140 and 190 control the operation of various processing units at transmitter 110 and receiver 150, respectively. Memory units 142 and 192 store data and program codes used by controllers 140 and 190, respectively.

[0024] For rate selection/rate control, channel estimator 172 may process the received pilot symbols and possibly the detected data symbols and derive channel estimates, e.g. SNR estimates, for the transmission channels. Rate selector 182 receives the CHANNEL estimates and the decoding results, selects a single code rate for all M data streams and a modulation scheme for each data stream, and provides M rates for the M data streams to controller 190. The rate for each data stream indicates the code rate and the modulation scheme to use for that data stream.

[0025] Controller 190 sends rate information (e.g., the M rates) and possibly other information (e.g., acknowledgments (ACKs) for packets decoded correctly) via a second communication link 152 to transmitter 110. Controller 140 at transmitter 110 receives the rate information and provides the M rates to TX data processor 120. FIG. 1 shows the rate selection being performed by receiver 150. In general, the rate selection may be performed by receiver 150, or transmitter 110, or both.

[0026] In an aspect, a single code rate is selected for all M data streams and a different modulation scheme may be selected for each data stream. The M rates for the M data streams thus have the same code rate and may have the same or different modulation schemes. The use of a single code rate for all data streams may simplify the encoding at the transmitter and the decoding at the receiver, may simplify rate selection and/or reduce the amount of rate feedback, and may improve performance for the data streams.

[0027] The system may support a set of code rates. Each code rate may be associated with a specific coding scheme and a specific amount of redundancy. The supported code rates may be associated with (1) different coding schemes or (2) the same coding scheme but different puncture rates. A coding scheme may comprise a convolutional code, a Turbo code, a block code, some other code, or a combination thereof.

[0028] Table 1 shows an exemplary set of rates supported by the system. Each supported rate is associated with a specific data rate, a specific code rate, a specific modulation scheme, and a specific minimum SNR required to achieve the desired level of performance. The data rate may be given in number of information bits per modulation symbol (bits/sym). The desired level of performance may be quantified by a target PER, e.g., 1% PER for a non-fading, AWGN channel. The required SNR for each rate may be obtained via computer simulation, empirical measurements, computation, and/or some other means and for a specific system design (e.g., the specific code rate, interleaving scheme, and modulation scheme used for that rate) and an AWGN channel.

[0029] For the example shown in Table 1, four code rates of 1/4, 1/2, 3/4 and 7/8 are supported. Modulation schemes of BPSK, QPSK, 16-QAM, 64-QAM, and 256-QAM may be used with code rates 1/4, 1/2 and 3/4. Modulation schemes of QPSK, 16-QAM, 64-QAM, and 256-QAM may be used with code rate 7/8. Hence, only certain rates (or code rate and modulation pairs) are allowed. In general, the system may support any set of code rates, which may include code rates not listed in Table 1 such as code rates 7/12, 5/8, 5/6, and so on. Furthermore, the system may allow any set of modulation schemes to be used with each code rate. Table 1 also shows the required SNRs for some rates.

Table 1 – Rate Set

Data Rate (bits/sym)	**Code Rate**	**MOD Scheme**	**Required SNR** (dB)	**Data Rate** (bits/sym)	**Code Rate**	**MOD Scheme**	**Required SNR** (dB)
0.25	1/4	BPSK	-1.8	0.5	1/2	BPSK	0.6
0.5	1/4	QPSK	1.2	1.0	1/2	QPSK	2.9
1.0	1/4	16-QAM	7.2	2.0	1/2	16-QAM	8.7
1.5	1/4	64-QAM	13.2	3.0	1/2	64-QAM	14.4
2.0	1/4	256-QAM	19.2	4.0	1/2	256-QAM	19.9
0.75	3/4	BPSK	3.8				
1.5	3/4	QPSK	6.4	1.75	7/8	QPSK	8.7
3.0	3/4	16-QAM	13.6	3.5	7/8	16-QAM	15.8
4.5	3/4	64-QAM	19.2	5.25	7/8	64-QAM	22.0
6.0	3/4	256-QAM	26.1	7.0	7/8	256-QAM	28.0

[0030] **FIG. 2** shows a process 200 for transmitting multiple (M) data streams to a single receiver using a single code rate and different modulation schemes according to an embodiment. A single code rate is selected for all M data streams and a modulation scheme is selected for each data stream based on channel estimates, e.g. SNR estimates, for these data streams (block 210). The estimates for the data streams may be dependent on the number of data streams being transmitted, the receiver spatial processing technique used by the receiver, and so on, as described below. The rate selection may be performed in various manners, as also described below.

[0031] The rate selection in block 210 may be performed by the receiver, and the selected rates may be sent back to the transmitter, as shown in FIG. 1. Alternatively, the rate selection may be performed by the transmitter based on information obtained from/for the receiver. For example, in a time division duplexed (TDD) system, the transmit link from the transmitter to the receiver and the receive link from the receiver to the transmitter may be assumed to be reciprocal of one another. In this case, the transmitter may derive channel estimates, e.g. SNR estimates, for the receive link based on a pilot received from the receiver. The transmitter may then derive estimates for the transmit link based on the estimates for the receive link and an asymmetric parameter indicative of the difference, e.g. the differences in the SNRs for the two links. The transmitter may then select the rates for the data streams based on the estimates for the transmit link. The transmitter and receiver may also jointly perform rate selection.

[0032] Regardless of how the rate selection is performed, the transmitter obtains the rates selected for the data streams. The transmitter then encodes the traffic data for all data streams in accordance with the single code rate selected for these data streams (block 212). The transmitter then modulates (or symbol maps) the coded data for each data stream in accordance with the modulation scheme selected for that stream (block 214). The transmitter further processes the data streams (e.g., for spatial transmission, OFDM, and so on) and transmits these data streams on multiple transmission channels (block 216).

[0033] The rate selection in block 210 may be performed at the start of a data transmission, in each frame or time slot, at designated times, and so on. The coding and modulation for the data streams are adjusted whenever new rates are selected for these data streams.

[0034] Different numbers of data streams (e.g., one, two, three, or more data streams) may be transmitted simultaneously. The data streams may interfere with one another, e.g., if these data streams are sent on multiple spatial channels of a MIMO channel. The highest overall throughput may be achieved by transmitting the maximum number of data streams or possibly fewer data streams, depending on the channel conditions and the amount of interference among these data streams.

[0035] **FIG. 3** shows a process 210a for selecting the rates for the data streams in a system with independent rate per stream according to an embodiment. Process 210a is an embodiment of block 210 in FIG. 2. Process 210a evaluates different numbers of data streams and different code rates and selects the number of data streams and the code rate that provide the highest overall throughput and are supported by the channel conditions. Each different number of data streams is also called a stream combination or a stream hypothesis. The number of stream combinations to evaluate is typically dependent on the number of transmission channels available for data transmission. For example, in a MIMO system with S spatial channels, S stream combinations for 1, 2, ..., and S data streams may be evaluated. The code rates to evaluate may be code rates 1/4, 1/2, 3/4 and 7/8 for the example shown in Table 1.

[0036] Initially, a variable max_otp used to store the current highest overall throughput is initialized to zero, or $max\_otp = 0$ (block 310). A variable M used to denote the number of data streams to transmit is initialized to one, or $M = 1$ (also block 310).

[0037] A loop 320 evaluates one stream combination at a time, starting with the fewest number of data streams (or $M = 1$) for the first iteration of this loop. A stream combination with M data streams is selected for evaluation (block 322). For this stream combination, an SNR estimate is determined for each data stream with the assumption that M data streams will be sent on M transmission channels (block 324). SNR estimation is described below.

[0038] A loop 330 evaluates one code rate at a time, e.g., starting with the lowest code rate for the first iteration of this loop. A code rate is selected for evaluation (block 332). For the current code rate, a modulation scheme is selected for each of the M data streams based on the SNR estimate for that data stream and possibly the SNR estimates for the other data streams (block 334). For example, the SNR estimate for each data stream may be compared against the required SNR for each modulation scheme allowed for the current code rate, and the highest order modulation scheme with a required SNR that is less than or equal to the SNR estimate may be selected for that data stream. Other schemes for selecting the modulation schemes for the M data streams are described below.

[0039] After selecting the modulation schemes for the M data streams, the data rate for each data stream is determined based on the modulation scheme selected for that data stream and the current code rate. The overall throughput for the current code rate is then computed as the sum of the data rates for the M data streams (block 336). If this overall throughput is greater than the current max_otp, as determined in block 338, then max_otp is updated with this overall throughput, and the current stream combination, the current code rate, and the modulation schemes for the M data streams are saved (block 340).

[0040] A determination is then made whether all code rates have been evaluated (block 342). If the answer is 'No', then the process returns to block 332 to evaluate another code rate, e.g., the next higher code rate. Otherwise, if all code rates have been evaluated for the current stream combination, then a determination is made whether all stream combinations have been evaluated (block 344). If the answer is 'No', then variable M is incremented as $M = M + 1$ (block 346), and the process returns to block 322 to evaluate another stream combination. Otherwise, if all stream combinations have been evaluated, then the stream combination, code rate, and modulation schemes with the highest overall throughput are provided for use (block 348).

[0041] Multiple code rates for a given stream combination may have the same highest overall throughput. In this case, the most robust code rate (which is the lowest code rate) among these multiple code rates may be selected. This may be achieved by (1) evaluating the code rates in sequential order starting with the lowest code rate and (2) saving a higher code rate only if the overall throughput is higher, as shown in FIG. 3.

