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(54) Title of the Invention: **Wireless communication method and apparatus**
Abstract Title: **A method of managing a transmission mode of a wireless device**

(57) The method is performed at the wireless device in communication with at least one further wireless device of a plurality of wireless devices and comprises receiving a signal transmitted from the further wireless device, determining a quality parameter associated with the received signal, and comparing the determined quality parameter with an existing quality parameter, and managing the transmission mode of the wireless device based on the comparison. In an alternative embodiment, the present and existing quality values are used to predict a value.

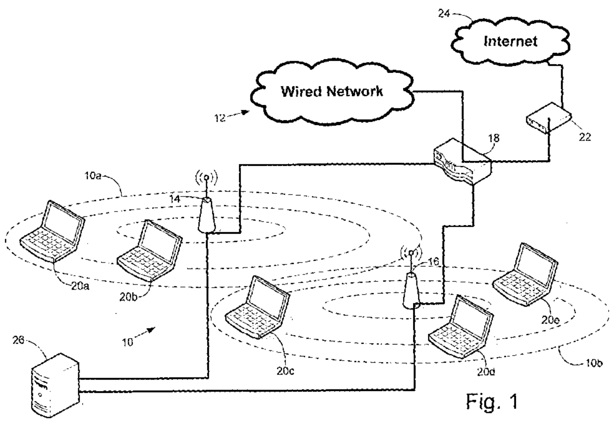

Fig. 1

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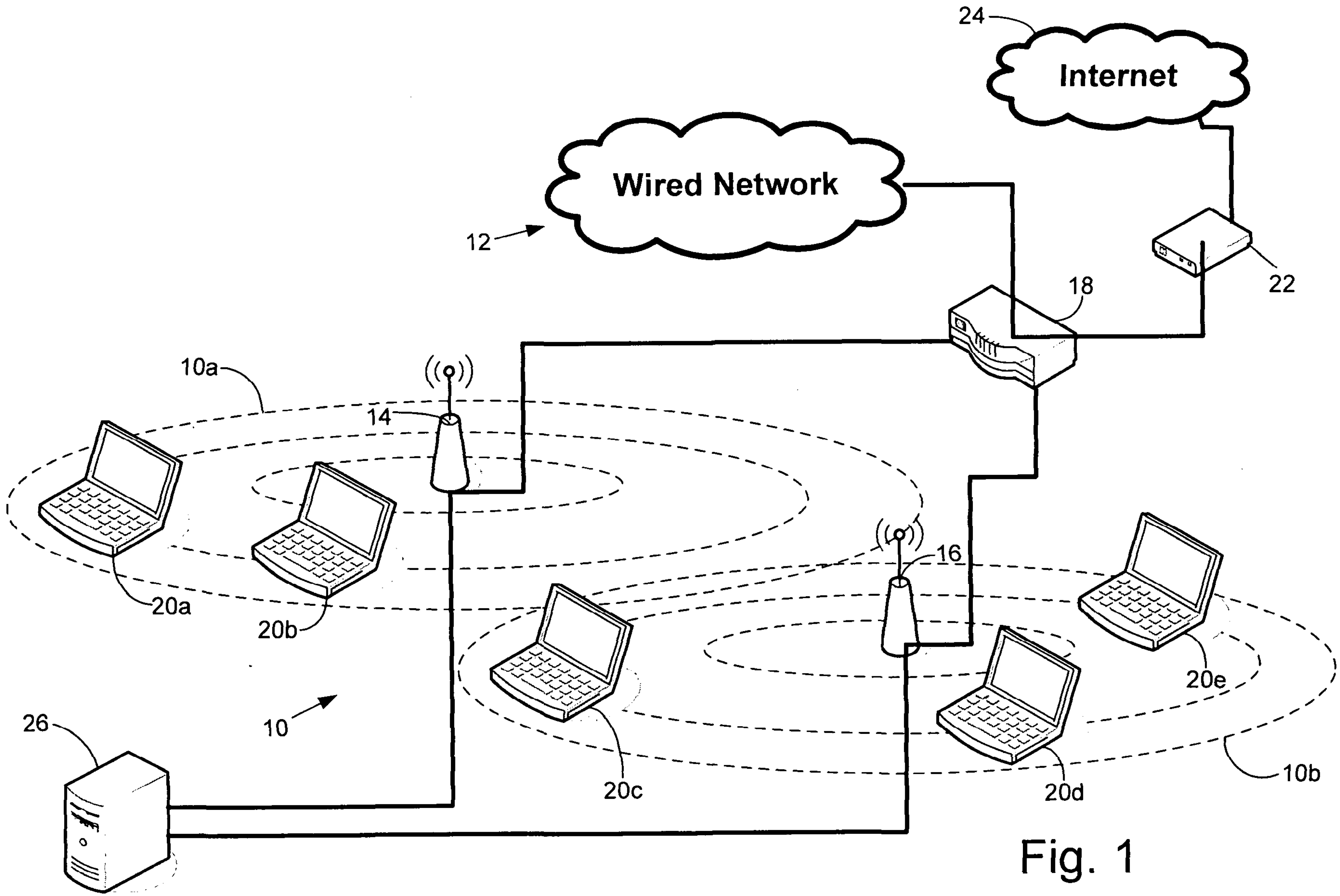
24
Internet
Wired Network
12
22
18
10a
14
16
20a
20b
20c
20d
20e
10b
10
26

