



US009271192B1

(12) **United States Patent**
Sampath et al.

(10) **Patent No.:** **US 9,271,192 B1**
(45) **Date of Patent:** ***Feb. 23, 2016**

(54) **RATE ADAPTATION IN WIRELESS SYSTEMS**

(71) Applicant: **Marvell International Ltd.**, Hamilton (BM)

(72) Inventors: **Hemanth Sampath**, Sunnyvale, CA (US); **Ravi Narasimhan**, Los Altos, CA (US)

(73) Assignee: **Marvell International Ltd.**, Hamilton (BM)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 8 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/244,750**

(22) Filed: **Apr. 3, 2014**

Related U.S. Application Data

(63) Continuation of application No. 12/983,825, filed on Jan. 3, 2011, now Pat. No. 8,693,331, which is a continuation of application No. 10/734,440, filed on Dec. 11, 2003, now Pat. No. 7,864,678.

(60) Provisional application No. 60/494,437, filed on Aug. 12, 2003.

(51) **Int. Cl.**
H04W 28/22 (2009.01)

(52) **U.S. Cl.**
CPC **H04W 28/22** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,989,201 A 1/1991 Glance
5,345,599 A 9/1994 Paulraj et al.

5,483,676 A 1/1996 Mahany et al.
5,912,931 A 6/1999 Matsumoto
5,959,660 A 9/1999 Levan
6,118,565 A 9/2000 Frigo
6,351,499 B1 2/2002 Paulraj et al.
6,377,636 B1 4/2002 Paulraj et al.
6,452,981 B1 9/2002 Raleigh et al.
6,499,008 B2 12/2002 Miet
6,618,591 B1 9/2003 Kalliokulju et al.
6,633,616 B2 10/2003 Crawford

(Continued)

FOREIGN PATENT DOCUMENTS

WO 03/001726 1/2003

OTHER PUBLICATIONS

Catreux, et al., "Adaptive Modulation and MIMO Coding for Broadband Wireless Data Networks", Jun. 2002, IEEE Communications Magazine, pp. 108-115.

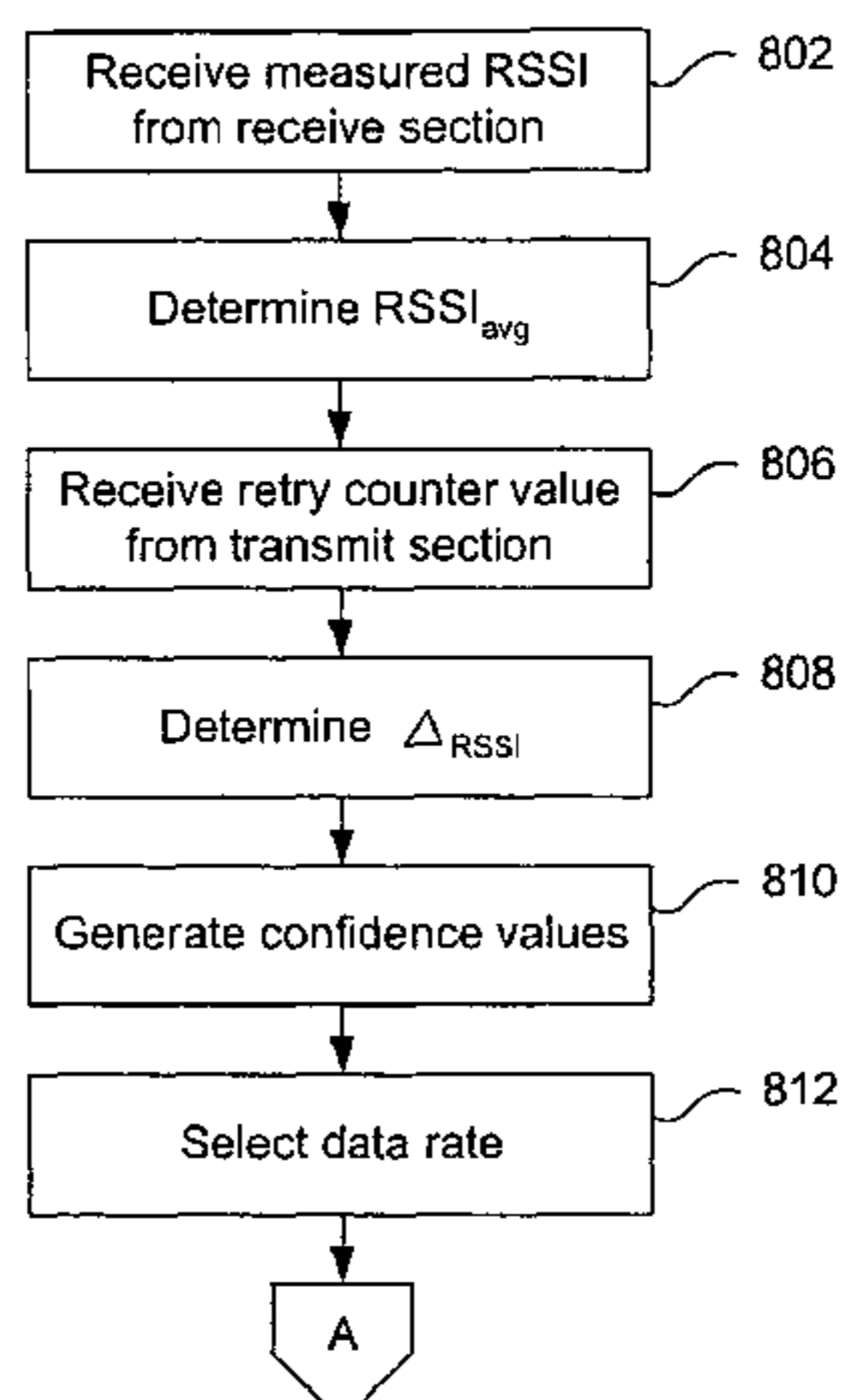
(Continued)

Primary Examiner — Chi H Pham
Assistant Examiner — Shick Hom

(57) **ABSTRACT**

Techniques and systems for rate adaption in wireless systems are disclosed. A disclosed technique includes generating confidence measures for a plurality of data rates based at least on a first indicator and a second indicator, the first indicator corresponding to packet loss associated with packets transmitted by a device at a first data rate that is selected from the plurality of data rates, and the second indicator corresponding to one or more signal quality values associated with one or more packets received by the device; selecting, from the plurality of data rates, a second data rate based at least on the confidence measures; and transmitting one or more additional packets at the second data rate.

22 Claims, 5 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

6,643,496	B1	11/2003	Shimoyama et al.	
6,675,012	B2	1/2004	Gray	
6,687,492	B1	2/2004	Sugar et al.	
6,760,882	B1	7/2004	Gesbert	
6,775,548	B1	8/2004	Rong et al.	
6,801,501	B1 *	10/2004	Knightly et al.	370/233
6,801,580	B2	10/2004	Kadous	
6,826,528	B1	11/2004	Wu et al.	
6,889,050	B1	5/2005	Willars et al.	
6,987,819	B2	1/2006	Thomas et al.	
7,032,157	B2	4/2006	Kim et al.	
7,046,963	B2	5/2006	Luo et al.	
7,075,913	B1	7/2006	Yavuz et al.	
7,164,655	B2	1/2007	Li	
7,180,326	B2	2/2007	Komyo et al.	
7,230,928	B2	6/2007	Katz	
7,302,009	B2	11/2007	Walton et al.	
7,408,976	B1	8/2008	Narasimhan et al.	
7,436,757	B1	10/2008	Wilson	
7,532,563	B1	5/2009	Shirali et al.	
7,590,188	B2	9/2009	Giannakis et al.	
7,640,373	B2	12/2009	Cudak et al.	
7,672,685	B2	3/2010	Itoh	
7,697,449	B1 *	4/2010	Shirali et al.	370/252
7,864,661	B2	1/2011	Hosur et al.	
7,864,678	B1 *	1/2011	Sampath et al.	370/232
8,149,810	B1	4/2012	Narasimhan et al.	
8,687,510	B1	4/2014	Shirali	
8,693,331	B1 *	4/2014	Sampath et al.	370/232
2001/0055276	A1	12/2001	Rogers et al.	
2002/0056066	A1	5/2002	Gesbert et al.	
2002/0141349	A1	10/2002	Kim et al.	
2002/0183010	A1	12/2002	Catreux et al.	
2002/0196842	A1	12/2002	Onggosanusi et al.	
2003/0003863	A1	1/2003	Thielecke et al.	
2003/0065712	A1	4/2003	Cheung et al.	
2003/0076787	A1	4/2003	Katz	
2003/0083088	A1	5/2003	Chang et al.	
2003/0086486	A1	5/2003	Graziano et al.	
2003/0100265	A1	5/2003	Wang et al.	
2003/0231655	A1	12/2003	Kelton et al.	
2004/0017773	A1	1/2004	Piche et al.	
2004/0017790	A1	1/2004	Del Prado et al.	
2004/0082356	A1	4/2004	Walton et al.	
2004/0153951	A1	8/2004	Walker et al.	
2004/0160922	A1	8/2004	Nanda et al.	
2004/0160979	A1	8/2004	Pepin et al.	
2004/0203456	A1	10/2004	Onggosanusi et al.	
2005/0027840	A1	2/2005	Theobald et al.	
2005/0047515	A1	3/2005	Walton	
2005/0099975	A1	5/2005	Catreux et al.	
2005/0117543	A1	6/2005	Heath et al.	
2005/0143027	A1	6/2005	Hiddink et al.	
2005/0249157	A1	11/2005	Qian et al.	
2005/0254592	A1	11/2005	Naguib et al.	
2011/0149723	A1	6/2011	Gong et al.	