[0042] Multiple stream combinations may also have the same highest overall throughput. In an embodiment, the stream combination with the fewest number of data streams is selected when multiple stream combinations have the same highest overall throughput. This may be achieved by (1) evaluating the stream combinations in sequential order starting with the stream combination having the fewest data steams and (2) saving a stream combination only if the overall throughput is higher, as shown in FIG. 3.

[0043] In another embodiment, the stream combination with the largest total SNR margin is selected when multiple stream combinations have the same highest overall throughput. The SNR margin for each data stream m may be expressed as:

$$\mathrm{SNR}_{margin}(m) = \mathrm{SNR}_{est}(m) - \mathrm{SNR}_{req}(R_m) \ , \qquad \text{for } m = 1, \ldots, \mathrm{M} \ , \qquad \text{Eq (1)}$$

where R_m is the rate selected for data stream m;

$\text{SNR}_{est}(m)$ is the SNR estimate for data stream m;

$\text{SNR}_{req}(R_m)$ is the required SNR for rate R_m; and

$\text{SNR}_{margin}(m)$ is the SNR margin for data stream m.

$\text{SNR}_{est}(m)$, $\text{SNR}_{req}(R_m)$, and $\text{SNR}_{margin}(m)$ are given in units of decibel (dB). The total SNR margin for all M data streams may be expressed as:

$$\text{SNR}_{total\_margin} = \sum_{m=1}^{M} \text{SNR}_{margin}(m) \; . \qquad \text{Eq (2)}$$

[0044] In yet another embodiment, when multiple stream combinations have the same highest overall throughput, a stream combination with more data streams is selected if its total SNR margin exceeds the total SNR margin of another stream combination with fewer data streams by a predetermined amount, which is denoted as Δmargin. In general, when multiple stream combinations have the same highest overall throughput, a steam combination with fewer data streams may be selected to reduce crosstalk among these streams and to simplify the processing at the transmitter and receiver. However, a stream combination with more data streams may be selected if improved performance (higher overall throughput, higher total SNR margin, and so on) can be achieved.

[0045] In general, when multiple stream combinations have the same highest overall throughput, any one, any combination, or all of the embodiments/criteria described above (code rate, number of streams, SNR margin, and so on) may be used to select one stream combination. For example, if multiple stream combinations have the same highest overall throughput, then (1) the stream combinations with the smallest number of streams may be selected, then (2) from those selected stream combinations the stream combinations with the highest SNR margin for say the lowest stream may be selected, then (3) from those selected stream combinations the stream combinations with the most robust code rate may be selected, and so on, until only one stream combination is selected.

[0046] In an embodiment of rate selection, which is shown in FIG. 3, a modulation scheme is independently selected for each data stream based solely on the SNR estimate for that data stream. This embodiment may be used, e.g., if the system allows for independent rate selection per stream and each data stream is independently encoded (described below). Selecting a modulation scheme with a positive SNR margin for each data stream ensures that each data stream can be reliably received.

[0047] In another embodiment of rate selection, the modulation schemes for the M data streams are selected with margin sharing. This embodiment may be used, e.g., if the system allows for independent rate selection per stream and the data streams are jointly encoded (described below). For this embodiment, a modulation scheme is initially selected for each data stream based on the SNR estimate for that data stream, as described above. The SNR margin for each data stream is determined as shown in equation (1). The total SNR margin for all M data streams is then computed as shown in equation (2). The total SNR margin is distributed to one or more data streams to allow a higher order modulation scheme to be selected for each of the one or more data streams, if possible.

[0048] The distribution of the total SNR margin may be performed in various manners. In a first scheme for margin sharing, the M data streams are sorted in descending order based on their SNR estimates, from highest to lowest SNR estimates. The sorted data streams are then selected one at a time for possible promotion, starting with the data stream having the highest SNR estimate. A promote SNR is computed for the selected data stream as the difference between the required SNR for the next higher order modulation scheme (if any) and the required SNR for the modulation scheme initially selected for this data stream. If the promote SNR is less than or equal to the total SNR margin, then the selected data stream is promoted to the next higher order modulation scheme, and the total SNR margin is reduced by the promote SNR. The selected data stream is thus allocated sufficient SNR margin to select the next higher order modulation scheme. The same processing is repeated for each remaining data stream until no data stream can be promoted.

[0049] In a second scheme for margin sharing, the M data streams are sorted in ascending order based on their SNR estimates, from lowest to highest SNR estimates. The sorted data streams are then selected one at a time for possible promotion, starting with the data stream having the lowest SNR estimate.

[0050] In a third scheme for margin sharing, the M data streams are sorted in ascending order based on their differential SNRs, from lowest to highest differential SNRs. The differential SNR for a data stream is the difference between the required SNR for the next higher order modulation scheme and the SNR estimate for the data stream. The sorted data streams are then selected one at a time for possible promotion, starting with the data stream having the lowest differential SNR. This scheme attempts to promote first the data stream that needs the least amount of SNR margin for promotion, which may improve performance and allow more data streams to be promoted.

[0051] In a fourth scheme for margin sharing, the M data streams are sorted in ascending order based on their promote SNRs, from lowest to highest promote SNRs. The sorted data streams are then selected one at a time for possible promotion, starting with the data stream having the lowest promote SNR. This scheme attempts to promote first the data stream having the smallest promote SNR, which may allow more data streams to be promoted.

[0052] Other schemes for performing margin sharing may also be used, and this is within the scope of the disclosure. In general, the total SNR margin may be distributed to the M data streams in various order and manners. In an embodiment, a data stream may be promoted to a modulation scheme that is more than one order higher. For example, the selected data stream may be promoted as much as possible based on the total SNR margin. In another embodiment, the amount of SNR margin that may be allocated to a data stream is limited to be within a predetermined value SNR_{allo_max}. SNR_{allo_max} limits the amount of negative SNR margin observed by any data stream and ensures that no data stream will be sent at a rate with a required SNR that is excessively above the SNR estimate for that data stream. SNR_{allo_max} may be a fixed value for all code rates. Alternatively, SNR_{allo_max} may be a variable value that is a function of code rate so that a smaller SNR_{allo_max} may be used for a less robust code rate (e.g., code rate 7/8) and a larger SNR_{allo_max} may be used for a more robust code rate (e.g., code rate 1/2).

[0053] A system may allow only certain combinations of rates, e.g., in order to reduce the amount of rate information to send back to the transmitter. The set of rate combinations allowed by the system is often called a vector-quantized rate set. Table 2 shows an exemplary vector-quantized rate set for a system in which the transmitter can transmit up to four data streams and code rates of 1/4, 1/2 and 3/4 may be selected. For each rate combination, the overall throughput (OTP), the number of data streams to transmit (Num Str), the code rate to use for all data streams, and the modulation scheme to use for each data stream are given in Table 2. In Table 2, “B” denotes BPSK, “Q” denotes QPSK, “16” denotes 16-QAM, “64” denotes 64-QAM, and “256” denotes 256-

QAM. As an example, for the rate combination with an overall throughput of 19.5 information bits/symbol period, four data streams are transmitted, code rate 3/4 is used for all four data streams, 256-QAM is used for data streams 1 and 2, 64-QAM is used for data stream 3, and 16-QAM is used for data stream 4. For rate combinations with just one data stream, all or a subset of the rates shown in Table 1 may be supported. The rate set may also be defined to cover other code rates such as, for example, code rates 7/12, 5/8, 5/6, 7/8, and so on.

Table 2 – Vector-Quantized Rate Set

OTP	Num Str	Code Rate	MOD for Stream				OTP	Num Str	Code Rate	MOD for Stream			
			1	2	3	4				1	2	3	4
1.0	2	1/4	Q	Q			9.75	3	3/4	64	64	B	–
1.5	2	1/2	Q	B	–	–	12.0	3	3/4	64	64	16	–
2.0	2	1/2	Q	Q	–	–	12.0	3	3/4	256	64	Q	–
3.0	2	1/2	16	Q	–	–	13.5	3	3/4	256	64	16	–
3.0	2	3/4	Q	Q	–	–	13.5	3	3/4	256	256	Q	–
4.5	2	3/4	16	Q			15.0	3	3/4	256	256	16	–
5.25	2	3/4	64	B	–	–	16.5	3	3/4	256	256	64	–
6.0	2	3/4	64	Q	–	–	7.5	4	1/2	64	16	Q	B
7.5	2	3/4	64	16	–	–	9.0	4	1/2	64	64	16	Q
9.0	2	3/4	64	64	–	–	11.0	4	1/2	64	64	64	16
9.0	2	3/4	256	16	–	–	10.5	4	3/4	64	16	Q	Q
10.5	2	3/4	256	64	–	–	13.5	4	3/4	64	64	16	Q
12.0	2	3/4	256	256	–	–	13.5	4	3/4	256	64	Q	Q
6.0	3	1/2	64	16	Q	–	15.0	4	3/4	256	64	16	Q
7.0	3	1/2	64	64	Q	–	18.0	4	3/4	256	64	64	16
7.0	3	1/2	256	16	Q	–	19.5	4	3/4	256	256	64	16
9.0	3	1/2	256	64	16	–	21.0	4	3/4	256	256	256	16

[0054] **FIG. 4** shows a process 210b for selecting the rates for the data streams in a system with a vector-quantized rate set according to an embodiment. Process 210b is another embodiment of block 210 in FIG. 2. Process 210b evaluates different stream combinations and different code rates based on the rate set supported by the system and selects the rate combination that provides the highest overall throughput and is supported by the channel conditions.

