A method and apparatus are directed toward optimizing clear channel assessment (CCA) parameters in wireless communications. A CCA parameter request is received from an optimizing station. A current CCA parameter is read and transmitted to the optimizing station. A notification is received from the optimizing station of an optimized CCA parameter to be used by the optimizing station.

START

Determine upper bound and lower bound on EDT parameter

Calculate value updated value of EDT parameter:

$$EDT = EDT + \left( \alpha \frac{PER_{Rx}}{PER_{Rx}} - \beta \frac{PER_{Tx}}{PER_{Tx}} \frac{DR_{MAX}}{DR_{MAX}} \right) \Delta$$

Bound EDT parameter:

$$EDT = \max(EDT_{MIN}, \min(EDT_{MAX}, EDT))$$

Update EDT value

END
START

DETERMINE UPPER BOUND AND LOWER BOUND ON EDT PARAMETER

CALCULATE VALUE UPDATED VALUE OF EDT PARAMETER:

\[ EDT = EDT + \left( \frac{\alpha}{\text{PER}_{\text{MAX}}} \right) \left( \frac{\beta}{\text{PER}_{\text{MAX}}} + \gamma \frac{\text{DR}_{\text{MAX}}}{\text{DR}_{\text{MAX}}} \right)_\Delta \]

BOUND EDT PARAMETER:

\[ EDT = \text{max}(\text{EDT}_{\text{MIN}}, \text{MIN}(\text{EDT}_{\text{MAX}}, \text{EDT})) \]

UPDATE EDT VALUE

END

FIG. 1

AP OR STATION 200

Rx

ENERGY DETECTOR (CARRIER ENERGY DETECTOR)

CHANNEL AVAILABILITY DETERMINATION DEVICE

CCA CALCULATION DEVICE

FIG. 2
METHOD AND APPARATUS FOR CLEAR CHANNEL ASSESSMENT OPTIMIZATION IN WIRELESS COMMUNICATION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 12/209,692, filed Sep. 12, 2008; which is a continuation of application Ser. No. 10/937,123, filed Sep. 9, 2004, which issued on Oct. 28, 2008 as U.S. Pat. No. 7,445,821; which claims the benefit of U.S. Provisional Application No. 65/535,021, filed Jan. 8, 2004, all of which are incorporated by reference as if fully set forth herein.

FIELD OF THE INVENTION

[0002] The present invention relates generally to wireless local area networks (WLANs), and more particularly, to a method for optimizing clear channel assessment parameters in a WLAN.

BACKGROUND

[0003] In WLAN systems, the Distributed Coordination Function (DCF) is the fundamental access method for asynchronous data transfer on a best effort basis. The WLAN DCF mode is used to support contention services promoting fair access to the channel for all stations. The multiple access scheme used to achieve this is Carrier Sense Multiple Access with Carrier Avoidance (CSMA/CA). One way by which stations detect if the channel is busy is by analyzing all detected packets that are sent from other WLAN users and by detecting activity in the channel via relative signal strength from other sources. The physical carrier sensing that is performed prior to data transmission is referred to as Clear Channel Assessment (CCA).

[0004] CCA is used for transmission and reception of packets in 802.11 devices. Prior to data transmission, the device must ensure that the wireless medium is free, by using CCA. For data reception, the device only senses packets that meet the CCA criterion for a busy channel.

[0005] The 802.11 standards define different CCA modes. A commonly used CCA mode requires carrier sense and energy above the Energy Detect Threshold (EDT) before reporting that the medium is busy. More specifically, CCA reports a busy medium upon detection of a WLAN type of signal with energy above the EDT. Other CCA modes require carrier sense only, or energy above the EDT only.

[0006] A single EDT parameter is typically used to tune CCA for both transmission and reception of packets. CCA is well-tuned for transmission when:

[0007] 1) The access point (AP) always senses the channel as busy when a station (STA) from its basic service set (BSS) is transmitting a packet.

[0008] 2) The AP always senses the channel as busy when the STA to which it has a packet to send also senses the channel as busy due to a packet transmission from a device in a neighboring BSS. By satisfying this condition, the AP defers to external packets that would cause transmission errors.