OTHER PUBLICATIONS

Foschini, et al., "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas", 1998, *Wireless Personal Communications*, pp. 311-335.

Goldsmith, et al., "Adaptive Coded Modulation for Fading Channels", May 1998, *IEEE Transactions on Communications*, vol. 46, No. 5, pp. 595-602.

Hayes, et al., "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications", International Standard, ISO/IEC 8802-11, ANSI/IEEE Std. 802.11, pp. i-xvi, pp. 1-512, 1999.

Hayes, et al., "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band", IEEE, Supplement to IEEE Standard for Information Technology, Std. 802.11a, pp. i-viii, pp. 1-83, 1999.

IEEE Computer Society, "Draft 802.20 Permanent Document : System Requirements for IEEE 802.20 Mobile Broadband Wireless Access Systems—Version 14", IEEE 802.20-PD-06, Jul. 2004.

IEEE Computer Society, "IEEE Standard for Information Technology—Draft Supplement to Standard [for] Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Further Higher Data Rate Extension in the 2.4 GHz Band", IEEE P802.11g/D8.2, Apr. 2003.

IEEE Computer Society, "IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment 5: Spectrum and Transmit Power Management Extensions in the 5 GHz Band in Europe", IEEE P802.11h-2003.

IEEE Computer Society, "Part 16: Air Interface for Fixed Broadband Wireless Access Systems", IEEE Std 802.16-2004.

IEEE Computer Society, "Supplement to IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Higher-speed Physical Layer Extension in the 2.4 GHz Band", IEEE Std 802.11b-1999.

IEEE Computer Society, "TGn Sync Proposal Technical Specification", IEEE Std 802.11n—First Edition, May 2005.

Sampath, et al. U.S. Appl. No. 10/834,745, filed Apr. 28, 2004.

Tarokh, et al., "Space-Time Block Codes from Orthogonal Designs", Jul. 1999, *IEEE Transactions on Information Theory*, vol. 45, No. 5, pp. 1456-1467.

Xin, et al., "Space-Time Constellation—Rotating Codes Maximizing Diversity and Coding Gains", 2001, *IEEE*, pp. 455-459.