[0055] Initially, the variable max_otp is initialized to zero, and the variable M is initialized to one (block 410). For the first iteration of loop 420, a stream combination with M data streams is selected for evaluation (block 422), and an SNR estimate is determined for each of the M data streams (block 424). Loop 430 is then performed once for each code rate that may be selected for the current stream combination.

[0056] For each iteration of loop 430, a code rate is selected for evaluation, e.g., starting with the lowest code rate allowed for the current stream combination (block 432). For the current code rate, the total SNR margin for each allowed rate combination is determined based on the SNR estimates for the M data streams (block 434). The total SNR margin for a given rate combination with M data streams may be determined as follows. The SNR margin for each data stream *m* in the rate combination is first computed as shown in equation (1), where $\text{SNR}_{req}(R_m)$ is the required SNR for the rate specified for data stream *m* by the rate combination. Because the rate for each data stream in the rate combination is specified, the SNR margin for each data stream may be a positive or negative value. If the SNR margin for any data stream in the rate combination is worse than a predetermined value (e.g., –2 dB), then that rate combination may be discarded. This predetermined value may be a fixed value or a variable value that is a function of code rate. For example, a more negative value (e.g., –3 dB) may be used for a more robust code rate (e.g., code rate 1/2), and a less negative value (e.g., –1 dB) may be used for a less robust code rate (e.g., code rate 3/4). The total SNR margin is then computed as the sum of the SNR margins for the M data streams, as shown in equation (2).

[0057] The rate combination with the highest overall throughput and a non-negative total SNR margin is identified (block 436). If multiple rate combinations have the same overall throughput, then the rate combination with the largest total SNR margin among these multiple rate combinations is selected. If the highest overall throughput is greater than the current max_otp, as determined in block 438, then max_otp is updated with this overall throughput, and the rate combination with this highest overall throughput is saved (block 440).

[0058] A determination is then made whether all code rates have been evaluated (block 442). If the answer is 'No', then the process returns to block 432 to evaluate another code rate. Otherwise, if all code rates have been evaluated for the current stream combination, then a determination is made whether all stream combinations have been evaluated (block 444). If the answer is 'No', then variable M is incremented as $M = M + 1$ (block 446), and the process returns to block 422 to evaluate another stream combination. Otherwise, if all stream combinations have been evaluated, then the rate combination with the highest overall throughput is provided for use (block 448).

[0059] Multiple rate combinations for a given stream combination may achieve the same highest overall throughput and have non-negative total SNR margins. In this case, the rate combination with the most robust code rate or the rate combination with the largest total SNR margin may be selected. Multiple rate combinations for different stream combinations may achieve the same highest overall throughput and have non-negative total SNR margins. In this case, the rate combination with the fewest data streams, the rate combination with the largest total SNR margin, the rate combination with more data streams but a larger total SNR margin by Δmargin, or some other rate combination may be selected.

[0060] In another embodiment for selecting rates in a system with a vector-quantized rate set, the rate set is ordered by required SNR for a designated data stream (e.g., the first data stream), for example from lowest required SNR to highest required SNR on the designated data stream. A minimum SNR margin of SNR_{margin_min} may be imposed on the designated data stream. The rate combinations in the rate set may be evaluated, one at a time, according to the schemes described above and in addition, by comparing the first data stream's SNR margin (which is the required SNR minus the actual SNR for the first data stream) against the minimum SNR margin. Since the rate combinations are ordered by the first data stream's required SNR, from lowest to highest, the SNR margin is progressively worse. Hence, upon encountering a rate combination with the first data stream having an SNR margin worse than the minimum SNR margin, the remaining rate combinations can be ignored since the first data stream for these rate combinations will have SNR margin worse than the minimum SNR margin. This ordering reduces the number of rate combinations that are evaluated. One of the rate combinations whose first data stream's SNR margin is better than SNR_{margin_min} may then be selected using any of the techniques described above. The rate combinations may be ordered by the required SNR for any data stream, and not necessarily the first data stream. Furthermore, the ordering may be performed across all rate combinations in the rate set or just the rate combinations for each code rate.

[0061] In yet another embodiment for selecting rates in a system with a vector-quantized rate set, a total required SNR is computed for each rate combination as the sum of the required SNRs for the rates specified for all of the data streams in that rate combination. The total required SNR and the overall throughput for each rate combination in the rate set may be stored in a look-up table. For rate selection, a total SNR estimate is computed as the sum of the SNR estimates for all M data streams. The rate combination with the highest overall throughput and a total required SNR that is less than or equal to the total SNR estimate is then selected. This embodiment does not limit the amount of SNR margin that may be allocated to each data stream.

[0062] Exemplary embodiments for performing rate selection for a system with independent rate per stream and a system with a vector-quantized rate set have been described above. The rate selection may also be performed in other manners, with and without margin sharing.

[0063] **FIG. 5** shows a block diagram of an embodiment of TX data processor 120 at transmitter 110 according to an embodiment. TX data processor 120 includes an encoder 510, a demultiplexer (Demux) 520, and M pairs of interleaver 522 and symbol mapping unit 524 for the M data streams. Encoder 510 encodes the traffic data in accordance with the single code rate and generates code bits. The single code rate may include a convolutional code, a Turbo code, a low density parity check (LDPC) code, a cyclic redundancy check (CRC) code, a block code, and so on, or a combination thereof. In an embodiment, encoder 510 implements a rate 1/2 binary convolutional encoder that generates two code bits for each data bit. A puncturing unit (not shown in FIG. 5) then punctures or deletes as many code bits as necessary to achieve the single code rate. Demultiplexer 520 receives the code bits from encoder 510, demultiplexes the code bits into M streams, and provides the M code bit streams to M interleavers 522a through 522m.

[0064] Encoder 510 encodes each packet of traffic data separately and the coded packet may be sent on one or multiple data streams. If each of the M data streams is independently encoded and modulated, then encoder 510 may be operated M times to separately encode the packets for the M data streams, and demultiplexer 520 provides each coded packet to one interleaver 522 for one data stream. Alternatively, M separate encoders may be used for the M data streams (not shown in FIG. 5). If the M data streams are jointly encoded but independently modulated, then encoder 510 encodes each packet, and demultiplexer 520 partitions each coded packet into multiple subpackets or blocks and provides these subpackets to different interleavers 522. In any case, each interleaver 522 interleaves or reorders the code bits in its stream in accordance with an interleaving scheme and provides interleaved bits to an associated symbol mapping unit 524. Each symbol mapping unit 524 maps the interleaved bits in accordance with the modulation scheme selected for its stream and provides a stream of data symbols. M symbol mapping units 524a through 524m provide M data symbol streams.

[0065] The data transmission and rate selection techniques described herein may be used for various systems and various types of transmission channels. The frequency response of a frequency-selective transmission channel m may be given by $h_m(k)$ for $k = 1, ..., \mathrm{K}$, where $h_m(k)$ is the complex channel gain for subband k of transmission channel m. The received SNR for each subband k of transmission channel m, $\gamma_m(k)$, may be expressed as:

$$\gamma_m(k) = 10 \log_{10}\left(P_m(k) \cdot \frac{|h_m(k)|^2}{N_0} \right), \quad \text{for } k = 1, ..., \mathrm{K} \text{ and } m = 1, ..., \mathrm{S}, \qquad \text{Eq (3)}$$

where $P_m(k)$ is the transmit power used for subband k of transmission channel m and N_0 is the noise variance at the receiver. Equation (3) shows an exemplary expression for received SNR. In general, a received SNR expression may include terms for various factors. For example, in a MIMO system, the received SNR is dependent on the spatial processing performed by the transmitter and the receiver, as described below. The received SNR in equation (3) and other SNR quantities in the following description are given in units of dB.

[0066] One data stream may be sent on each transmission channel. An SNR estimate may be derived for each data stream/transmission channel in various manners. An embodiment for deriving the SNR estimate is described below. For this embodiment, the average SNR for each data stream m, $\gamma_{\text{avg},m}$, is computed as:

$$\gamma_{\text{avg},m} = \frac{1}{\mathrm{K}} \cdot \sum_{k=1}^{\mathrm{K}} \gamma_m(k) \ . \qquad \text{Eq (4)}$$

The variance of the received SNRs for each data stream m, $\sigma^2_{\text{snr},m}$, may be computed as:

$$\sigma^2_{\text{snr},m} = \frac{1}{(\mathrm{K}-1)} \cdot \sum_{k=1}^{\mathrm{K}} \left(\gamma_m(k) - \gamma_{\text{avg},m} \right)^2 \ . \qquad \text{Eq (5)}$$

The SNR estimate for each data stream m, $\mathrm{SNR}_{est}(m)$, may then be computed as:

$$\mathrm{SNR}_{est}(m) = \gamma_{\mathrm{avg},m} - \gamma_{\mathrm{bo},m} \ , \qquad \text{Eq (6)}$$

where $\gamma_{\mathrm{bo},m}$ is a back-off factor for data stream m. The back-off factor $\gamma_{\mathrm{bo},m}$ may be used to account for variability in the received SNRs across the data stream and may be computed as a function of the average SNR and the SNR variance, e.g., $\gamma_{\mathrm{os},m} = \mathrm{K}_{\mathrm{bo}} \cdot \sigma^2_{\mathrm{snr},m}$ where K_{bo} is a constant. The back-off factor may also account for other factors such as, for example, the diversity order for the data stream, the coding and interleaving schemes used for the data stream, the packet size, and so on.