Fig. 1

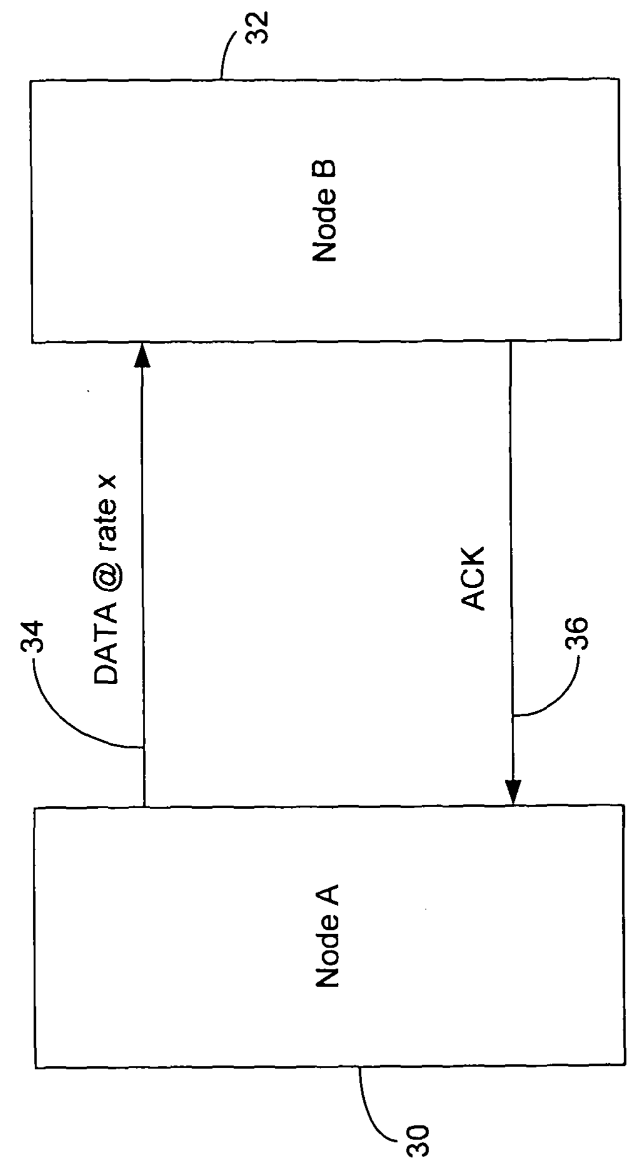

Fig. 2

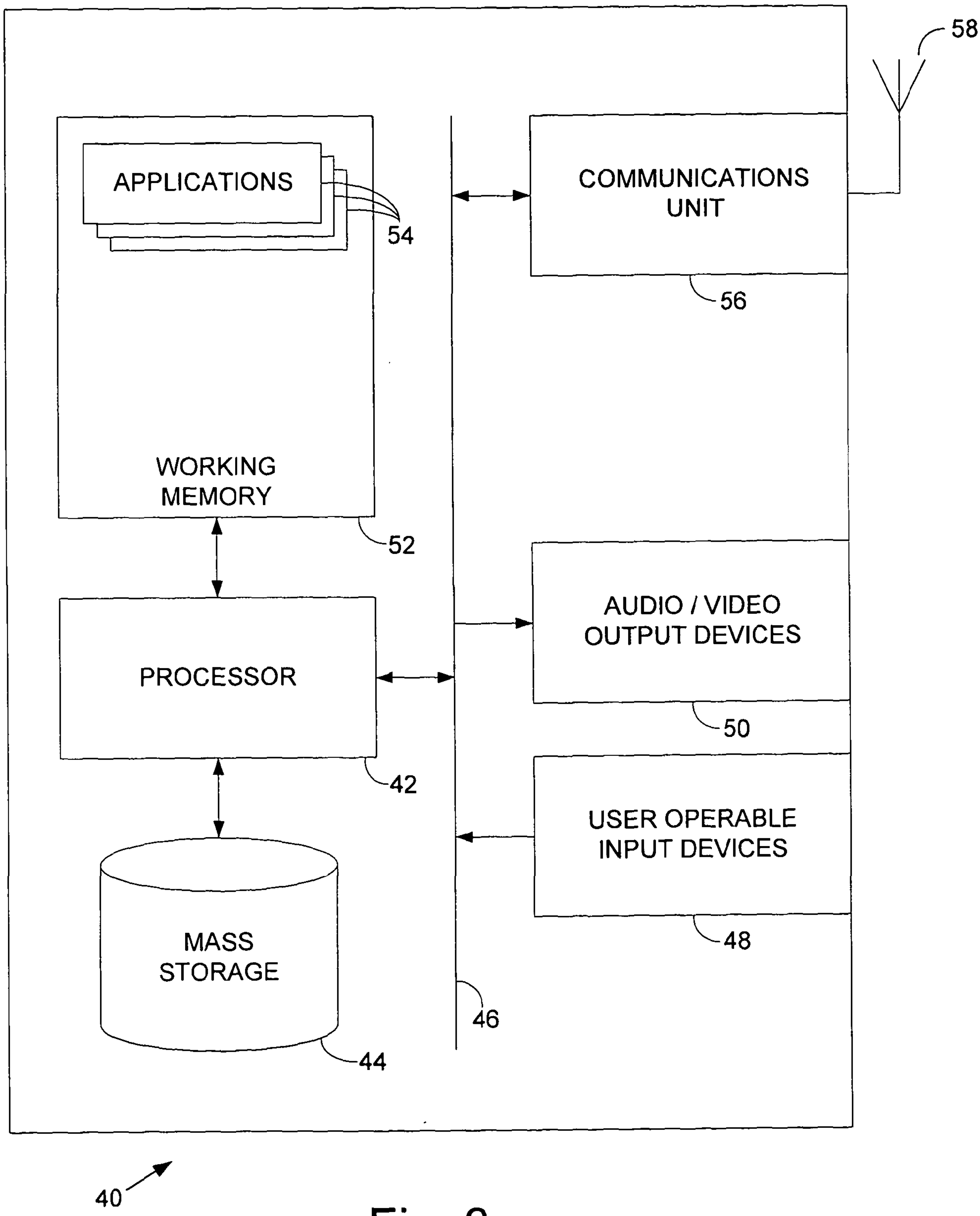
58
APPLICATIONS
54
COMMUNICATIONS UNIT
56
WORKING MEMORY
52
AUDIO / VIDEO OUTPUT DEVICES
PROCESSOR
50
42
USER OPERABLE INPUT DEVICES
48
MASS STORAGE
46
44
40