* cited by examiner

FIG. 1

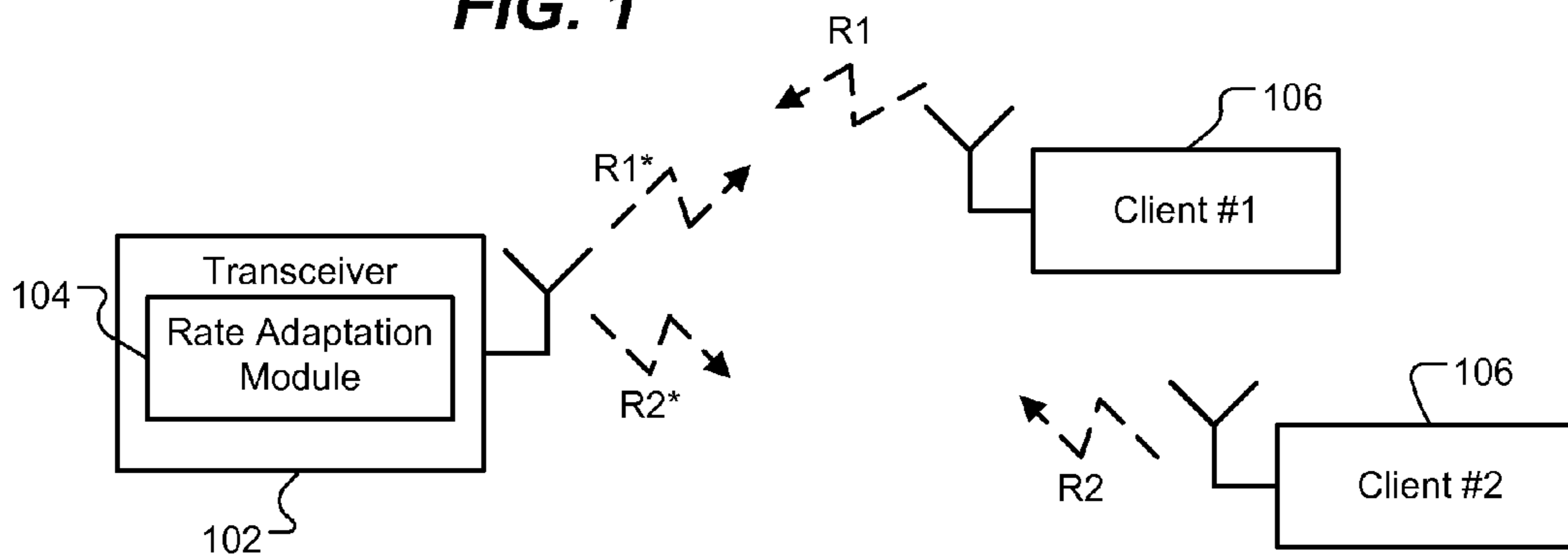


FIG. 2

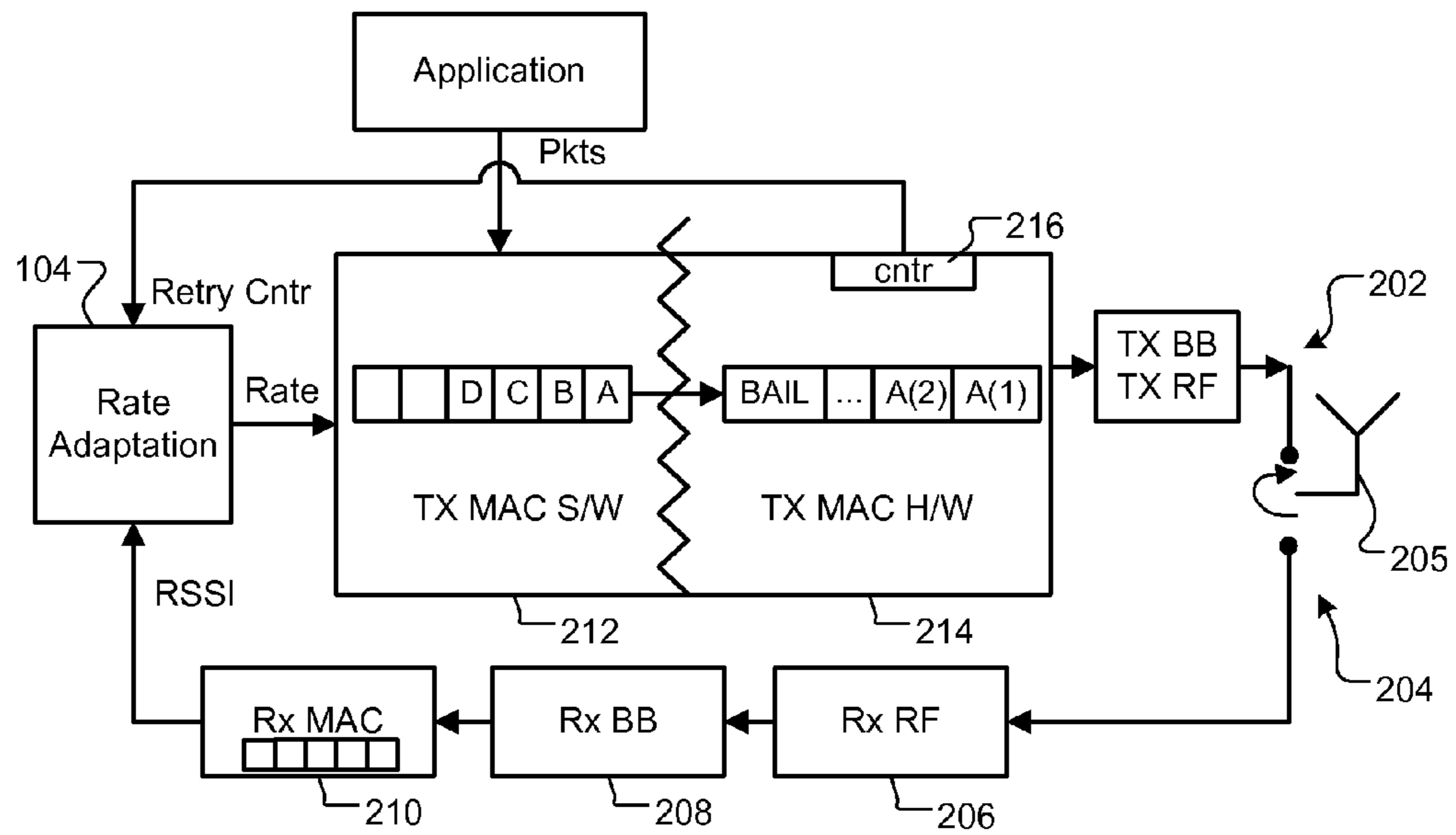


FIG. 3

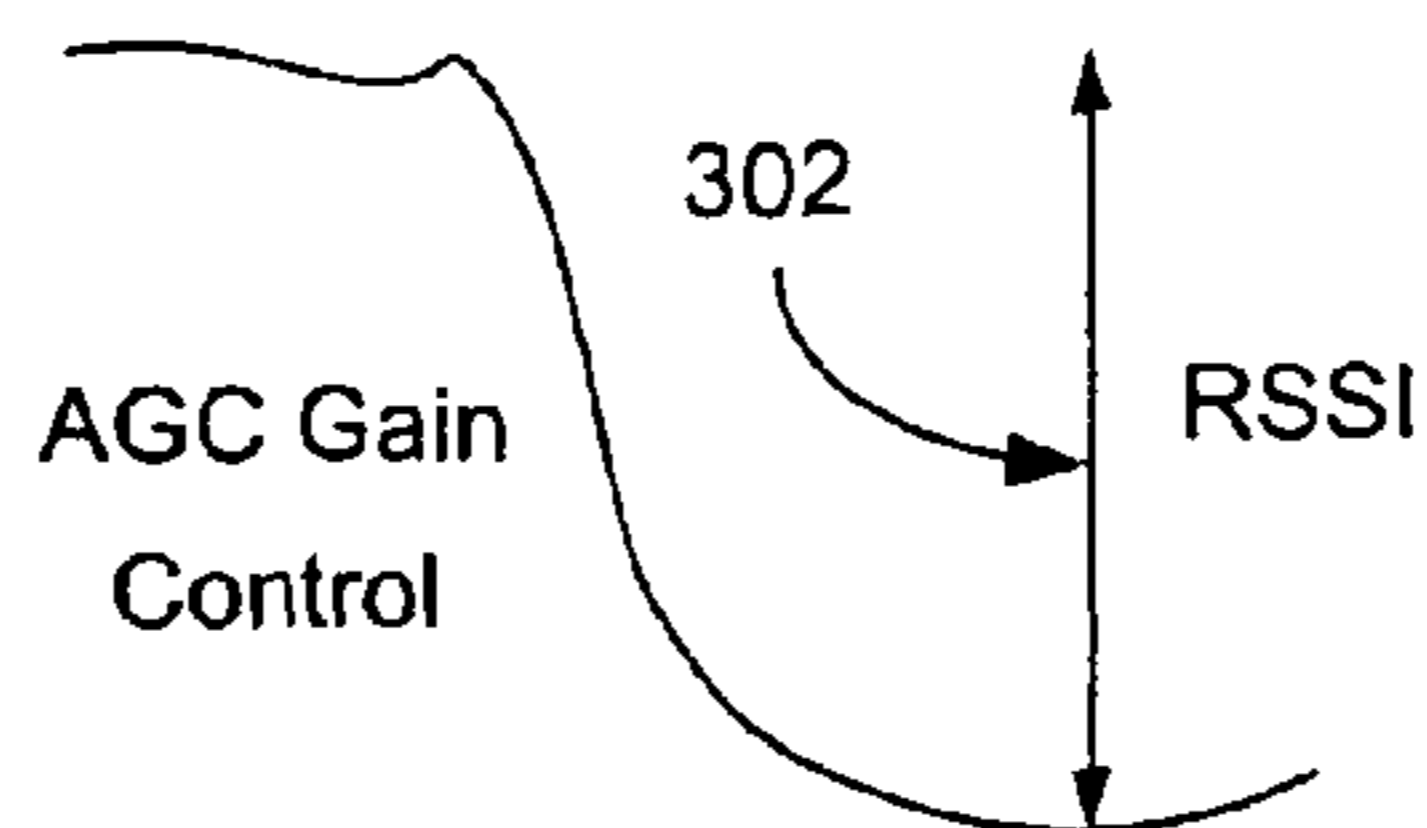