[0067] For a MIMO-OFDM system, the MIMO channel between the transmitter and the receiver may be characterized by a set of K channel response matrices, $\underline{\mathbf{H}}(k)$ for $k = 1, ..., \mathrm{K}$. Each channel response matrix $\underline{\mathbf{H}}(k)$ has a dimension of $\mathrm{R} \times \mathrm{T}$ and contains a complex gain between each transmit antenna and each receive antenna for subband k. Each matrix $\underline{\mathbf{H}}(k)$ includes S spatial channels, where $\mathrm{S} \leq \min\{\mathrm{T}, \mathrm{R}\}$. Up to S wideband spatial channels may be formed for the MIMO channel, where each wideband spatial channel includes one spatial channel for each of the K subbands. For example, each wideband spatial channel may correspond to the K subbands of one transmit antenna. As another example, each wideband spatial channel may include one eigenmode for each of the K subbands. Each wideband spatial channel may be used as a transmission channel.

[0068] For MIMO and MIMO-OFDM systems, different transmission channels may be formed with the transmitter performing different spatial processing. For example, the transmitter may perform eigensteering, no steering, or spatial spreading.

[0069] For eigensteering, the channel response matrix $\underline{\mathbf{H}}(k)$ for each subband may be diagonalized by performing eigenvalue decomposition, as follows:

$$\underline{\mathbf{R}}(k) = \underline{\mathbf{H}}^H(k) \cdot \underline{\mathbf{H}}(k) = \underline{\mathbf{E}}(k) \cdot \underline{\Lambda}(k) \cdot \underline{\mathbf{E}}^H(k) \ , \qquad \text{Eq (7)}$$

where $\underline{\mathbf{E}}(k)$ is a unitary matrix of eigenvectors, $\underline{\Lambda}(k)$ is a diagonal matrix, and "^{H}" denotes the conjugate transpose. The transmitter may transmit data on up to S orthogonal spatial channels (or eigenmodes) of each subband k using $\underline{\mathbf{E}}(k)$. The diagonal matrix $\underline{\Lambda}(k)$ for each subband k contains the power gains for the S eigenmodes of $\underline{\mathbf{H}}(k)$. The channel response matrix $\underline{\mathbf{H}}(k)$ for each subband may also be diagonalized by performing singular value decomposition, as follows:

$$\underline{\mathbf{H}}(k)=\underline{\mathbf{U}}(k)\cdot\underline{\Sigma}(k)\cdot\underline{\mathbf{E}}^{H}(k) \ , \qquad \text{Eq (8)}$$

where $\underline{\mathbf{U}}(k)$ is a unitary matrix of left singular vectors, $\underline{\mathbf{E}}(k)$ is a unitary matrix of right singular vectors (which is also the matrix of eigenvectors), and $\underline{\Sigma}(k)$ is a diagonal matrix of channel gains for the S eigenmodes of $\underline{\mathbf{H}}(k)$.

[0070] For no steering, the transmitter transmits data without any spatial processing, e.g., transmits one data stream from each transmit antenna. For spatial spreading, the transmitter transmits data with different steering matrices $\underline{\mathbf{V}}(k)$ across subbands and/or symbol periods so that the data transmission observes an ensemble of effective channels.

[0071] Table 3 shows the spatial processing performed by the transmitter for eigensteering ("*es*"), no steering ("*ns*"), and spatial spreading ("*ss*") for one subband, with subband index *k* being omitted for clarity. $\underline{\mathbf{s}}$ is a vector with up to S data symbols to be sent on one subband in one symbol period. $\underline{\mathbf{x}}_x$ is a vector with up to T transmit symbols to be sent from the T transmit antennas on one subband in one symbol period for mode *x*, where *x* may be "*es*", "*ns*" or "*ss*". $\underline{\mathbf{H}}_x$ is an effective channel response matrix observed by the data vector $\underline{\mathbf{s}}$ for mode *x*.

Table 3 – Transmitter Spatial Processing

	Eigensteering	**No Steering**	**Spatial Spreading**
Spatial Processing	$\underline{\mathbf{x}}_{es}=\underline{\mathbf{E}}\cdot\underline{\mathbf{s}}$	$\underline{\mathbf{x}}_{ns}=\underline{\mathbf{s}}$	$\underline{\mathbf{x}}_{ss}=\underline{\mathbf{V}}\cdot\underline{\mathbf{s}}$
Effective Channel	$\underline{\mathbf{H}}_{es}=\underline{\mathbf{H}}\cdot\underline{\mathbf{E}}$	$\underline{\mathbf{H}}_{ns}=\underline{\mathbf{H}}$	$\underline{\mathbf{H}}_{ss}=\underline{\mathbf{H}}\cdot\underline{\mathbf{V}}$

[0072] The received symbols obtained by the receiver may be expressed as:

$$\underline{\mathbf{r}}_x=\underline{\mathbf{H}}\cdot\underline{\mathbf{x}}_x+\underline{\mathbf{n}}=\underline{\mathbf{H}}_x\cdot\underline{\mathbf{s}}+\underline{\mathbf{n}} \ , \qquad \text{Eq (9)}$$

where $\underline{\mathbf{r}}_x$ is a vector of received symbols for mode *x* and $\underline{\mathbf{n}}$ is a vector of noise, which may be assumed to be AWGN with a variance of σ_n^2.

[0073] Table 4 shows the spatial processing performed by the receiver to obtain detected symbols $\hat{\underline{s}}$, which are estimates of the data symbols $\underline{s}$. The full channel state information (full-CSI) technique may be used for eigensteering. The channel correlation matrix inversion (CCMI) and the minimum mean square error (MMSE) techniques may be used for eigensteering, no steering, and spatial spreading. For each technique, the receiver derives a spatial filter matrix $\underline{\mathbf{M}}$ for each subband based on the actual or effective channel response matrix for that subband. The receiver then performs spatial matched filtering on the received symbols with the spatial filter matrix.

Table 4 – Receiver Spatial Processing

	Receiver Spatial Processing	Received SNR
Full-CSI	$\underline{\mathbf{M}}_{es} = \underline{\Lambda}^{-1} \cdot \underline{\mathbf{E}}^H \cdot \underline{\mathbf{H}}^H$ $\hat{\underline{\mathbf{s}}}_{es} = \underline{\mathbf{M}}_{es} \cdot \underline{\mathbf{r}}_{es}$	$\gamma_{es,m}(k) = 10\log_{10}\left(\frac{P_m(k)\cdot\lambda_m(k)}{\sigma_n^2}\right)$
CCMI	$\underline{\mathbf{M}}_{ccmi} = [\underline{\mathbf{H}}_x^H \cdot \underline{\mathbf{H}}_x]^{-1} \cdot \underline{\mathbf{H}}_x^H$ $\hat{\underline{\mathbf{s}}}_{ccmi} = \underline{\mathbf{M}}_{ccmi} \cdot \underline{\mathbf{r}}_x$	$\gamma_{ccmi,m}(k) = 10\log_{10}\left(\frac{P_m(k)}{r_m(k)\cdot\sigma_n^2}\right)$
MMSE	$\underline{\mathbf{M}}_{mmse} = [\underline{\mathbf{H}}_x^H \cdot \underline{\mathbf{H}}_x + \sigma_n^2 \cdot \underline{\mathbf{I}}]^{-1} \cdot \underline{\mathbf{H}}_x^H$ $\underline{\mathbf{D}}_{mmse} = [\,\text{diag}\ [\underline{\mathbf{M}}_{mmse} \cdot \underline{\mathbf{H}}_x]]^{-1}$ $\hat{\underline{\mathbf{s}}}_{mmse} = \underline{\mathbf{D}}_{mmse} \cdot \underline{\mathbf{M}}_{mmse} \cdot \underline{\mathbf{r}}_x$	$\gamma_{mmse,m}(k) = 10\log_{10}\left(\frac{q_m(k)}{1-q_m(k)}P_m(k)\right)$

[0074] Table 4 also shows the received SNR for each subband k of transmission channel m for the three receiver spatial processing techniques. For the full-CSI technique, $\lambda_m(k)$ is the m-th diagonal element of $\underline{\Lambda}(k)$. For the CCMI technique, $r_m(k)$ is the m-th diagonal element of $\underline{\mathbf{R}}_x^{-1}(k) = [\underline{\mathbf{H}}_x^H(k)\cdot\underline{\mathbf{H}}_x(k)]^{-1}$. For the MMSE technique, $q_m(k)$ is the m-th diagonal element of $\underline{\mathbf{M}}_{mmse}(k)\cdot\underline{\mathbf{H}}_x(k)$. As indicated in Table 4, the received SNRs for each transmission channel are dependent on the MIMO channel response, the receiver spatial processing technique used by the receiver, and the transmit power allocated to the transmission channel. The total transmit power P_{total} is typically fixed for the transmitter. The amount of transmit power P_m allocated to each transmission channel m may be dependent on the number of data streams to transmit, e.g., $P_m = P_{total}/\text{M}$. The received SNRs for each transmission channel may be used to derive the SNR estimate for that transmission channel, as described above for equations (3) through (6).