Fig. 3

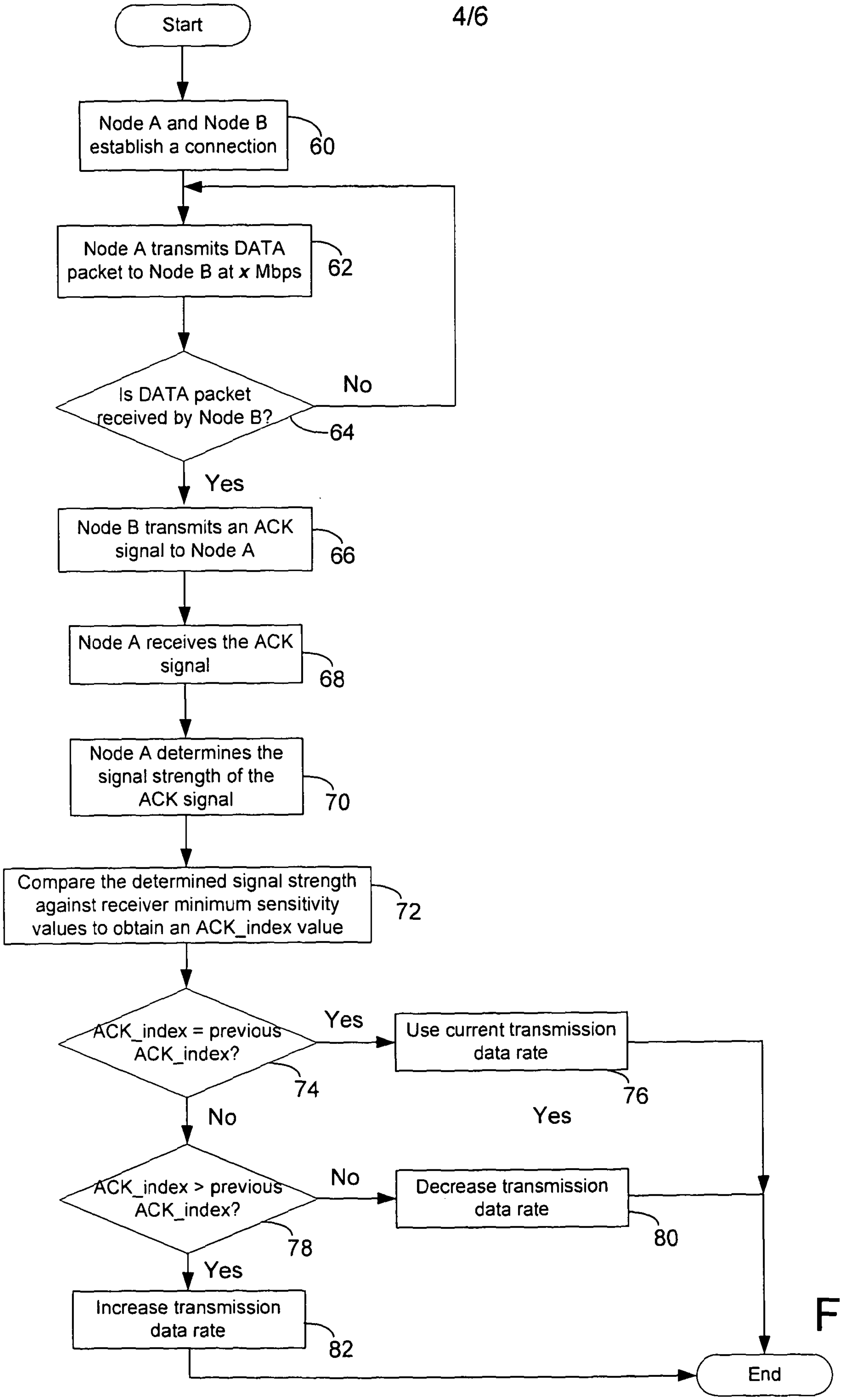
Start
Node A and Node B establish a connection
60
Node A transmits DATA packet to Node B at x Mbps
62
Is DATA packet received by Node B?
No
64
Yes
Node B transmits an ACK signal to Node A
66
Node A receives the ACK signal
68
Node A determines the signal strength of the ACK signal
70
Compare the determined signal strength against receiver minimum sensitivity values to obtain an ACK_index value
72
ACK_index = previous ACK_index?
Yes
Use current transmission data rate
74
76
No
Yes
ACK_index > previous ACK_index?
No
Decrease transmission data rate
78
80
Yes
Increase transmission data rate
82
End

Fig. 4

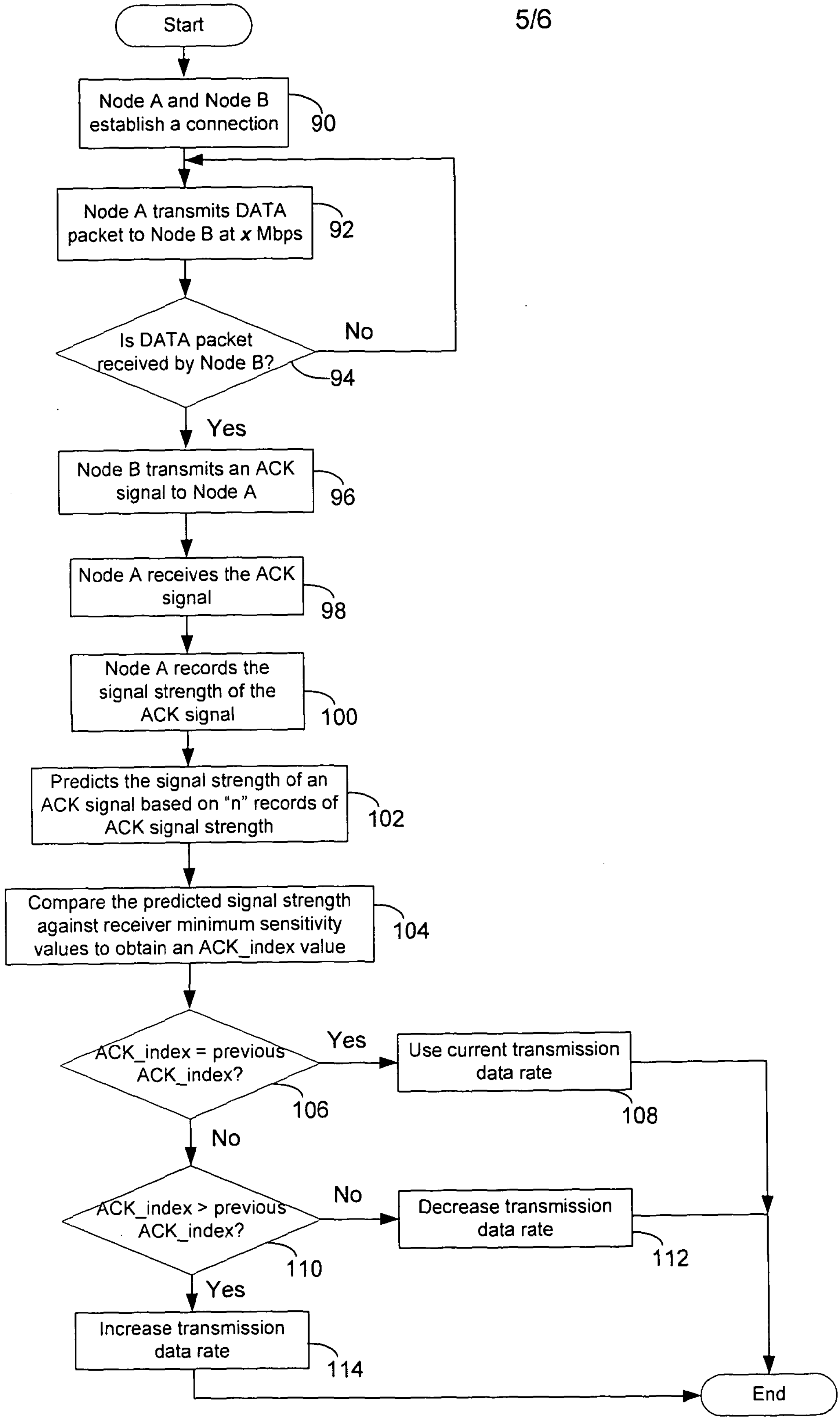
Start
Node A and Node B establish a connection
90
Node A transmits DATA packet to Node B at x Mbps
92
Is DATA packet received by Node B?
No
94
Yes
Node B transmits an ACK signal to Node A
96
Node A receives the ACK signal
98
Node A records the signal strength of the ACK signal
100
Predicts the signal strength of an ACK signal based on "n" records of ACK signal strength
102
Compare the predicted signal strength against receiver minimum sensitivity values to obtain an ACK_index value
104
ACK_index = previous ACK_index?
Yes
Use current transmission data rate
106
108
No
ACK_index > previous ACK_index?
No
Decrease transmission data rate
110
112
Yes
Increase transmission data rate
114
End