FIG. 4

Data Rates (Mbps)	RSSI _{TH} (dB)
54	36
48	33
36	27
24	22
12	16
11	12
6	10

FIG. 5

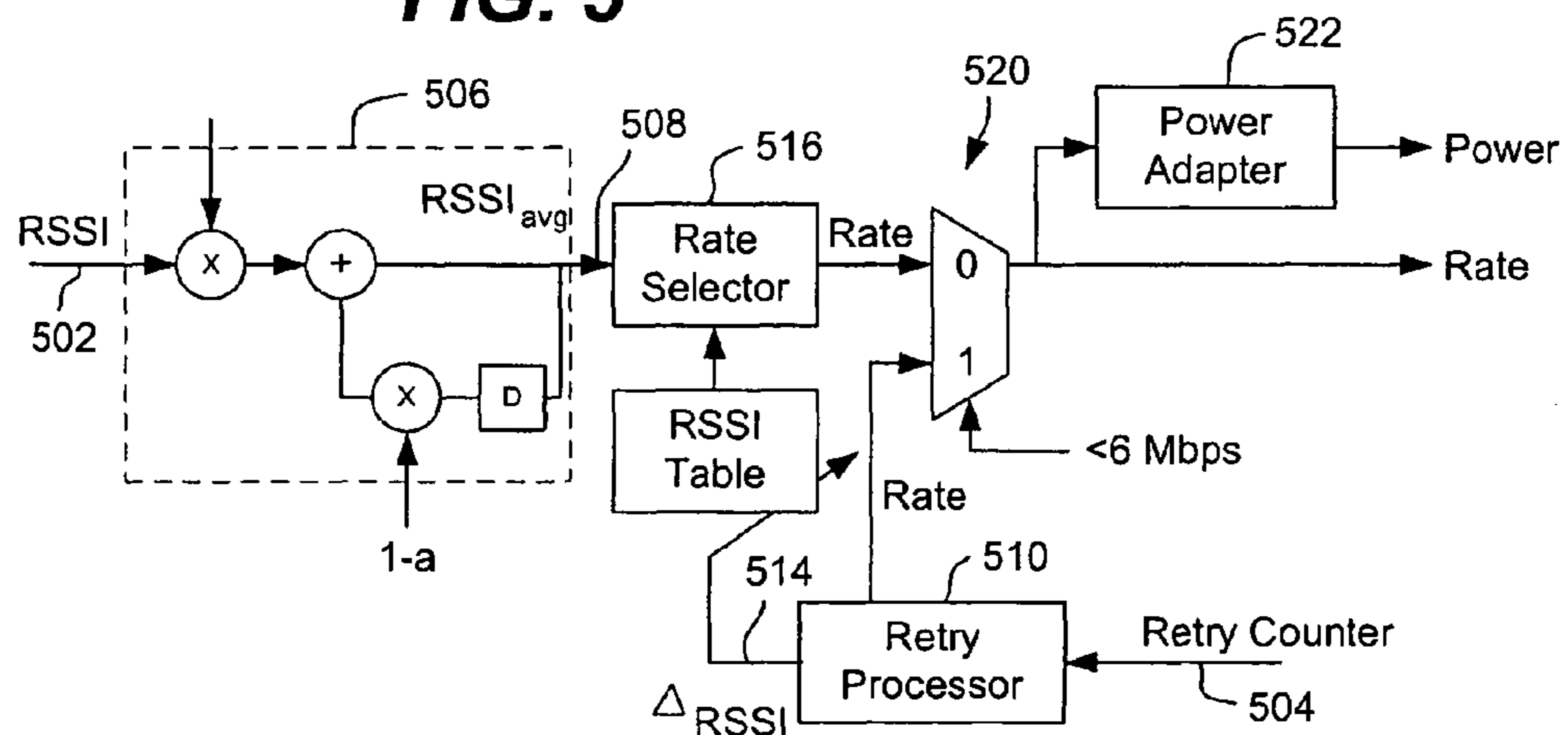
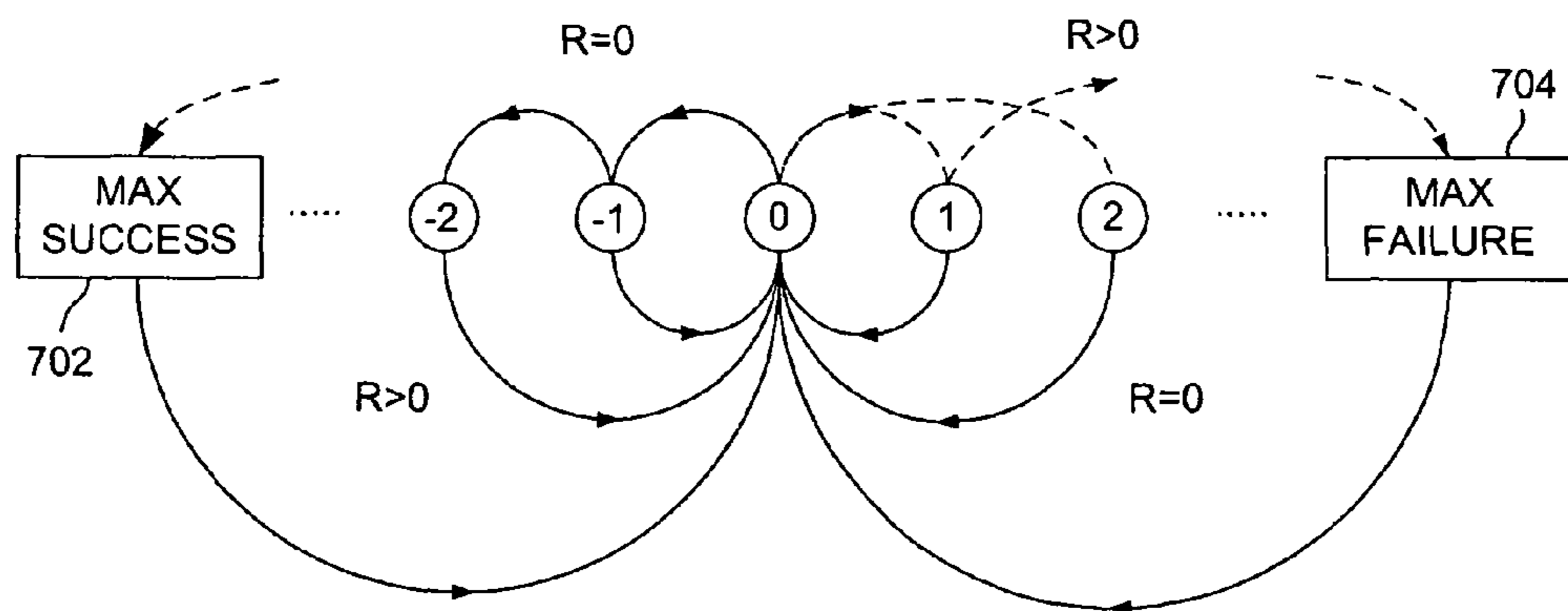