[0075] The data transmission and rate selection techniques described herein may be implemented by various means. For example, these techniques may be implemented in hardware, software, or a combination thereof. For a hardware implementation, the processing units used to process data for transmission (e.g., TX data processor 120 in FIGS. 1 and 5) may be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, electronic devices, other electronic units designed to perform the functions described herein, or a combination thereof. The processing units used for rate selection (e.g., rate selector/ controller 182 in FIG. 1) may also be implemented within one or more ASICs, DSPs, processors, and so on.

[0076] For a software implementation, the techniques described herein may be implemented with modules (e.g., procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in a memory unit (e.g., memory unit 142 or 192 in FIG. 1) and executed by a processor (e.g., main controller 140 or 190). The memory unit may be implemented within the processor or external to the processor, in which case it can be communicatively coupled to the processor via various means as is known in the art.

[0077] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present disclosure. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the disclosure. Thus, the present disclosure is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0078] **WHAT IS CLAIMED IS:**

CLAIMS

1. An apparatus comprising:

a controller operative to obtain a selection of a single code rate and a plurality of modulation schemes for a plurality of data streams to be sent to a single receiver; and

a processor operative to encode the plurality of data streams in accordance with the single code rate and to modulate the plurality of data streams in accordance with the plurality of modulation schemes.

2. The apparatus of claim 1, wherein the plurality of data streams is constrained to one code rate selected from among a plurality of code rates supported by the system, wherein each of the plurality of code rates is associated with a respective set of modulation schemes, wherein the single code rate is the one code rate selected from among the plurality of code rates, and wherein a modulation scheme for each of the plurality of data streams is selected from among the set of modulation schemes associated with the single code rate.

3. The apparatus of claim 1, wherein the single code rate and the plurality of modulation schemes are for a rate combination selected from among a plurality of rate combinations supported by the system.

4. The apparatus of claim 1, wherein the controller is operative to receive the selection of the single code rate and the plurality of modulation schemes from the single receiver.

5. The apparatus of claim 1, wherein the controller is operative to determine signal-to-noise-and-interference ratio (SNR) estimates for the plurality of data streams and to select the single code rate and the plurality of modulation schemes based on the SNR estimates.

6. The apparatus of claim 1, wherein the processor is operative to encode and modulate each of the plurality of data streams independently.

7. The apparatus of claim 1, wherein the processor is operative to encode the plurality of data streams jointly and to modulate each of the plurality of data streams independently.

8. The apparatus of claim 1, further comprising:

a second processor operative to spatially process the plurality of data streams for transmission via a plurality of spatial channels in a multiple-input multiple-output (MIMO) channel.

9. A method of transmitting data in a communication system, comprising:

obtaining a selection of a single code rate and a plurality of modulation schemes for a plurality of data streams to be sent to a single receiver;

encoding the plurality of data streams in accordance with the single code rate; and

modulating the plurality of data streams in accordance with the plurality of modulation schemes.

10. The method of claim 9, further comprising:

spatially processing the plurality of data streams for transmission via a plurality of spatial channels in a multiple-input multiple-output (MIMO) channel.

11. An apparatus comprising:

means for obtaining a selection of a single code rate and a plurality of modulation schemes for a plurality of data streams to be sent to a single receiver;

means for encoding the plurality of data streams in accordance with the single code rate; and

means for modulating the plurality of data streams in accordance with the plurality of modulation schemes.

12. The apparatus of claim 11, further comprising:

means for spatially processing the plurality of data streams for transmission via a plurality of spatial channels in a multiple-input multiple-output (MIMO) channel.

13. An apparatus comprising:

a processor operative to determine channel estimates for a plurality of data streams to be sent to a single receiver; and

a controller operative to select a single code rate and a plurality of modulation schemes for the plurality of data streams based on the channel estimates.

14. The apparatus of claim 13, wherein the controller is operative to select one code rate from among a plurality of code rates supported by the system and to provide the one code rate as the single code rate for the plurality of data streams.

15. The apparatus of claim 14, wherein each of the plurality of code rates is associated with a respective set of modulation schemes, and wherein the controller is operative to select a modulation scheme for each of the plurality of data streams from among the set of modulation schemes associated with the single code rate.

16. The apparatus of claim 13, wherein the controller is operative to select a modulation scheme for each of the plurality of data streams to achieve a non-negative SNR margin for the data stream.

17. The apparatus of claim 13, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the controller is operative to select the plurality of modulation schemes for the plurality of data streams such that at least one data stream has negative SNR margin and the plurality of data streams has a non-negative total SNR margin.

18. The apparatus of claim 17, wherein the controller is operative to limit the negative SNR margin for each of the at least one data stream to be within a predetermined value.

19. The apparatus of claim 18, wherein the predetermined value is determined by the single code rate selected for the plurality of data streams.

20. The apparatus of claim 18, wherein the predetermined value is determined by the single code rate selected for the plurality of data streams, an index of

each of the plurality of data streams, modulation selected for each data stream, the number of data streams being transmitted, or a combination thereof.

21. The apparatus of claim 13, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the controller is operative to determine an overall throughput and a total SNR margin for each of a plurality of code rates, to select a code rate having a highest overall throughput and a non-negative total SNR margin among the plurality of code rates, and to provide the selected code rate as the single code rate for the plurality of data streams.

22. The apparatus of claim 21, wherein the controller is operative to select a lowest code rate among multiple code rates having the highest overall throughput.

23. The apparatus of claim 13, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the controller is operative to determine an overall throughput and a total SNR margin for each of a plurality of code rates for each of a plurality of stream combinations, to select a code rate and a stream combination having a highest overall throughput and a non-negative total SNR margin among the plurality of code rates and the plurality of stream combinations, and to provide the selected code rate as the single code rate, wherein each stream combination corresponds to a different number of data streams, and wherein the plurality of data streams are for the selected stream combination.

24. The apparatus of claim 23, wherein the controller is operative to select a stream combination with fewest data streams among multiple stream combinations having the highest overall throughput.

25. The apparatus of claim 13, wherein the controller is operative to select a rate combination from among a plurality of rate combinations supported by the system and to obtain the single code rate and the plurality of modulation schemes from the selected rate combination.

26. The apparatus of claim 13, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the controller is

operative to determine a total SNR margin for each of a plurality of rate combinations, to select a rate combination having a highest overall throughput and a non-negative total SNR margin among the plurality of rate combinations, and to obtain the single code rate and the plurality of modulation schemes from the selected rate combination, wherein each rate combination is associated with a specific number of data streams, a specific code rate for all of the data streams, a specific modulation scheme for each of the data streams, and a specific overall throughput for all of the data streams.

27. The apparatus of claim 26, wherein the controller is operative to select a rate combination with fewest data streams among multiple rate combinations having the highest overall throughput.

28. The apparatus of claim 26, wherein the controller is operative to select a rate combination with a largest total SNR margin among multiple rate combinations having the highest overall throughput.

29. The apparatus of claim 26, further comprising:

a memory configured to store a look-up table of the plurality of rate combinations arranged in an order determined by a required SNR for one data stream in each of the plurality of rate combinations, and wherein the controller is operative to select the rate combination based on the look-up table.

30. The apparatus of claim 13, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the processor is operative to determine received SNRs for a plurality of frequency subbands for each of the plurality of data streams and to determine an SNR estimate for each data stream based on the received SNRs for the data stream.

31. A method of performing rate selection in a communication system, comprising:

determining channel estimates for a plurality of data streams to be sent to a single receiver; and

selecting a single code rate and a plurality of modulation schemes for the plurality of data streams based on the channel estimates.

32. The method of claim 31, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the selecting the single code rate and the plurality of modulation schemes comprises

selecting a modulation scheme for each of the plurality of data streams to achieve a non-negative SNR margin for the data stream.

33. The method of claim 31, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the selecting the single code rate and the plurality of modulation schemes comprises

selecting the plurality of modulation schemes for the plurality of data streams such that at least one data stream has negative SNR margin and the plurality of data streams have a non-negative total SNR margin.

34. The method of claim 31, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the selecting the single code rate and the plurality of modulation schemes comprises

determining an overall throughput and a total SNR margin for each of a plurality of code rates, and

selecting a code rate having a highest overall throughput and a non-negative total SNR margin among the plurality of code rates, wherein the single code rate is the selected code rate.

35. The method of claim 31, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the selecting the single code rate and the plurality of modulation schemes comprises

determining an overall throughput and a total SNR margin for each of a plurality of code rates for each of a plurality of stream combinations, wherein each stream combination corresponds to a different number of data streams, and

selecting a code rate and a stream combination having a highest overall throughput and a non-negative total SNR margin among the plurality of code rates and the plurality of stream combinations, wherein the single code rate is the selected code rate and the plurality of data streams are for the selected stream combination.

36. The method of claim 31, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the selecting the single code rate and the plurality of modulation schemes comprises

determining a total SNR margin for each of a plurality of rate combinations, wherein each rate combination is associated with a specific number of data streams to transmit, a specific code rate for all of the data streams, a specific modulation scheme for each of the data streams, and a specific overall throughput for all of the data streams, and

selecting a rate combination having a highest overall throughput and a non-negative total SNR margin among the plurality of rate combinations, wherein the single code rate and the plurality of modulation schemes are for the selected rate combination.

37. An apparatus comprising:

means for determining channel estimates for a plurality of data streams to be sent to a single receiver; and

means for selecting a single code rate and a plurality of modulation schemes for the plurality of data streams based on the channel estimates.