Fig. 5

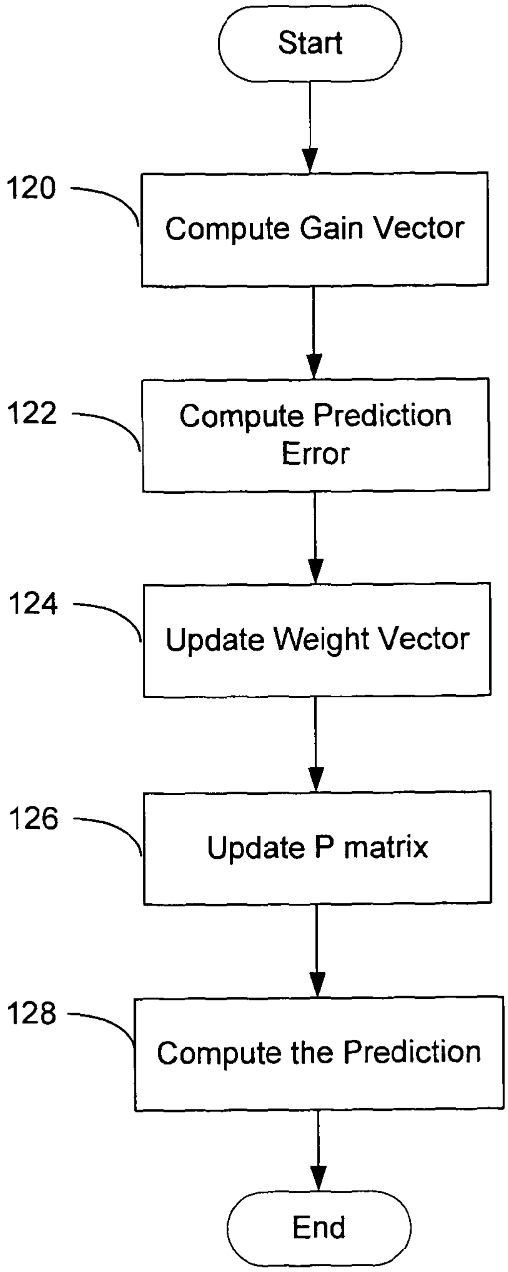
Start
120
Compute Gain Vector
122
Compute Prediction Error
124
Update Weight Vector
126
Update P matrix
128
Compute the Prediction
End

Fig. 6

WIRELESS COMMUNICATION METHOD AND APPARATUS

Field of the Invention

The present invention relates to wireless communication. It is particularly, but not exclusively, concerned with a method and apparatus for managing transmission mode of a communication device in a wireless network.

Background of the Invention

Wireless communication between electronic devices is becoming increasingly in demand, particularly due to the growth of multimedia communication services, such as video streaming, video conferencing, packet data transfer and so on. Accordingly, wireless networks are widely deployed to support these services. Generally, these networks are capable of supporting communications for multiple users by sharing the available network resources. One example of such network is a wireless local area network (WLAN).

A typical arrangement of a WLAN is illustrated in figure 1. Such a WLAN 10 includes one or more access points (APs) 14, 16 that serve one or more wireless devices (WDs) 20. An AP (14 or 16) is typically a stand-alone device that is connected to an Ethernet switch 18 in a wired network 12, and it relays data between the wireless devices 20 and devices in the wired network 12. Each of the APs manages wireless traffic in the area of coverage (10a, 10b), and typically allows the devices 20 to communicate to and from a wired network 12. The Ethernet switch 18 can be connected to a modem 22 to allow the devices 20 to connect to the Internet 24.

As shown in Figure 1, two or more APs 14, 16 may link together to form a larger network to allow the WDs 20 to roam from one WLAN 10a to another WLAN 10b. The WDs 20 described herein may be mobile terminals such as personal digital assistants (PDAs), notebook computers, or fixed terminals such as desktops and workstations that are equipped with a wireless network interface.

Many WLAN standards allow for a number of different modes of operation to be available for use, depending on operating conditions. For instance, in conditions wherein little channel interference is encountered, a high speed, low robustness operating mode can be employed. In contrast, in conditions more susceptible to channel interference, a lower speed, more robust approach may need to be employed.

For instance, in a communications system compliant with the 802.11 standard, a communication device is provided with multi-rate transmission capability to manage transmission of data in varying channel conditions using a range of data transmission rates. The term "communication device" is used herein to refer to an AP (14 or 16) or a mobile device 20. The term "transmission rate" is used herein to connote the amount of information that can be successfully transmitted by a communication device in a given time period.

Generally, it is desirable to transmit data over a communicaton channel using the highest transmission rate available such that data can be transmitted over a short period of time, thereby achieving maximum throughput. However, if a communication device uses a relatively high transmission rate to transmit data in a noisy channel, the likelihood of a transmission failure is also high. Conversely, if the same transmission rate is employed under relatively good channel condition, the likelihood of a transmission failure is therefore lower.

In contrast, if the communication device uses a lower transmission rate, the likelihood that the data transmission will fail is lower even if the data is transmitted under poor channel condition. It is noted that a data transmission using a lower transmission rate may, depending on channel conditions, be more robust than a data transmission using a higher transmission rate. However, this can also result in the data being transmitted more slowly over a longer period of time. Consequently, this robustness comes at a cost of reduced throughput and increased medium occupation.

Therefore, in order to achieve maximum throughput, it is desirable to use a high data transmission rate that is sufficiently robust for data to be transmitted successfully through the channel. Most approaches to transmission rate adaptation are based on either the Received Signal Strength Indicator (RSSI) or historic information about the channel. However, the condition of a wireless channel is not static and so a more realistic or recent knowledge of the channel condition can aid in improving the achievable throughput. In order to achieve this, the communication device is required to infer the channel condition and to select an appropriate transmission rate for data transmission.