FIG. 6

Data Rates (Mbps)	Confidence (dB)
54	-10
48	-7
36	-1
24	4
12	10
11	15
6	20

FIG. 7



R : Retry Cnt

State = # of consecutive success or failure

$$\Delta \text{RSSI} = \Delta \text{RSSI} - \Delta 1$$

$$\Delta \text{RSSI} = \Delta \text{RSSI} + \Delta 2$$

IF (state == MAX SUCCESS)

IF (state == MAX FAILURE)

FIG. 8A

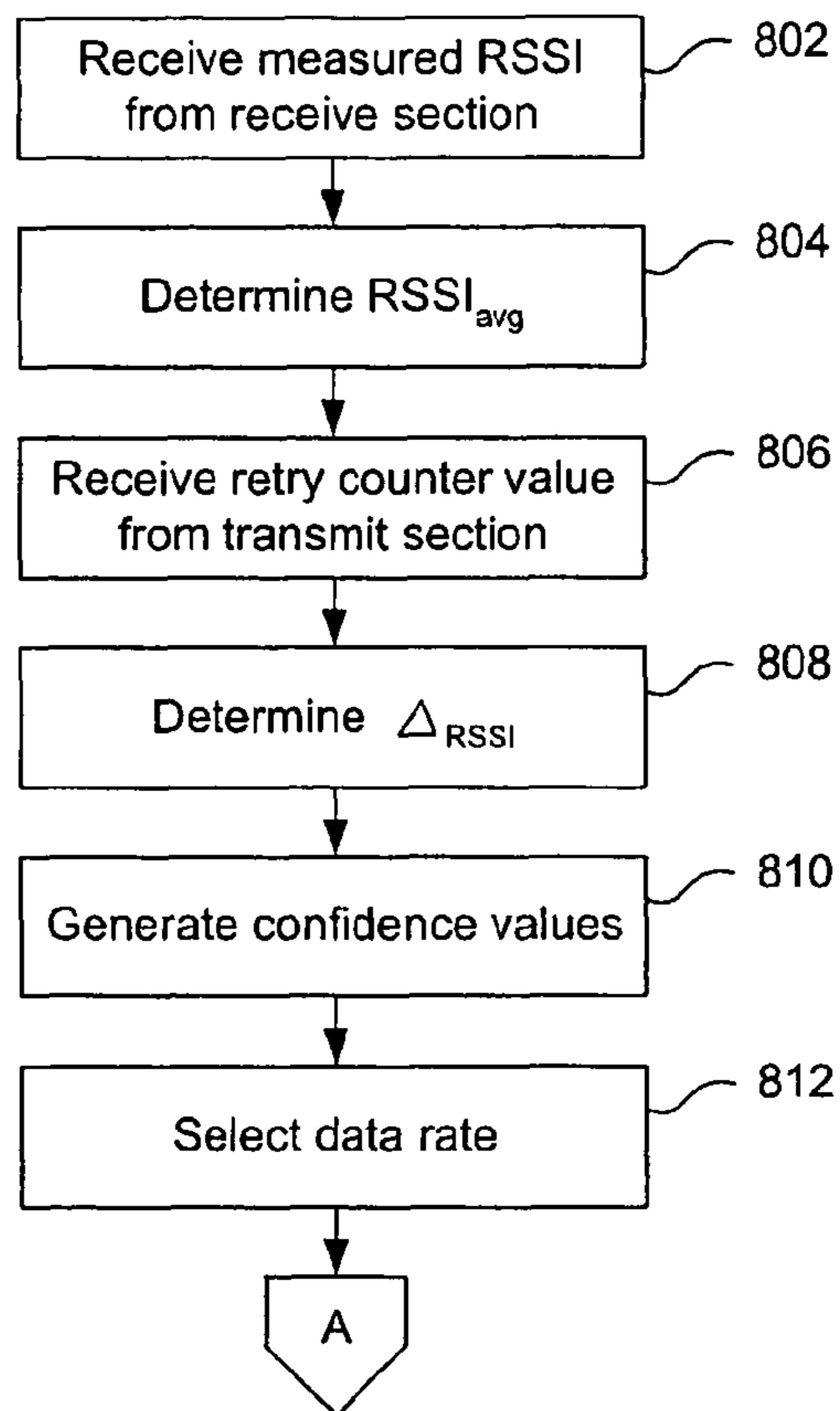
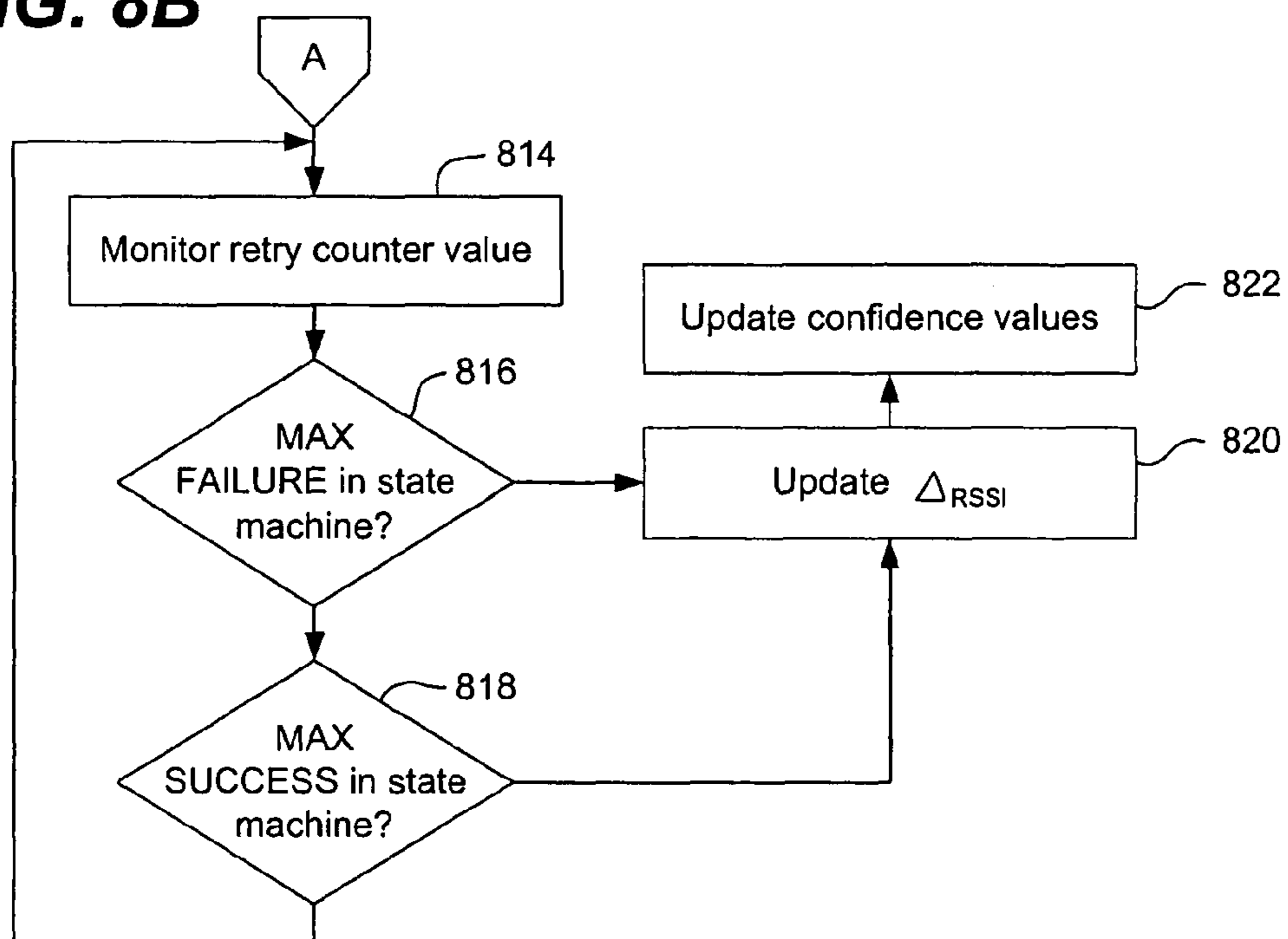