38. The apparatus of claim 37, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the means for selecting the single code rate and the plurality of modulation schemes comprises

means for selecting a modulation scheme for each of the plurality of data streams to achieve a non-negative SNR margin for the data stream.

39. The apparatus of claim 37, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the means for selecting the single code rate and the plurality of modulation schemes comprises

means for selecting the plurality of modulation schemes for the plurality of data streams such that at least one data stream has negative SNR margin and the plurality of data streams have a non-negative total SNR margin.

40. The apparatus of claim 37, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the means for selecting the single code rate and the plurality of modulation schemes comprises

means for determining an overall throughput and a total SNR margin for each of a plurality of code rates, and

means for selecting a code rate having a highest overall throughput and a non-negative total SNR margin among the plurality of code rates, wherein the single code rate is the selected code rate.

41. The apparatus of claim 37, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the means for selecting the single code rate and the plurality of modulation schemes comprises

means for determining an overall throughput and a total SNR margin for each of a plurality of code rates for each of a plurality of stream combinations, wherein each stream combination corresponds to a different number of data streams, and

means for selecting a code rate and a stream combination having a highest overall throughput and a non-negative total SNR margin among the plurality of code rates and the plurality of stream combinations, wherein the single code rate is the selected code rate and the plurality of data streams are for the selected stream combination.

42. The apparatus of claim 37, wherein the channel estimates comprises a signal-to-noise-and-interference ratio (SNR) estimates and wherein the means for selecting the single code rate and the plurality of modulation schemes comprises

means for determining a total SNR margin for each of a plurality of rate combinations, wherein each rate combination is associated with a specific number of data streams, a specific code rate for all of the data streams, a specific modulation scheme for each of the data streams, and a specific overall throughput for all of the data streams, and

means for selecting a rate combination having a highest overall throughput and a non-negative total SNR margin among the plurality of rate combinations, wherein the single code rate and the plurality of modulation schemes are for the selected rate combination.

43. A processor readable media for storing instructions operable to:

determine channel estimates for a plurality of data streams to be sent to a single receiver; and select a single code rate and a plurality of modulation schemes for the plurality of data streams based on the channel estimates.

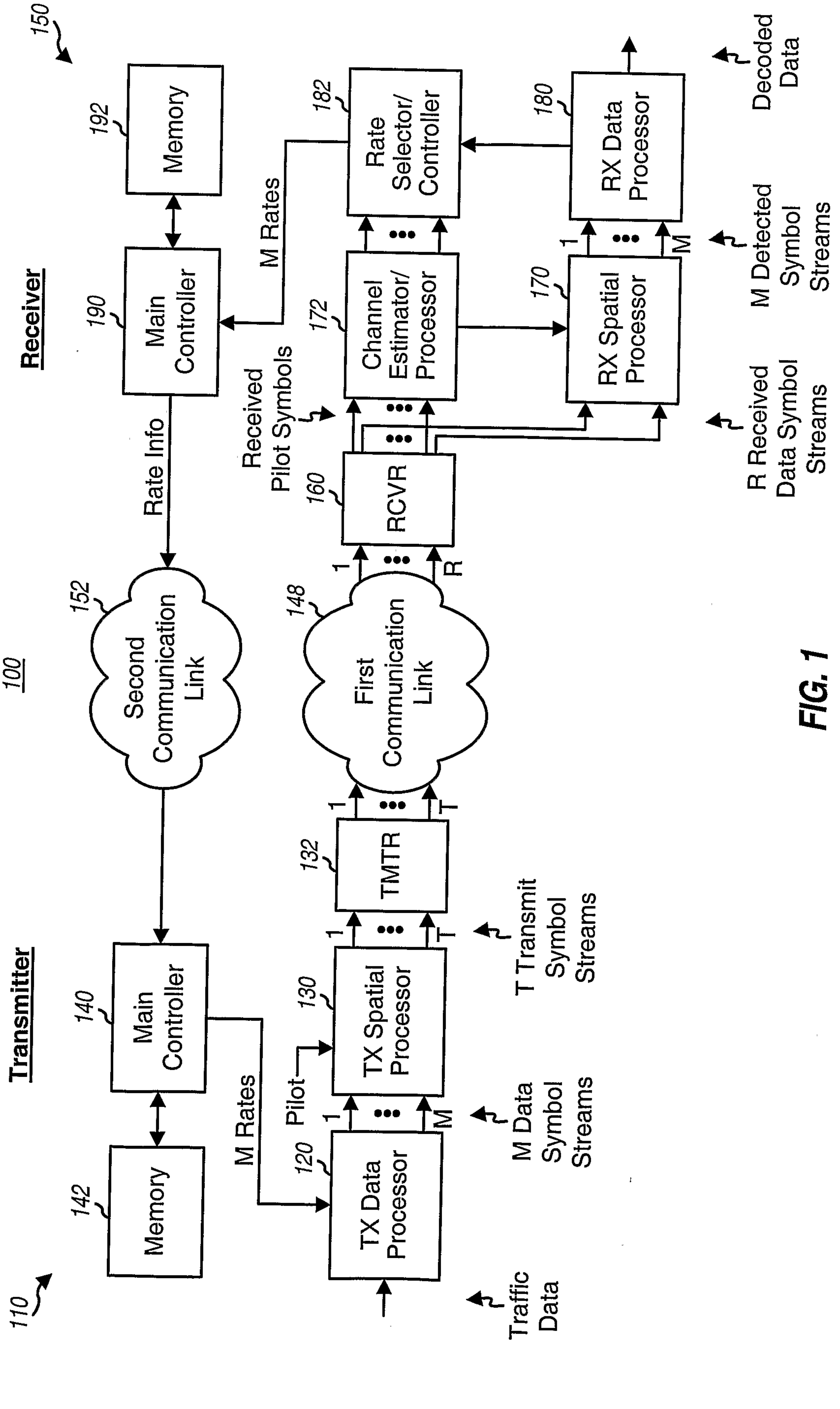
100
Transmitter
Receiver
110
150
Memory
142
Main Controller
140
M Rates
Traffic Data
TX Data Processor
120
1
M
M Data Symbol Streams
Pilot
TX Spatial Processor
130
1
T
T Transmit Symbol Streams
TMTR
132
1
T
First Communication Link
148
Second Communication Link
152
1
R
RCVR
160
Rate Info
Received Pilot Symbols
R Received Data Symbol Streams
Channel Estimator/ Processor
172
RX Spatial Processor
170
1
M
M Detected Symbol Streams
RX Data Processor
180
Decoded Data
Rate Selector/ Controller
182
M Rates
Main Controller
190
Memory
192

FIG. 1

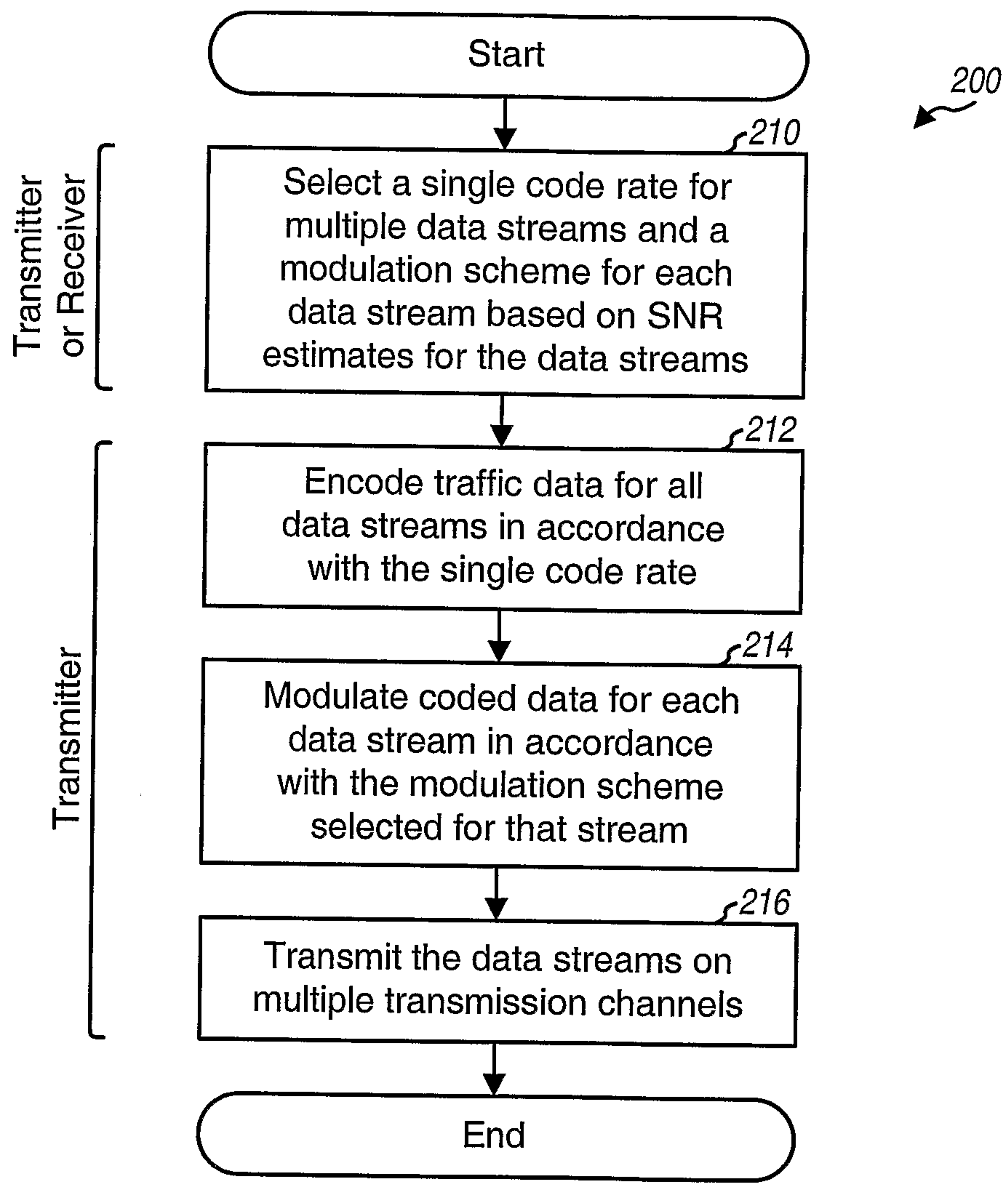
Start
200
210
Transmitter or Receiver
Select a single code rate for multiple data streams and a modulation scheme for each data stream based on SNR estimates for the data streams
212
Transmitter
Encode traffic data for all data streams in accordance with the single code rate
214
Modulate coded data for each data stream in accordance with the modulation scheme selected for that stream
216
Transmit the data streams on multiple transmission channels
End