There are two methods of inferring the channel namely, the closed loop method, and the open loop method.

The closed loop method is generally preferred over the open loop method because the "true" channel condition as experienced at a receiver is determined by the receiver and is subsequently provided to the transmitter. However, a disadvantage with this method is that it introduces overheads in terms of communicating information from the receiver to the transmitter. Furthermore, system interoperability is essential, for example the transmitter and receiver are required to be compatible with each other in order for the transmitter to receive the channel information from the receiver.

Thus, the open loop method has also been widely considered as an alternative to determine the channel condition. Generally, the open loop method is performed using either statistics-based solutions or signal strength based solutions.

Statistics-based solutions are generally well known for their good performance under stable channel conditions. However, statistics-based solutions do not respond to rapid variations in channel conditions. In contrast, signal strength based solutions are known for determining the variations in the channel accurately. The signal strength based solutions use a rate-throughput mapping or dynamically adjustable rate-signal strength thresholds to select the transmission rate to be used.

Specific algorithms with which present day wireless cards switch modes are implementation dependent. It is noted that one method of sending information back from the receiver to the transmitter is via the presence or absence of ACKs (acknowledgements).

The presence of an ACK at the transmitter means that the receiver received a transmitted DATA packet successfully. The absence of an ACK could mean one of the following:

1. The DATA frame was never received (e.g. deep fade)
2. The DATA frame was destructively interfered with.
3. The ACK frame was never received (e.g. deep fade)
4. The ACK frame was destructively interfered with.

There may also be other causes. Nonetheless, whatever the cause for packet failure, the transmitter responds by transmitting the DATA packet again but at a lower rate than in the previous transmission. The manner in which rate is adapted, such as in terms of the extent to which rate is lowered, or how rapidly rate is lowered, is implementation dependent.

An example of a data-control flow diagram representing transmissions between an AP and a WD (or herein referred to as node A and node B respectively) is illustrated in figure 2. In this example, node A 30 transmits a DATA packet 34 to node B 32 at a data rate of x Mbps. Upon successful receipt of this packet, node B 32 responds with an ACK signal 36.

By way of background, a conventional method for data transmission between two nodes A and B will now be described. In this example, the messages to be transmitted are 1000 bytes long using the 802.11a transmission rates. It is understood that the transmission time required to transmit a DATA packet (for example, a packet of 1000 bytes) is dependent on the transmission rate, which can be represented by equation 1:

$$T \text{ x Time} = T_{preamble} + T_{signal} + T_{sym} \text{ x Ceiling } (16+8\text{x length} + 6)/Ndbps \qquad (1)$$

Where $T_{preamble} = 8\mu s$

$T_{signal} = 4\mu s$

$T_{sym} = 4\mu s$

The list of transmission time required for transmitting 1000 bytes long packets according to 802.11a standard is given in Table 1.

Table 1

802.11a transmission rates	Transmit time for 1000 byte packets	Ndbps
54 Mbps	172 us	216
48 Mbps	188 us	192
36 Mbps	244 us	144
24 Mbps	356 us	96
18 Mbps	468 us	72
12 Mbps	692 us	48
9 Mbps	912 us	36
6 Mbps	1340 us	24

US 7,336,634 discloses a system and method for determining a transmission rate of a mobile station in a wireless local area network (WLAN). In this document, a transmission-rate reference table based on the received signal-strength measurement is generated and updated. Accordingly, the updated table is used to adjust the transmission rate of each station. Essentially, the mobile station determines an averaged Received Signal Strength (RSS) value of a plurality of incoming frames. The averaged RSS value is then compared with the reference table having a minimum RSS value corresponding to one of a plurality of transmission rate in the reference table. Based on the result of the comparison, a new transmission rate for a subsequent frame transmission is selected. In addition, it is determined whether the transmitted frame is a retransmission of an earlier frame. If the same frame has been retransmitted more than a predetermined number of times, the next lower transmission rate will be selected for the next transmission. It is noted that retransmission could be cause by either poor channel conditions or high contention of the channel, and that there is no mechanism to discriminate between two causes. As a result the transmission rate could be reduced unnecessarily, such as the loss of the data transmission is due to the high contention of the channel.

US 7,369,510 discloses an adaptive rate technique for determining transmission rate of a WLAN transmitter using a lookup Received Signal Strength Indicator (RSSI) table of multiple acknowledgment (ACK) packets. The lookup RSSI is determined using a median value of RSSIs based on number of retransmissions. Subsequently one or more valid data rates from a group of supported data rates are determined such that the data rate is selected based on an RSSI threshold less than or equal to the lookup RSSI. It is noted that such approach provides reasonable performance under stable channel conditions. However, one of the drawbacks of this approach is that it is generally slow to adapt under rapidly changing channel conditions which is commonly found in a WLAN environment.

Summary of the Invention

In a first aspect of the present invention there is provided a method of managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said method being performed at said wireless device in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the method comprising receiving a signal transmitted from said further wireless device, processing the received signal, said processing including determining a quality parameter associated with said received signal, and comparing the determined quality parameter with an existing quality parameter, and managing said transmission mode of said wireless device based on said comparison.

Use of signal strength of a received signal to manage the transmission mode of a wireless device provides an advantage that no further information is required to be received in order to manage the transmission mode of the wireless device, thereby preserving the spectrum efficiency of the channel. In addition, the comparison of the quality parameter value of the received signal with an existing quality parameter provides an accurate guide for the wireless device to decide a subsequent transmission mode to be used. It is noted that this provides an advantage of ensuring a sufficiently robust transmission mode to be used while achieving maximum throughput.

The existing quality parameter may be a quality parameter of a preceding received signal. This can allow the most recent quality parameter to be used such that the transmission mode can be managed more accurately.

The step of determining a quality parameter of the received signal includes determining a signal strength value of the received signal, and comparing said determined signal strength value with a set of predetermined values associated with the further wireless device, each of said predetermined values having a corresponding quality parameter value associated thereto.

The received signal may be an acknowledgement frame

The acknowledgment frame may be in accordance with the IEEE 802.11 WLAN standard.

The transmission mode may include a transmission rate of said wireless device.

The step of managing said transmission mode of said wireless device may include adjusting the transmission rate of said wireless device according to the comparison. Therefore, this can allow the transmission rate of the wireless device to be adjusted to a lower rate if the signal strength of the acknowledgement frame is relatively low, indicating a poor quality channel.