FIG. 8B



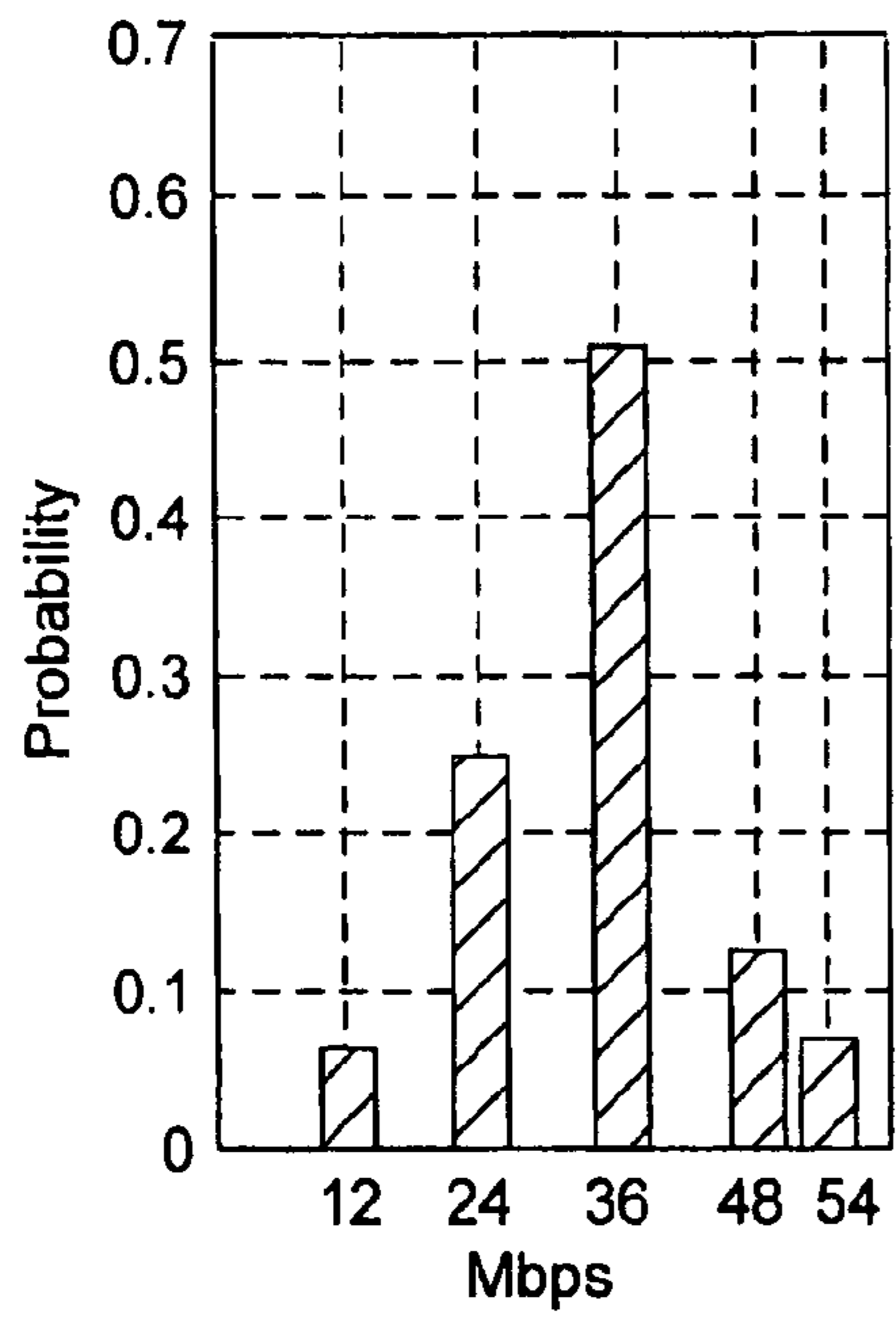


FIG. 9A

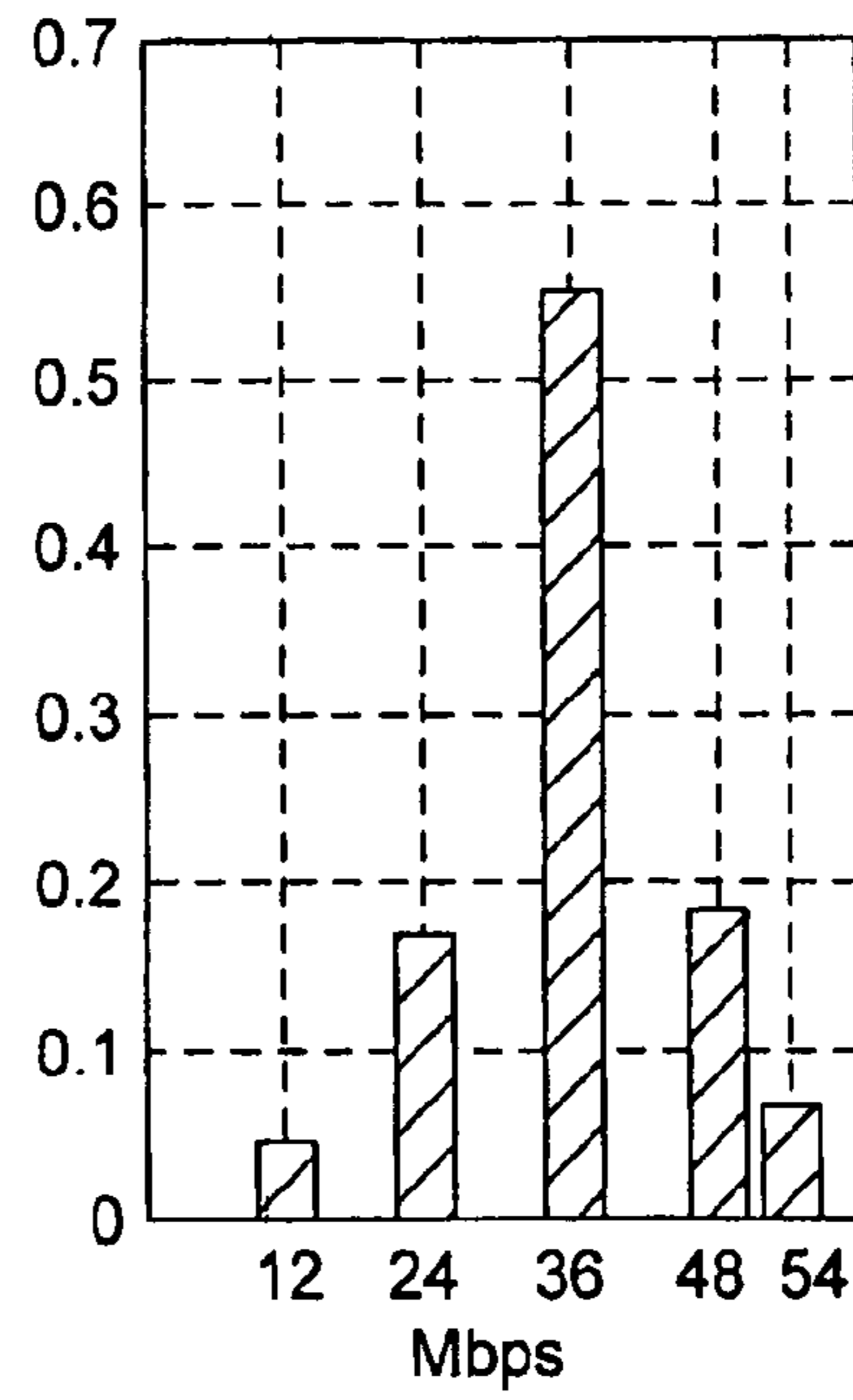


FIG. 9B

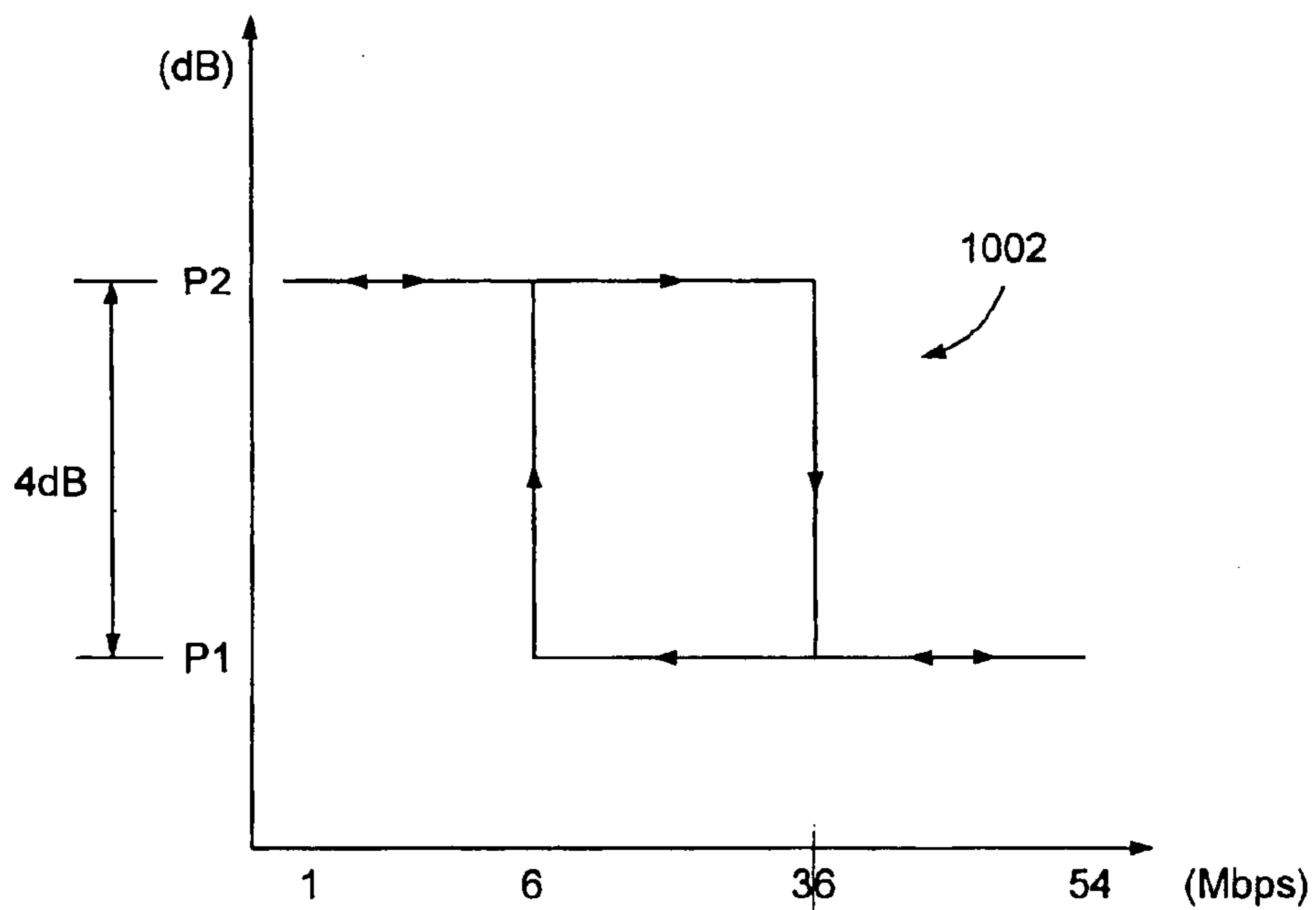


FIG. 10

RATE ADAPTATION IN WIRELESS SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of and claims priority to U.S. patent application Ser. No. 12/983,825, filed on Jan. 3, 2011 (now U.S. Pat. No. 8,693,331), which is a continuation of and claims priority to U.S. patent Ser. No. 10/734,440, filed on Dec. 11, 2003 (now U.S. Pat. No. 7,864,678), which claims priority to U.S. Provisional Application Ser. No. 60/494,437, filed on Aug. 12, 2003.

BACKGROUND

The data rate at which a wireless device transmits may depend on the wireless environment in which the device is transmitting. The wireless environment may be affected by such factors as interference, packet collisions, reflections, etc. A wireless device may attempt to select an optimal data rate for a given environment using a data rate selection algorithm.

In the IEEE 802.11 family of specifications, a wireless device initiates transmission at the highest possible data rate. If the wireless device receives an acknowledgement (ACK) from a receiving device, it is assumed that the wireless environment can support the highest data rate and further transmissions occur with this (highest) data rate. Otherwise the data rate is lowered in a step-wise fashion until an ACK is obtained. Such a strategy may waste bandwidth. Furthermore, this strategy can lead to successive packet failures, which may cause TCP timeouts and associated decreases in link throughput.

SUMMARY

A transceiver may include a transmit section operative to transmit packets, a receive section operative to receive packets, and a rate selector operative to select a data rate for transmission. The rate selector may select the data rate based upon a received signal quality value determined by the receive section and a packet loss indicator value determined by the transmit section. The received signal quality value may be, e.g., an RSSI (Received Signal Strength Indicator) value, an SNR (signal to noise ratio) value, an SINR (signal to interference noise ratio) value, or a SQM (signal quality measure, which is the mean (geometric, arithmetic, or other) of the SNRs across all tones). The packet loss indicator value may be, e.g., a retry counter value, a bit-error update value, a packet error update value, a symbol error update value, or a CRC (Cyclic Redundancy Check) indicator value.

The rate selector may include a table including available data rates, each associated with a nominal received signal quality value. The rate selector may generate a confidence value for each available data rate using the received signal quality value and the packet loss indicator value. In an embodiment using RSSI for the signal quality value and a retry counter for the packet loss indicator value, the confidence value is obtained by solving the equation:

$$\text{Confidence}[j] = \text{RSSI}_{\text{avg}} - \text{RSSI}_{TH}[j] - \Delta_{RSSI},$$

where $\text{RSSI}_{TH}[j]$ comprises a nominal received signal strength value associated with a data rate [j] in a table. The rate selector then selects a data rate associated with a positive confidence value, in an embodiment, the lowest positive confidence value.

The rate selector may include a state machine that monitors the packet loss indicator value and determines whether a

current data rate causes an excessive number of failed packet transmissions or an excessive number of successful packet transmissions, and updates an adjustment value for the signal quality value accordingly.

The transceiver selector may include a power adaptor that increases a transmit power of the transmit section in response to the selected data rate falling below a minimum threshold data rate and decreases the transmit power in response to the selected data rate exceeding a maximum threshold data rate.

The rate selector may include a hardware section that progressively decreases the data rate in response to the packet loss indicator value increasing until a "successful" data rate is achieved.

The rate selector may select a data rate value directly from the packet loss indicator value in response to the received signal quality value falling below a minimum signal quality value.

The transceiver may be used in a wireless LAN system that complies with one of the IEEE 802.11 family of specifications.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a wireless system.

FIG. 2 is a block diagram of a transceiver with a rate adaptation module.

FIG. 3 is a plot illustrating an RSSI (Received Signal Strength Indicator) measurement.

FIG. 4 shows a nominal RSSI table.

FIG. 5 is a block diagram of a rate adaptation module.

FIG. 6 shows an adjusted RSSI table.

FIG. 7 shows a state machine in a retry processor.

FIGS. 8A and 8B show a flowchart describing a rate adaptation algorithm.

FIGS. 9A and 9B show results from two experiments using transceivers with a rate adaptation module.

FIG. 10 is a plot illustrating the response of a power adapter in the transceiver.

DETAILED DESCRIPTION

FIG. 1 shows a wireless system. The system may be an ad hoc network of wireless devices, e.g., a wireless Local Area Network (WLAN) that complies with one of the IEEE 802.11 family of specifications. The system may include a wireless transceiver 102 with a rate adaptation module 104 and one or more wireless client transceivers 106.

The transceiver 102 may communicate with a client transceiver 106 on an uplink channel (client transmitting to transceiver) and on a downlink channel (transceiver transmitting to client). The data rates in the uplink and downlink channels depend on the characteristics of the wireless environment and may differ from each other.

In an embodiment, the transceiver 102 may use a rate adaptation scheme to optimize a data rate in communicating with the client transceivers 106. For a given data rate, throughput depends on the wireless environment, which may be affected by, e.g., interference, packet collisions, multipath fading, and implementation losses. The transceiver may select a physical (PHY) layer data rate based on the wireless channel qualities of the uplink and downlink to maximize average throughput.

FIG. 2 shows a schematic of a transceiver according to an embodiment. The transceiver may have a transmit section 202 and a receive section 204. The rate adaptation module 104 may use packet loss data from the transmit section 202 and a

signal quality measure from the receive section **204** to determine a suitable data rate for transmission in a given wireless environment.