FIG. 2

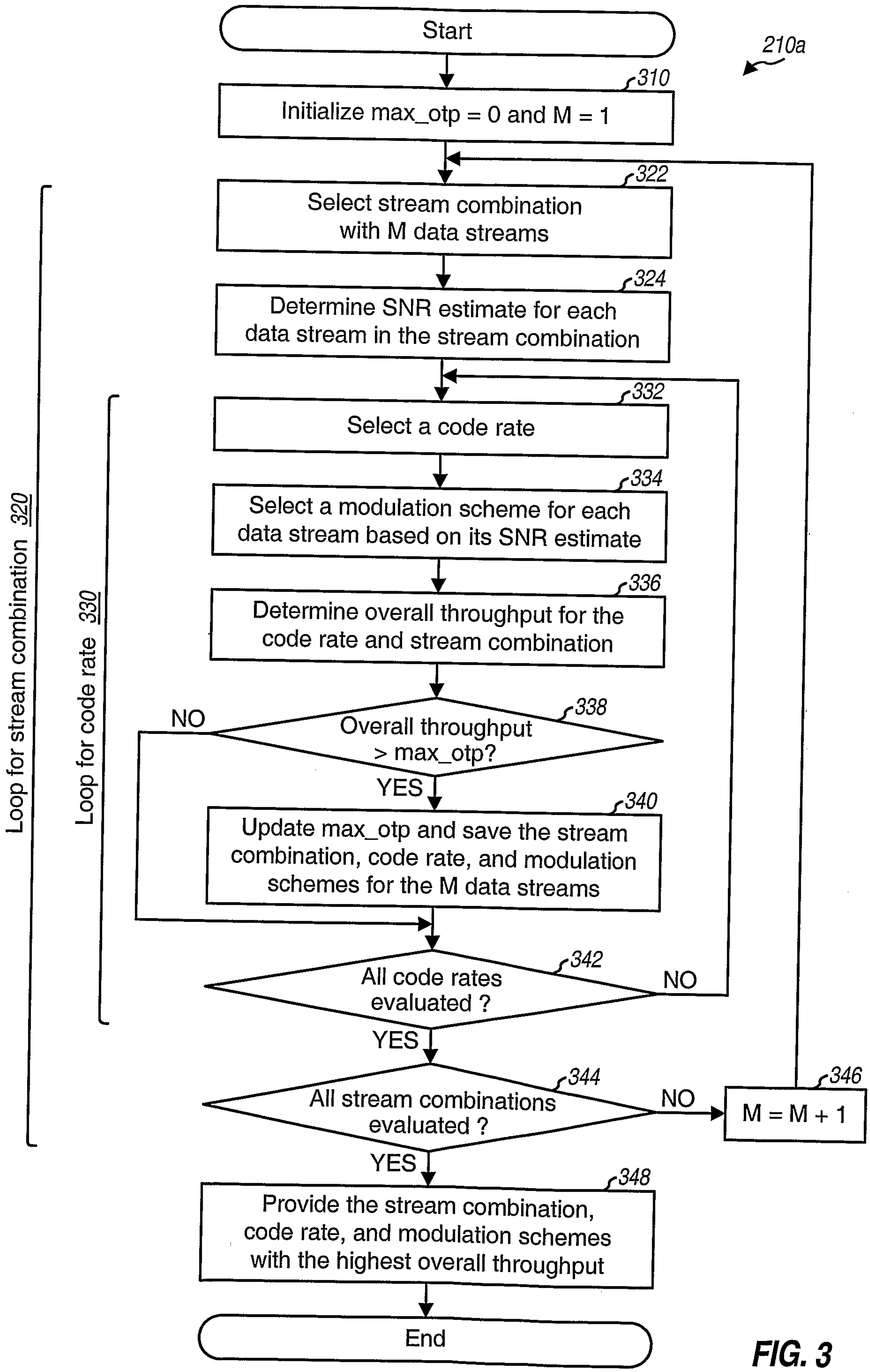
210a
Start
310
Initialize max_otp = 0 and M = 1
322
Select stream combination with M data streams
324
Determine SNR estimate for each data stream in the stream combination
332
Select a code rate
334
Select a modulation scheme for each data stream based on its SNR estimate
336
Determine overall throughput for the code rate and stream combination
338
Overall throughput > max_otp?
NO
YES
340
Update max_otp and save the stream combination, code rate, and modulation schemes for the M data streams
342
All code rates evaluated ?
NO
YES
344
All stream combinations evaluated ?
NO
YES
346
M = M + 1
348
Provide the stream combination, code rate, and modulation schemes with the highest overall throughput
End
Loop for stream combination 320
Loop for code rate 330

FIG. 3

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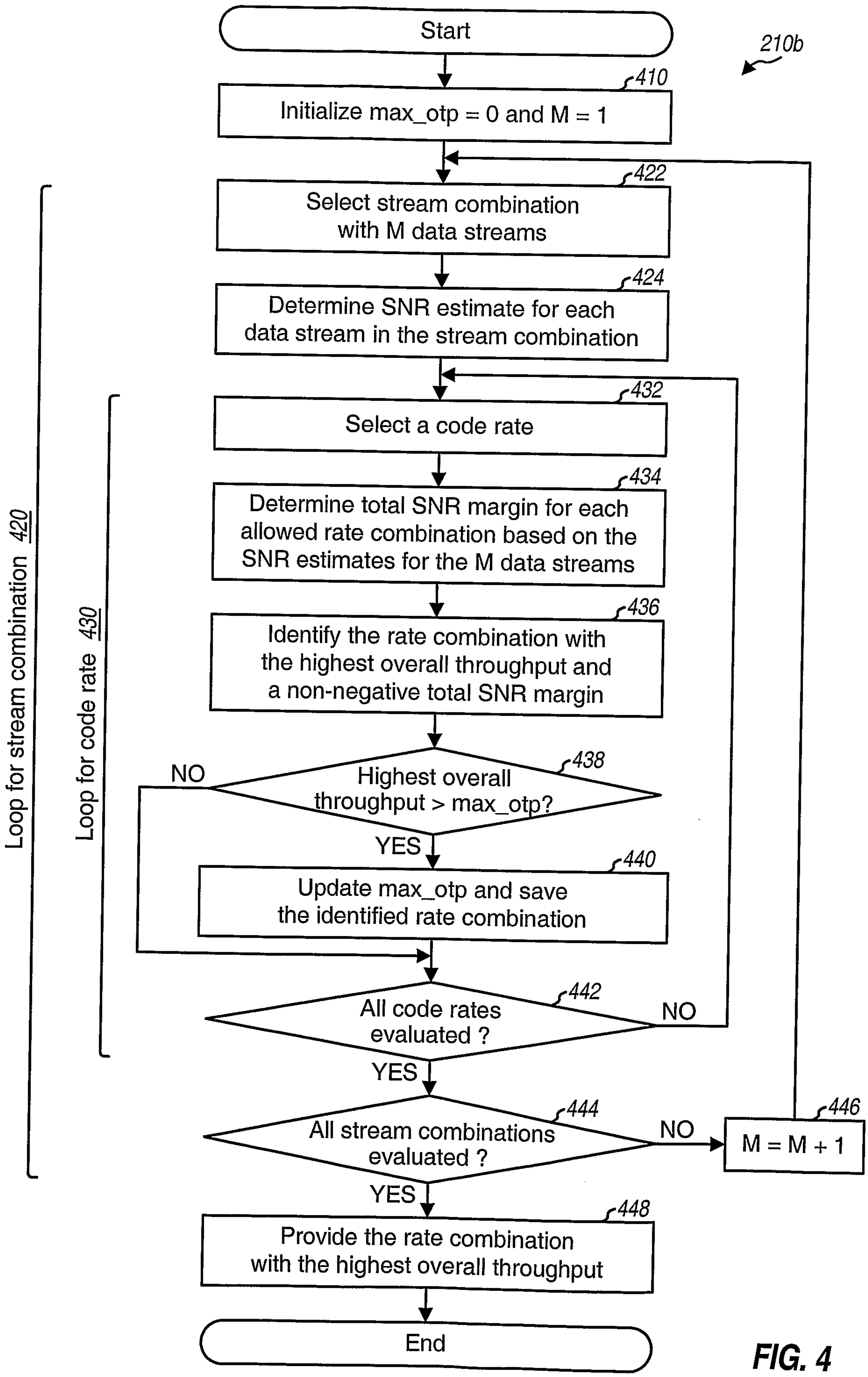