In a second aspect of the present invention there is provided a method of managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said method being performed at said wireless device in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the method comprising receiving a signal transmitted from said further wireless device, processing said received signal, said processing including determining a signal strength value of said received signal, storing said determined signal strength value in a data storage means comprising at least one further determined signal strength value determined over a preceding time interval, predicting a quality parameter using said determined signal strength value and said at least one further determined signal strength value, and comparing said predicted quality parameter with an existing quality parameter, and managing said transmission mode of said wireless device based on said comparison.

Predicting a quality parameter based on the determined signal strength value and the preceding quality can allow a wireless device to manage the transmission mode proactively, thereby allowing the wireless device to adapt quickly to changes in the communication channel between the wireless device and the further wireless device.

The existing quality parameter may be a preceding predicted quality parameter. This can allow the most recent predicted quality parameter to used such that the transmission mode can be managed more accurately.

The step of predicting said quality parameter of the received signal includes predicting a signal strength value based on said determined signal strength value and said at least one further determined signal strength value, and comparing said predicted signal strength value with a set of predetermined values associated with the further wireless device, each of said predetermined values having a corresponding quality parameter value associated thereto.

The received signal may be an acknowledgement frame.

The acknowledgment frame may be in accordance with the IEEE 802.11 WLAN standard.

The transmission mode may include a transmission rate of said wireless device.

The step of managing said transmission mode of said wireless device may include adjusting the transmission rate of said wireless device according to the comparison.

The step of predicting the signal strength value may be performed by means of an adaptive filtering algorithm.

In one embodiment of the present invention, the adaptive filtering algorithm may be a Recursive Least Squares (RLS) algorithm. One of the benefits of using a RLS algorithm is that there is no need to invert large matrices, thereby saving computing power. Another advantage of using a RLS algorithm is that its rate of convergence is, in general, faster than other adaptive filtering algorithm, for example the Least Means Squares (LMS) algorithm. Therefore, the RLS algorithm can adapt quickly to changes in the underlying channel condition and predicts the quality parameter accurately in a short period of time.

The wireless devices may include at least one wireless access point, and at least one wireless terminal.

Of course, it will be appreciated by the reader that it is not mandatory for a network incorporating the invention to include an access point. The invention can also be embodied by two wireless terminals operating in ad-hoc mode and communicating directly with each other (as opposed to infrastructure modes where such devices would have to communicate through an access point)

In a third aspect of the present invention there is provided an apparatus for managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said wireless device being in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the apparatus comprising means for receiving a signal transmitted from said further wireless device, a signal processing means for processing the received signal, said signal processing means being operable to determine a quality parameter associated with said received signal, and to compare the determined quality parameter with an existing quality parameter, and means for managing said transmission mode of said wireless device based on said comparison.

In a fourth aspect of the present invention there is provided an apparatus for managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said wireless device being in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the apparatus comprising means for receiving a signal transmitted from said further wireless device, a signal processing means for processing said received signal, said signal processing means being operable to determine a signal strength value of said received signal, data storage means arranged to store said determined signal strength, said data storage means further storing at least one further determined signal strength value determined over a preceding time interval, said signal processing means further operable to predict a quality parameter using said determined signal strength value and said at least one further determined signal strength value, and to compare said predicted quality parameter with an existing quality parameter, and means for managing said transmission mode of said wireless device based on said comparison.

Aspects of the invention may comprise a computer program product comprising computer executable instructions operable to cause a computer to become configured to perform a method in accordance with any of the above identified aspects of the invention. The computer program product can be in the form of an optical disc or other computer readable storage medium, a mass storage device such as a flash memory, or a read only memory device such as ROM. The method may be embodied in an application specific device such as an ASIC, or in a suitably configured device such as a DSP or an FPGA. A computer program product could, alternatively, be in the form of a signal, such as a wireless signal or a physical network signal.

Brief description of the drawings

Embodiments of the present invention will now be described with reference to the accompanying drawings, wherein:

Figure 1 illustrates an exemplary prior art of WLAN arrangement;

Figure 2 is a data control flow diagram illustrating data transmissions between two communication devices;

Figure 3 is a schematic diagram of an example communications device;

Figure 4 is a flow diagram illustrating a process of managing the transmission mode of a communication device in accordance with a first embodiment of the invention;

Figure 5 is a flow diagram illustrating a process of managing the transmission mode of a communication device in accordance with a second embodiment of the invention; and

Figure 6 illustrates the process of predicting signal strength in accordance with the second embodiment of the present invention.

Detailed Description

Specific embodiments of the present invention will be described in further detail on the basis of the attached diagrams. It will be appreciated that this is by way of example only, and should not be viewed as presenting any limitation on the scope of protection sought.

Figure 3 illustrates schematically a communication device 40 providing an example of background to the invention. In this example, the communication device can be an AP (14 or 16) or a WD 20 as illustrated in figure 1. The communication device 40 comprises a processor 42 operable to execute machine code instructions stored in a working memory 52 and/or retrievable from a mass storage device 44. By means of a general-purpose bus 46, user operable input devices 48 are in communication with the processor 42. The user operable input devices 48 comprise, in this example, a keyboard and a touchpad, but could include a mouse or other pointing device, a contact sensitive surface on a display unit of the device, a writing tablet, speech recognition means, haptic input means, or any other means by which a user input action can be interpreted and converted into data signals.

Audio/video output devices 50 are further connected to the general-purpose bus 46, for the output of information to a user. Audio/video output devices 50 include a visual display unit, and a speaker, but can also include any other device capable of presenting information to a user.

A communications unit 56 is connected to the general-purpose bus 46, and further connected to an antenna 58. By means of the communications unit 56 and the antenna 58, the communication device 40 is capable of establishing wireless communication with another communication device (for example, an AP). The communications unit 40 is operable to convert data passed thereto on the bus 46 to an RF signal carrier in accordance with a communications protocol previously established for use by a system in which the communication device 40 is appropriate for use.

In the communication device 40 of figure 3, the working memory 52 stores user applications 54 which, when executed by the processor 42, cause the establishment of a user interface to enable communication of data to and from a user. The applications 54 thus establish general purpose or specific computer implemented utilities and facilities that might habitually be used by a user.

The process of managing the transmission mode of a communication device according to a first embodiment of the invention will be described with reference to the flow chart of figure 4.

Referring to figure 4, the example commences in a situation whereby two communication devices, such as an AP and a WD (or in this example are referred to as node A and node B respectively), establish a communication link with each other in step 60. In step 62, a DATA packet is transmitted at x Mbps from node A to node B. Upon successful receipt of the DATA packet, an ACK signal is transmitted from node B to node A. Conversely, through the absence of an ACK signal being received at node A which indicates that the DATA packet is not received by node B, node A will then retransmit the DATA packet at the same data rate (that is x Mbps).