In an embodiment, the signal quality measure is the RSSI (Received Signal Strength Indicator). In alternative embodiments, other signal quality measures, such as SNR (signal to noise ratio), SINR (signal to interference noise ratio), SQM (signal quality measure, which is the mean (geometric, arithmetic, or other) of the SNRs across all OFDM tones), etc., may be used.

The RSSI (or other signal quality measure) may be determined from successfully received packets, i.e., those packets received at the antenna **205** and processed by the RF (radio frequency) section **206**, baseband section **208**, and MAC (Media Access Control) section **210**. RSSI corresponds to a drop **302** in the AGC for a successfully received packet, as shown in FIG. 3. The magnitude of the drop in AGC depends on the strength of the signal on which the packet is received.

be sent (e.g., A(1), A(2), . . .) may be queued in a hardware portion **214** of the transmit section. A packet may need to be resent, or “retried”, until an acknowledgment (ACK) signal signifying a successful transmission of the packet is received from the receiving client. A retry counter **216** may be incremented on each retry of a packet to be sent, and the retry counter value provided to the rate adaptation module **104**.

In an embodiment, the hardware section can be designed so that successive “retried” packets (e.g., A(1), A(2), . . .) are sent at progressively lower rates until a “successful” transmission. The retry counter **216** may be incremented on each retry of a packet to be sent, and the retry counter value provided to the rate adaptation module **104**. Such a feature allows successful packet transmission, while the rate adaptation algorithm can adapt to the changing environment (on a slower time scale, depending upon the retry counter). The following table provides an exemplary relationship between data rates transmitted vs. retry counter value.

HARDWARE PACKET RETRY TABLE

Index	Retry Count = 0 (Mbps)	Retry Count = 1 (Mbps)	Retry Count = 2 (Mbps)	Retry Count = 3 (Mbps)	Retry Count = 4 (Mbps)	Retry Count = 5 (Mbps)	Retry Count = 6 (Mbps)	Retry Count = 7 (Mbps)	Retry Count = 8 (Mbps)
13	72	72	54	48	36	24	12	6	1
12	54	54	48	36	24	12	6	2	1
11	48	48	36	24	12	6	2	1	1
10	36	36	24	12	6	2	1	1	1
9	24	24	12	6	2	1	1	1	1
8	18	18	12	6	2	1	1	1	1
7	12	12	6	2	1	1	1	1	1
6	9	9	6	2	1	1	1	1	1
5	6	6	2	1	1	1	1	1	1
4	22	22	11	5.5	2	1	1	1	1
3	11	11	5.5	2	1	1	1	1	1
2	5.5	5.5	2	1	1	1	1	1	1
1	2	2	1	1	1	1	1	1	1
0	1	1	1	1	1	1	1	1	1

A higher RSSI indicates a “better” channel, which may support higher data rates. In an embodiment, the RSSI measurement has a measurement error corresponding to the AGC step height, e.g., +/-2 dB, and may be reliable above approximately 5 dB.

The RSSI may be used to construct a nominal RSSI table which may be adapted on a per-client basis. Depending on the complexity of implementation, multiple RSSI tables can also be maintained, which may be indexed by “packet size” (e.g., 64 bytes, 1500 bytes, etc.), “wireless environment” (e.g., home, outdoors, stadium, enterprise, etc.), etc. In other words, for different applications and environments, different tables can be used.

FIG. 4 shows an exemplary nominal RSSI table. A data rate may be selected based on a measured RSSI. For example, in this table, an RSSI of 34 (or any other value between 33 and <36) would indicate a channel quality capable of supporting a data rate of 48 Mbps.

The rate adaptation module **104** may receive a packet loss indicator from the transmit section. In an embodiment, the packet loss indicator is a retry counter value. In alternative embodiments, other packet loss indicators, such as bit-error update, packet error update, symbol error update, CRC (Cyclic Redundancy Check) indicators, etc., may be used.

Packets (e.g., A, B, C, D) may be queued in a software portion **212** of the transmit section, and copies of a packet to

For example, let the data rate as predicted by the rate adaptation algorithm be 54 Mbps (2nd row of the table). If this packet is retried, the first transmission occurs at 54 Mbps, the next transmission occurs at 48 Mbps, the next at 36 Mbps, and so on until the packet is successfully transmitted.

The number of retries for a given packet may depend on the quality of the channel. A higher number of retries may indicate a “worse” channel, which may only support lower data rates. The transmit section may only retry the packet up to a maximum number. If the maximum retry count is achieved, the retry counter may signal a bailout (“BAIL”), in which case, the transmit section may drop the data rate for transmission to a lowest possible rate.

FIG. 5 is a schematic diagram of a rate adaptation module according to an embodiment. The rate adaptation module receives two inputs; an RSSI value **502** from the receive section, and a retry counter value **504** from the transmit section. A filter **506** may be used to determine an average RSSI value ($RSSI_{avg}$) **508** from the input RSSI **502**, which may minimize noise effects and provide a more stable measurement. A retry processor **510** may use the input retry counter value to calibrate the average RSSI value, with) a Δ_{RSSI} **514** measurement. The Δ_{RSSI} is an adjustment to the average RSSI value due to differences in transmit/receive vendor boards, differences in transmit and receive wireless environment, or power and/or link imbalances between transmission and reception of data packets.

5

A rate selector **516** may use the $RSSI_{avg}$ value **508**, the Δ_{RSSI} value **514**, and the $RSSI_{TH}$ values in a nominal table (such as that shown in FIG. 4) to form a confidence value. The confidence value may be given by:

$$\text{Confidence}[j]=RSSI_{avg}-RSSI_{TH}[j]-\Delta_{RSSI} \quad 1 \leq j \leq 54$$

FIG. 6 shows an example for a measured $RSSI_{avg}$ of 24 dB and Δ_{RSSI} of -2 dB. A positive confidence value indicates a data rate that can be supported by the channel quality and a negative confidence value indicates a data rate that cannot be supported by the channel quality. An optimal data rate may be selected by selecting the highest data rate in the table with a positive confidence value, i.e.,

$$\text{Rate}=\text{argmin}(j)\{RSSI_{avg}-RSSI_{TH}[j]-\Delta_{RSSI}\}+$$

In this example, the rate selector may select a data rate of 24 Mbps, the highest data rate with a positive confidence value. This may maximize throughput while maintaining reliable link quality.

Although FIG. 6 shows an adjusted RSSI table including confidence values calculated for all data rates, in an embodiment the rate selector **516** may only calculate confidence values for data rates in the table adjacent to the data rate corresponding to the measured $RSSI_{avg}$ value, e.g., 38 Mbps and 12 Mbps in FIG. 6.

The retry processor may include a state machine, such as that shown in FIG. 7. The state machine may be used to determine whether the adjusted table is too optimistic (i.e., data rate is too high for the conditions) or too pessimistic (i.e., data rate is too low for the conditions). The state machine may track the number of successful ($R=0$) and unsuccessful ($R>0$) packet transmissions. Too many successive packet transmissions without retry may suggest that the adjusted table is too pessimistic, and too many successive transmissions with retry values greater than zero may suggest that the adjusted table is too optimistic. The retry processor may use this information to adjust the Δ_{RSSI} up or down. The adjustment in Δ_{RSSI} may change the confidence values in the adjusted table and possibly the data rate. However, a change in Δ_{RSSI} will not necessarily result in a change in data rate.

The retry processor **516** may start at state 0. If the retry counter returns a retry count of zero, i.e., the packet is transmitted successfully without retry, the state machine may move to from state 0 to state -1. If the next packet is not successfully sent (i.e., $R>0$), the state machine may return to state 0. Alternatively, if the next packet is successfully sent without retry, the machine may move from state -1 to state -2. Successive successful transmissions without retries may move the state machine to a maximum success state **702**. If the state machine reaches this state, it is assumed that the table is too pessimistic and must be adjusted. In this case, Δ_{RSSI} may be adjusted to a value $\Delta_{RSSI}-\Delta_1$, where Δ_1 is a pre-selected adjustment value.

From state 0, if the retry counter returns a value greater than zero (indicating a packet was resent), the state machine may move from state 0 to state 1. If packet is successfully sent in the next retry, the state machine may return to state 0. Alternatively, if the packet is retried again, the state machine may move to state 2. The state machine may move to progressively higher states as the same packet, or the next packet, is repeatedly retried. This may continue up until a maximum failure state **704**. If the state machine reaches this state, it is assumed that the table is too optimistic and must be adjusted. In this case, Δ_{RSSI} may be adjusted to a value of $\Delta_{RSSI}+\Delta_2$, where Δ_2 is a pre-selected adjustment value.

The state machine may be modified from that shown in FIG. 7 in alternative embodiments. For example, from state 0,

6

if the retry counter returns a value N greater than zero (indicating a packet was resent), the state machine may move from state 0 to state N. If packet is successfully sent in the next retry, the state machine may go to state N-1. Alternatively, if the packet is retried again, the state machine may move to state N+1.