210b
Start
410
Initialize max_otp = 0 and M = 1
422
Select stream combination with M data streams
424
Determine SNR estimate for each data stream in the stream combination
432
Select a code rate
434
Determine total SNR margin for each allowed rate combination based on the SNR estimates for the M data streams
436
Identify the rate combination with the highest overall throughput and a non-negative total SNR margin
438
Highest overall throughput > max_otp?
NO
YES
440
Update max_otp and save the identified rate combination
442
All code rates evaluated ?
NO
YES
444
All stream combinations evaluated ?
NO
446
M = M + 1
YES
448
Provide the rate combination with the highest overall throughput
End
Loop for stream combination 420
Loop for code rate 430

FIG. 4

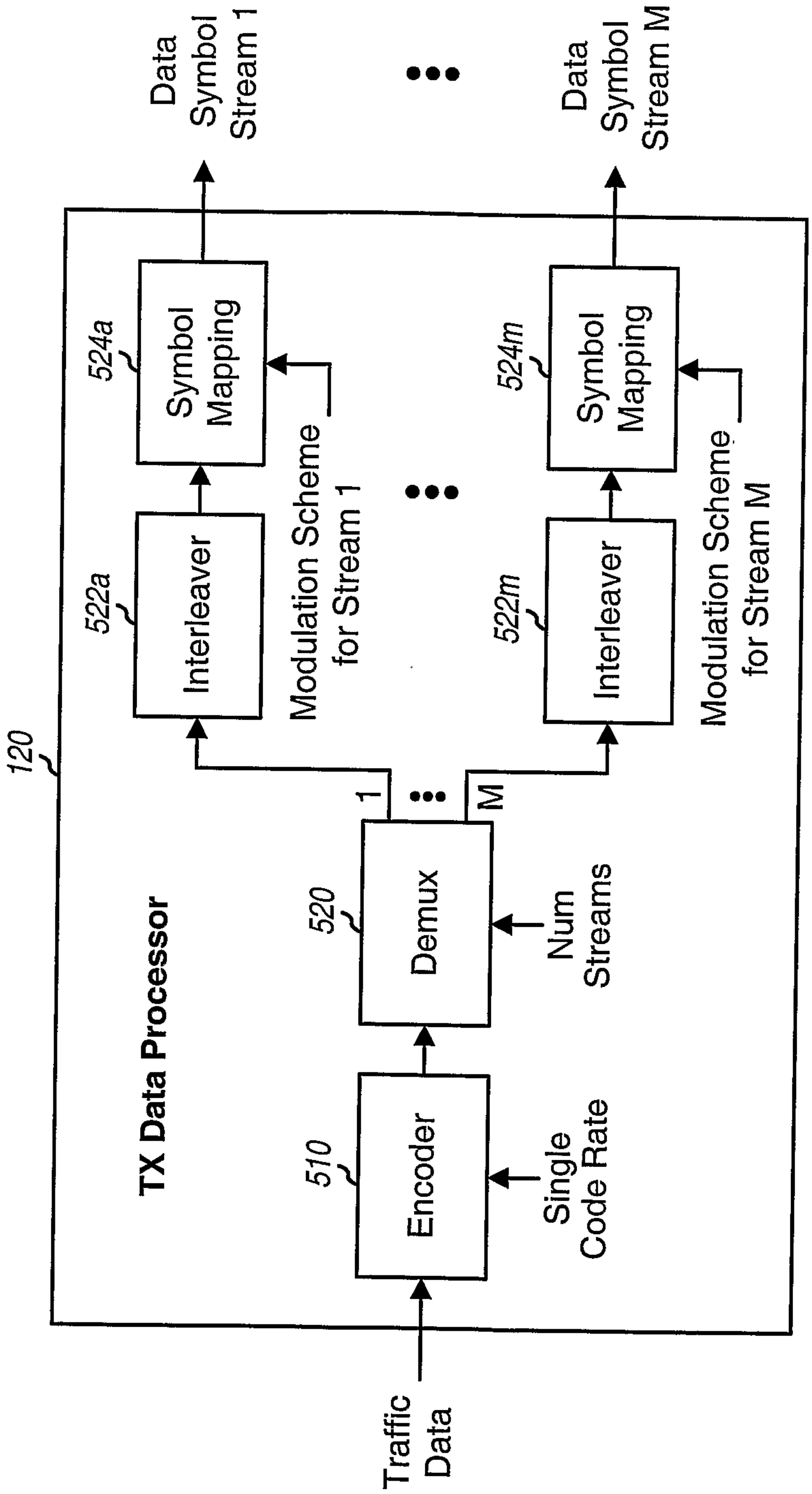
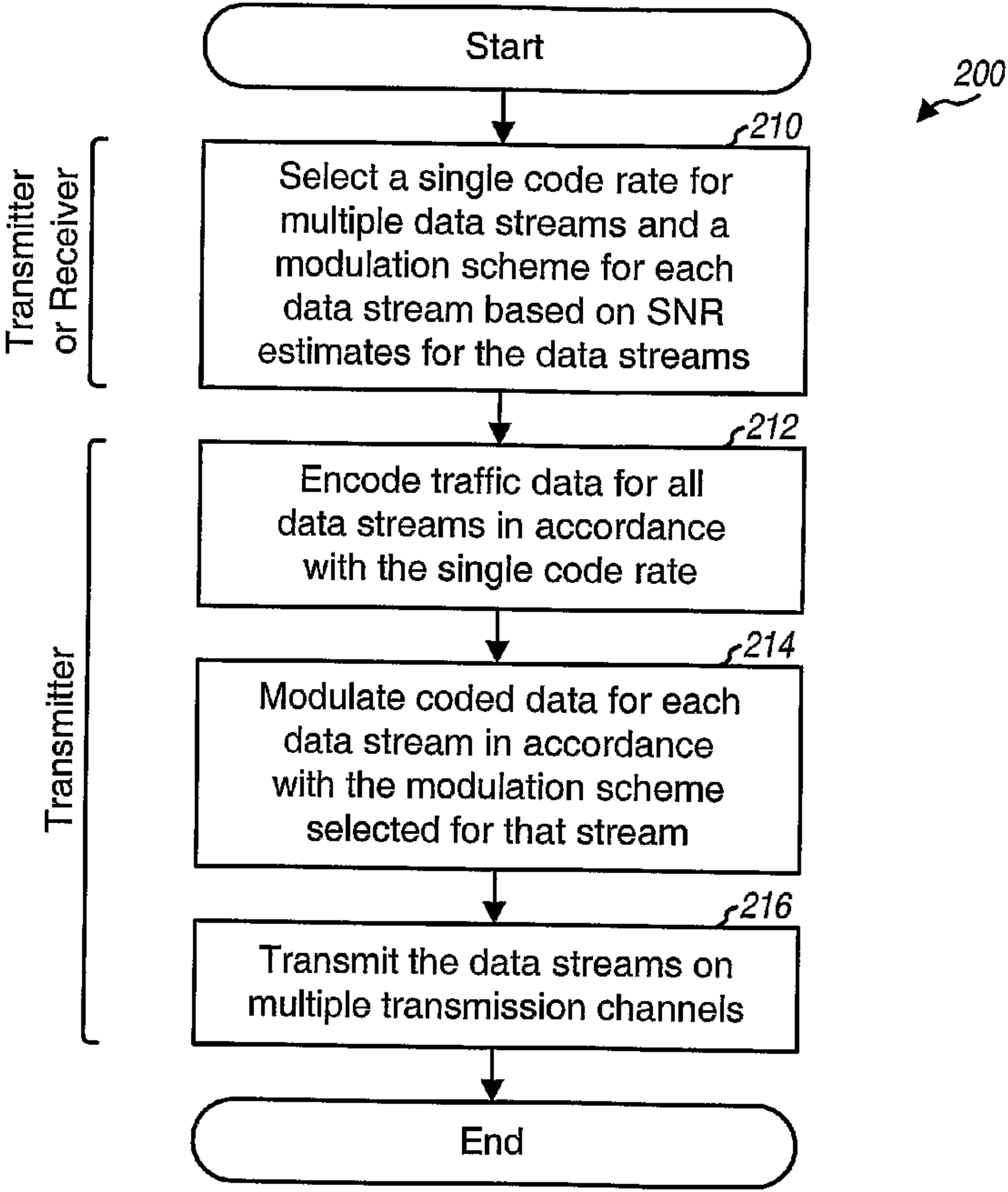

TX Data Processor
120
Traffic Data
510
Encoder
Single Code Rate
520
Demux
Num Streams
1
M
522a
Interleaver
524a
Symbol Mapping
Modulation Scheme for Stream 1
Data Symbol Stream 1
522m
Interleaver
524m
Symbol Mapping
Modulation Scheme for Stream M
Data Symbol Stream M

FIG. 5


Start
200
210
Select a single code rate for multiple data streams and a modulation scheme for each data stream based on SNR estimates for the data streams
Transmitter or Receiver
212
Encode traffic data for all data streams in accordance with the single code rate
214
Modulate coded data for each data stream in accordance with the modulation scheme selected for that stream
216
Transmit the data streams on multiple transmission channels
Transmitter
End