It should be noted that it is not mandatory that, subsequent to a failed transmission attempt, the retransmission should occur at x Mbps. It may also be carried out at the base rate or any other rate lower than x Mbps to ensure robustness. The invention is not restricted to using x Mbps and the use of any other data rate falls within the scope of the invention.

Once the ACK signal is received at node A (step 68), the signal strength of the ACK signal is determined in step 70. In step 72, the signal strength is then compared with a set of receiver minimum sensitivity values defined in a Receiver Minimum Input Sensitivity (RMIS) table. An example of a RMIS table for a communication device compliant with the 802.11 standard is defined in accordance with Table 2 below.

Table 2

Index	Data Rate (Mbps)	Min. Receiver Sensitivity (dBm)
0	6	-82
1	9	-81
2	12	-79
3	18	-77
4	24	-74
5	36	-70
6	48	-66
7	54	-65

Accordingly, the index (herein referred to as the ACK_index) of the highest data rate for which the specified receiver minimum input sensitivity value is less than the signal strength of the ACK signal is used. The ACK_index is used as an indication of the data transmission rate. For example if the signal strength of the ACK signal is –72 dBm, the highest data rate for which the receiver minimum input sensitivity is less than the ACK signal strength is 24 Mbps. Therefore, in this case the corresponding ACK_index is 4.

In step 74, the ACK_index is compared with the ACK_index of a previous data transmission rate. If the ACK_index is equal to the ACK_index of a previous data transmission rate, the current data transmission rate x Mbps will be used for the subsequent data transmission (step 76). However, if the ACK_index is higher than the ACK_index of the previous data transmission rate, node A will interpret the channel as good quality and will then increase the transmission rate accordingly (steps 78 and 82) to transmit a subsequent DATA packet. Otherwise, the data transmission rate for the subsequent transmission will be decreased (steps 78 and 80).

Therefore, two modes of changing the existing data transmission rate namely, the one-step mode and the multi-step mode. In the one-step mode, the data transmission rate will increase (or decrease) successively to a next higher (or lower) transmission rate. For example, if the current data transmission rate is 12 Mbps (ACK_index = 2), and new ACK_index = 6 (48 Mbps) indicating a good channel condition, the subsequent transmission rate will be 18 Mbps (ACK_index = 3). In the multi-step approach, the data transmission is changed according to the new ACK_index. For example, if the current data transmission rate is 12 Mbps (ACK_index = 2), and new ACK_index = 6 (48 Mbps) indicating a good channel condition, the subsequent transmission rate will be 48 Mbps (ACK_index = 6). It is noted that the multi-step mode approach will allow the transmitter to respond rapidly to varying channel conditions.

Eight levels of granularity for data transmissions are used in Table 2 as an example. However, it will be appreciated that other levels of granularity can also be applied. It will further be understood that the higher the number of levels of data transmission rate is used, the higher the granularity of the indication of the channel condition.

The process of managing the transmission mode of a communication device according to a second embodiment of the invention will be described with reference to the flow chart of figure 5.

Essentially, the managing process illustrated in figure 5 is similar to that described in figure 4 above, except that the managing process of figure 5 predicts the signal strength by using the measured signal strength of "n" recent measured signal strength of the ACK_signal. Similarly, the predicted signal strength is then compared with a set of receiver minimum sensitivity values of Table 2 to obtain the corresponding ACK_index.

Referring to figure 5, the example commences in a situation whereby two communication devices, such as an AP and a WD (or in this example are referred to as node A and node B respectively), establish a communication link with each other in step 90. In step 92, a DATA packet is transmitted at *x* Mbps from node A to node B. Upon successful receipt of the DATA packet, an ACK signal is transmitted from node B to node A. Conversely, through the absence of an ACK signal being received at node A which indicates that the DATA packet is not received by node B, node A will then retransmit the DATA packet at the same data rate (that is *x* Mbps). It will be noted that, again, this is an example specific embodiment and the invention is not restricted tot his approach.

Once the ACK signal is received at node A (step 98), the signal strength of the ACK signal is recorded in step 100. In step 102, the signal strength is predicted using a "n" number of recently recorded ACK signal strength.

In step 104, the predicted signal strength is then compared with a set of receiver minimum sensitivity values as defined in the RMIS table (table 2). Accordingly, the index (herein referred to as the ACK_index) of the highest data rate for which the specified receiver minimum input sensitivity value is less than the signal strength of the ACK signal is used. The ACK_index is used as an indication of the data transmission rate. For example if the signal strength of the ACK signal is –72 dBm, the highest data rate for which the receiver minimum input sensitivity is less than the ACK signal strength is 24 Mbps. Therefore, in this case the corresponding ACK_index is 4.

In step 106, the ACK_index is compared with the ACK_index of a previous data transmission rate. If the ACK_index is equal to the ACK_index of a previous data transmission rate, the current data transmission rate *x* Mbps will be used for subsequent data transmission (step 108). However, if the ACK_index is higher than the ACK_index of the previous data transmission rate, node A will interpret the channel as good quality and will increase the transmission rate accordingly (steps 110 and 114) to transmit a subsequent data packet. Otherwise, the data transmission rate for the subsequent transmission will be decreased (steps 110 and 112).

The characteristic of using predicted signal strength is that the correlation between successive channel quality measurements (in this example, the signal strength) can be exploited to estimate the channel quality in the future, thereby providing a proactive decision. It is noted that the effectiveness of such a decision is dependent on the quality of the prediction. It is noted that the prediction step can be implemented by means of an adaptive filter algorithm. An example of such an algorithm is an iterative Recursive Least Squares (RLS) algorithm which provides an advantage of fast convergence property compared to other adaptive algorithm. Therefore, the RLS algorithm can adapt quickly to changes in the underlying channel condition and predicts the channel condition accurately in a short period of time. It will be appreciated that the signal strength can also be predicted using other algorithm such as the Least Mean Squares (LMS) algorithm, and it is not limited to only RLS algorithm.

In this example, an iterative Recursive Least Squares (RLS) algorithm is executed to predict signal strength over the next interval (step 56). RLS algorithm has an advantage of fast convergence property compared to other adaptive algorithm. The execution of an iteration of the RLS algorithm will be described with reference to figure 6, and the steps below.