The values of Δ_1 and Δ_2 may be programmable in software. For example, in an embodiment, the following values were used: $\Delta_1=0.5$ dB, MAX SUCCESS=3; and $\Delta_2=1$ dB, MAX FAILURE=2.

Other measures of packet loss may be used in the state machine, such as bit-error, packet error, symbol error, CRC failures, etc.

In normal operation, the adjusted RSSI (or other signal quality measure) table may be matched to the environment. Sporadic failures may occur due to additive white Gaussian noise (AWGN), phase noise, scrambler effects, collision, or interference, but typically, the conditions will require the Δ_{RSSI} be adjusted only rarely or in both directions, thereby canceling the adjustments out. Repeated successes or failures may indicate that the RSSI table is not matched to the environment and may lead to Δ_{RSSI} updates. However, as stated above, a change in Δ_{RSSI} will not necessarily result in a change in data rate. Multiple Δ_{RSSI} updates are typically required to actually change rates. The updates may merely change the confidence factors.

FIGS. 8A and 8B show a flowchart describing an exemplary rate adaptation algorithm. The rate adaptation module receives a measured RSSI value from the receive section (block **802**) and determines $RSSI_{avg}$ using the filter **506** (block **804**). The rate adaptation module receives the retry counter value from the transmit section (block **806**) and determines a Δ_{RSSI} value (block **808**). The rate adaptation generates confidence values corresponding to different data rates using the $RSSI_{avg}$ value, Δ_{RSSI} value, and $RSSI_{TH}$ values in a nominal RSSI table (block **810**). The rate adaptation module may then select a data rate having the lowest positive confidence value (block **812**). The rate adaptation module may continue to monitor the retry counter value (block **814**). If the retry counter value causes the state machine (FIG. 7) to reach a maximum failure value (block **816**) or a maximum success value (block **818**), the rate adaptation module may update the Δ_{RSSI} value (block **820**) and the confidence values (block **822**).

FIGS. 9A and 9B are plots showing the results of two experiments conducted to test the rate adaptation algorithm. Both tests used a transceiver in a cubicle, with a client receiver 45 feet away and transmissions on channel 11. The first test simulates an office environment, with a mean Δ_{RSSI} of 3.15 dB. In this scenario, the rate adaptation module selected a data rate of 36 Mbps over 50% of the time. In the second experiment, a bias of 6 dB was applied to simulate a different environment, with a resulting mean Δ_{RSSI} of 9.27 dB. In this scenario, the rate adaptation module also selected a data rate of 36 Mbps over 50% of the time.

In an embodiment, the rate adaptation module may include a switch **520** (FIG. 5), which may select the output of the retry processor **510** over the output of the rate selector **516** if the data rate falls below a minimum data rate, e.g., 6 Mbps, below which the RSSI measurement may not be accurate.

In an embodiment, the rate adaptation module may include a power adaptor **522**. FIG. 10 is a graph showing the response of the power adaptor for different data rates. The power may be increased for lower data rates to account for presumed low link quality. The power may be reduced for high data rates for presumed good link quality. The response may include a hysteresis loop **1002** to prevent too frequent changes in

power, e.g., due to the user walking away from an access point. The power adaptor 522 may be used to improve range for low data rates and reduce power amplifier non-linearity at high data rates.

A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, blocks in the flowchart may be skipped or performed out of order and still produce desirable results. Accordingly, other embodiments are within the scope of the following claims.

The invention claimed is:

1. A method comprising:

generating confidence measures for a plurality of data rates based at least on a first indicator and a second indicator, wherein the first indicator corresponds to packet loss associated with packets transmitted by a device at a first data rate that is selected from the plurality of data rates, and the second indicator corresponds to one or more signal quality values associated with one or more packets received by the device;

selecting, from the plurality of data rates, a second data rate based at least on the confidence measures; and transmitting one or more additional packets at the second data rate.

2. The method of claim 1, wherein selecting the second data rate comprises selecting as the second data rate a data rate associated with a positive confidence measure of the confidence measures.

3. The method of claim 1, wherein generating the confidence measures comprises determining an average value associated with the second indicator.

4. The method of claim 3, comprising:

determining a calibration value associated with the first indicator, the calibration value determined to refine the average value; and

determining a confidence measure based on the average value and the calibration value.

5. The method of claim 1, comprising:

identifying a nominal signal quality parameter from a nominal table containing a plurality of signal quality parameters including the second indicator, each of the plurality of signal quality parameters having a different value and corresponding to a different data rate supported by a channel through which packets are transmitted or received,

wherein selecting the second data rate is performed based on the first indicator, the second indicator, and the nominal signal quality parameter.

6. The method of claim 1, comprising:

monitoring a number of unsuccessful packets transmitted at the second data rate; and

adjusting, based on the monitored number, the second data rate to a third data rate at which packets are to be transmitted, the third data rate being lower than the second data rate.

7. A system comprising:

a transceiver configured to transmit packets and receive packets; and

circuitry communicatively coupled with the transceiver, the circuitry configured to:

generate confidence measures for a plurality of data rates based at least on a first indicator and a second indicator, wherein the first indicator corresponds to packet loss associated with packets transmitted by the transceiver at a first data rate that is selected from the plurality of data rates, and the second indicator cor-

responds to one or more signal quality values associated with one or more packets received by the transceiver,

select, from the plurality of data rates, a second data rate based at least on the confidence measures, and cause the transceiver to transmit one or more additional packets at the second data rate.

8. The system of claim 7, wherein the circuitry is configured to select as the second data rate a data rate associated with a positive confidence measure of the confidence measures.

9. The system of claim 7, wherein the circuitry is configured to determine an average value associated with the second indicator.

10. The system of claim 9, wherein the circuitry is configured to determine a calibration value associated with the first indicator, the calibration value determined to refine the average value, and determine a confidence measure based on the average value and the calibration value.

11. The system of claim 7, wherein the circuitry is configured to identify a nominal signal quality parameter from a nominal table containing a plurality of signal quality parameters including the second indicator, each of the plurality of signal quality parameters having a different value and corresponding to a different data rate supported by a channel through which packets are transmitted or received,

wherein the second data rate is selected based at least on the first indicator, the second indicator, and the nominal signal quality parameter.

12. The system of claim 7, wherein the circuitry is configured to:

monitor a number of unsuccessful packets transmitted at the second data rate; and

adjust, based on the monitored number, the second data rate to a third data rate at which packets are to be transmitted, the third data rate being lower than the second data rate.

13. The system of claim 7, wherein the first indicator includes a retry counter parameter, wherein the circuitry is configured to increment the retry counter parameter in response to a packet retransmission due to an unsuccessful transmission, and wherein the second data rate is selected based at least on the retry counter parameter.

14. The system of claim 7, wherein the circuitry is configured to:

adjust the first indicator by a first predetermined value when a number of successive successful transmissions of the one or more additional packets at the second data rate exceeds a first predetermined threshold, and adjust the first indicator by a second predetermined value when a number of successive unsuccessful transmissions of the one or more additional packets at the second data rate exceeds a second predetermined threshold.

15. A device comprising:

circuitry configured to generate confidence measures for a plurality of data rates based at least on a first indicator and a second indicator, wherein the first indicator corresponds to packet loss associated with transmitted packets that are transmitted at a first data rate that is selected from the plurality of data rates, and the second indicator corresponds to one or more signal quality values associated with one or more received packets; and

a rate selector configured to select, from the plurality of data rates, a second data rate based at least on the confidence measures, and cause a transmission of one or more additional packets at the second data rate.

9

16. The device of claim 15, wherein the rate selector is configured to select as the second data rate a data rate associated with a positive confidence measure of the confidence measures.

17. The device of claim 15, wherein the circuitry is configured to determine an average value associated with the second indicator.

18. The device of claim 17, wherein the circuitry is configured to determine a calibration value associated with the first indicator, the calibration value determined to refine the average value, and determine a confidence measure based on the average value and the calibration value.

19. The device of claim 15, wherein the circuitry is configured to identify a nominal signal quality parameter from a nominal table containing a plurality of signal quality parameters including the second indicator, each of the plurality of signal quality parameters having a different value and corresponding to a different data rate supported by a channel through which packets are transmitted or received,

wherein the second data rate is selected based at least on the first indicator, the second indicator, and the nominal signal quality parameter.

20. The device of claim 15, wherein the circuitry is configured to:

10

monitor a number of unsuccessful packets transmitted at the second data rate; and

adjust, based on the monitored number, the second data rate to a third data rate at which packets are to be transmitted, the third data rate being lower than the second data rate.

21. The device of claim 15, wherein the first indicator is based on a retry counter parameter, wherein the circuitry comprises a retry processor configured to increment the retry counter parameter in response to a packet retransmission due to an unsuccessful transmission, and wherein the second data rate is selected based at least on the retry counter parameter.

22. The device of claim 15, wherein the circuitry is configured to:

adjust the first indicator by a first predetermined value when a number of successive successful transmissions of the one or more additional packets at the second data rate exceeds a first predetermined threshold, and

adjust the first indicator by a second predetermined value when a number of successive unsuccessful transmissions of the one or more additional packets at the second data rate exceeds a second predetermined threshold.

* * * * *