Step 120 – Compute gain vector:

$$\mathbf{K}(\mathbf{n}) = \frac{\lambda^{-1}\mathbf{P}(\mathbf{n}-1)\mathbf{u}(\mathbf{n})}{1+\lambda^{-1}\mathbf{u}^{T}(\mathbf{n})\mathbf{P}(\mathbf{n}-1)\mathbf{u}(\mathbf{n})}$$

Step 122 – Compute prediction error:

$$\mathbf{e}(\mathbf{n}) = \mathbf{u}(\mathbf{n}) - \mathbf{uhat}$$

Step 124 – Update weight vector:

$$\mathbf{w}(\mathbf{n}) = \mathbf{w}(\mathbf{n}-1) + \mathbf{K}(\mathbf{n}) * \mathbf{e}(\mathbf{n})$$

Step 126 – Update P matrix:

$$\mathbf{P}(\mathbf{n}) = \lambda^{-1}\mathbf{P}(\mathbf{n}-1) - \lambda^{-1}\mathbf{K}(\mathbf{n})\mathbf{u}^{T}(\mathbf{n})\mathbf{P}(\mathbf{n}-1)$$

Step 128 – Compute the prediction:

$$\mathbf{uhat} = \mathbf{u}^{T}(\mathbf{n})\mathbf{w}(\mathbf{n})$$

The notations used in the RLS algorithm are as follows:

n current step (current time instant)

N number of past samples (history) required to compute a prediction

u(n) "Nx1" input (vector) containing signal strength values of the "N" intervals of the recent past

w(n) "Nx1" weight (vector) containing weights associated with the recent past values of signal strength values. Initially, all values in the weight vector are set to 0. These values adapt online as time progresses

uhat Predicted value of signal strength over the next Sampling Period

e(n) Prediction error (scalar) at time "n"

λ Forgetting factor which governs the level of importance should be given to past observations

P(n-1) "NxN" matrix (inverse of the input autocorrelation matrix)

K(n) "Nx1" gain vector (updating step size)

The invention as described in the foregoing paragraph clearly illustrates the key advantages of the present invention such as:

1. the present invention can be easily implemented onto existing wireless communications systems or standards without any substantial modification;
2. the transmission rate of a wireless device can be determined without requiring any feedbacks or coordination with other wireless devices in the network; and
3. the present invention is able to respond quickly to rapidly changing channel conditions.

It will be understood that the invention has been described above purely by way of example, and modifications of detail can be made within the scope of the invention. Each feature disclosed in the description and (where appropriate) the claims and drawings may be provided independently or in any appropriate combination.

CLAIMS:

1. A method of managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said method being performed at said wireless device in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the method comprising receiving a signal transmitted from said further wireless device, processing the received signal, said processing including determining a quality parameter associated with said received signal, and comparing the determined quality parameter with an existing quality parameter, and managing said transmission mode of said wireless device based on said comparison.

2. A method according to claim 1 wherein the existing quality parameter includes a quality parameter of a preceding received signal.

3. A method according to claim 1 or claim 2 wherein the step of determining a quality parameter of the received signal includes determining a signal strength value of the received signal, and comparing said determined signal strength value with a set of predetermined values associated with the further wireless device, each of said predetermined values having a corresponding quality parameter value associated thereto.

4. A method according to any preceding claim wherein the received signal includes an acknowledgement frame.

5. A method according to claim 4 wherein the acknowledgment frame is in accordance with the IEEE 802.11 WLAN standard.

6. A method according to any one of the preceding claims wherein the transmission mode includes a transmission rate of said wireless device.

7. A method according to claim 6 wherein the step of managing said transmission mode of said wireless device includes adjusting the transmission rate of said wireless device according to the comparison.

8. A method of managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said method being performed at said wireless device in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the method comprising receiving a signal transmitted from said further wireless device, processing said received signal, said processing including determining a signal strength value of said received signal, storing said determined signal strength value in a data storage means comprising at least one further determined signal strength value determined over a preceding time interval, predicting a quality parameter using said determined signal strength value and said at least one further determined signal strength value, and comparing said predicted quality parameter with an existing quality parameter, and managing said transmission mode of said wireless device based on said comparison.

9. A method according to claim 8 wherein the existing quality parameter include a preceding predicted quality parameter.

10. A method according to claim 8 and claim 9 wherein the step of predicting said quality parameter of the received signal includes predicting a signal strength value based on said determined signal strength value and said at least one further determined signal strength value, and comparing said predicted signal strength value with a set of predetermined values associated with the further wireless device, each of said predetermined values having a corresponding quality parameter value associated thereto.

11. A method according to any one of claims 8 to 10 wherein the received signal includes an acknowledgement frame.

12. A method according to claim 11 wherein the acknowledgment frame is in accordance with the IEEE 802.11 WLAN standard.

13. A method according to any one of claims 8 to 12 wherein the transmission mode includes a transmission rate of said wireless device.

14. A method according to claim 13 wherein the step of managing said transmission mode of said wireless device includes adjusting the transmission rate of said wireless device according to the comparison.

15. A method according to claims 10 to 14 wherein the step of predicting the signal strength value is performed by means of an adaptive filtering algorithm.

16. A method according to claim 15 wherein the adaptive filtering algorithm may be a Recursive Least Squares (RLS) algorithm.

17. A method according to any one of the preceding claims wherein the wireless devices include at least one wireless access point, and at least one wireless terminal.

18. An apparatus for managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said wireless device being in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the apparatus comprising means for receiving a signal transmitted from said further wireless device, a signal processing means for processing the received signal, said signal processing means being operable to determine a quality parameter associated with said received signal, and to compare the determined quality parameter with an existing quality parameter, and means for managing said transmission mode of said wireless device based on said comparison.

19. An apparatus for managing a transmission mode of a wireless device in a wireless network having a plurality of wireless devices, said wireless device

being in communication with at least one further wireless device of said plurality of wireless devices through a communication channel, and the apparatus comprising means for receiving a signal transmitted from said further wireless device, a signal processing means for processing said received signal, said signal processing means being operable to determine a signal strength value of said received signal, data storage means arranged to store said determined signal strength, said data storage means further storing at least one further determined signal strength value determined over a preceding time interval, said signal processing means further operable to predict a quality parameter using said determined signal strength value and said at least one further determined signal strength value, and to compare said predicted quality parameter with an existing quality parameter, and means for managing said transmission mode of said wireless device based on said comparison.

20. A storage medium storing computer executable instructions which, when executed on general purpose computer controlled communications apparatus, cause the apparatus to become configured to perform the method of any of claims 1 to 17.

Application No: GB0820054.5 **Examiner:** Mr Nigel Hall
Claims searched: 1-20 **Date of search:** 29 January 2009

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1,18	EP 1422898 A1 (Sony) See abstract
X	1,18	WO 2005/036809 A1 (Matsushita) See abstract
X	8,19	US 2004/0142698 A1 (Pietraski) See abstract

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

H4L

Worldwide search of patent documents classified in the following areas of the IPC

H04L

The following online and other databases have been used in the preparation of this search report

Online: EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
H04L	0001/00	01/01/2006