[0009] 3) The AP always senses the channel as free when the STA to which it has a packet to send senses the channel as free, even if a device from a neighboring BSS is using the channel. By satisfying this condition, unnecessary deferrals are avoided.

[0100] On the other hand, CCA is well-tuned for reception when:

[0111] 1) The AP is capable of receiving packets from all STAs within the coverage area of its BSS. If the EDT parameter is set too high, the AP might not receive packets that are transmitted by a STA located at the cell edge.

[0112] 2) The AP does not sense packets from devices in neighboring BSSs. If the EDT parameter is set too low, the AP might “carrier lock” onto packets that are transmitted by STAs that are located outside of its BSS or transmitted by other APs. By “locking” on external transmissions, the AP will miss any transmission from a STA in its own BSS. Such a scenario would result in a packet error, as the packet from the STA in its own BSS would collide with the external packet that the AP is receiving.

[0113] Determining the ideal EDT setting involves a trade-off between optimizing for packet transmission and optimizing for packet reception. Moreover, a dynamic method for adjusting the EDT parameter is required in order to adapt to varying network conditions (e.g., a change in the BSS size).

SUMMARY

[0114] Three methods for optimizing CCA parameters in a WLAN having an access point (AP) and at least one non-AP station (STA) are described. The term “CCA parameters” is used herein to designate collectively the CCA mode and the value of the EDT parameter.

[0115] The first method does not require any specific signaling between STAs, or between a STA and an AP. In this method, each STA or AP attempts to independently find the optimal setting for its own CCA parameters based on certain statistics. There is no sharing of information between the STAs and AP regarding the setting of the CCA parameters. This method begins by receiving a trigger condition. An upper bound and a lower bound for the EDT parameter are determined. A value of the EDT parameter is calculated and is bound by the upper bound and the lower bound. Lastly, the EDT parameter is updated. The method can be performed at any one STA, all STAs, or at the AP.

[0116] The second method requires signaling between STAs or between a STA and an AP, to communicate the values of CCA parameters used by the STAs or the AP. In this method, each node (STA or AP) has the possibility of learning about the values of the CCA parameters used by other STAs or the AP, but a node can only modify its own CCA parameters. This second method begins with a STA or the AP requesting from other STAs and/or the AP to report the values of the CCA parameters currently used. The requested STAs and/or the AP report these values to the requesting STA or AP. The requesting STA or AP then computes the optimal values to use for its own CCA parameters. Following this computation, the requesting STA or AP may change the values of its own CCA parameters and, optionally, signal the new values to the other STAs or the AP.

[0117] The third method requires signaling between STAs or between a STA and an AP, that enables one STA or the AP to modify the values of the CCA parameters used by other STAs or the AP. In this third method, a node may determine the optimum settings of the CCA parameters for itself as well as for other nodes in the system, and may request that the other nodes use their respective optimum CCA parameters as determined by the requesting node. In an infrastructure BSS comprising one AP and one or several STAs, the requesting node should preferably be the AP. This method begins with
the AP calculating the optimal CCA parameters for one or multiple STAs associated to the AP. This calculation may (or may not) be the same as the calculation used in the first method. Following the determination of the optimal CCA parameters for each STA, the AP signals the respective values of the optimal CCA parameters to each STA. The STAs determine if the requested change of parameters is possible and indicates the success or failure of the change in a response message to the AP.

0018 An access point for optimizing CCA parameters in a wireless local area network having at least one station comprises a receiver, an energy detector, a channel availability determination device, and a CCA calculation device which receives input parameters from the access point and calculates the CCA parameters.

0019 A station for optimizing CCA parameters in a wireless local area network having an access point comprises a receiver, an energy detector, a channel availability determination device, and a CCA calculation device which receives input parameters from the station and calculates the CCA parameters.

0020 An integrated circuit for optimizing CCA parameters in a wireless local area network comprises a receiver, an energy detector, a channel availability determination device, and a CCA calculation device which receives input parameters and calculates the CCA parameters.

BRIEF DESCRIPTION OF THE DRAWINGS

0021 A more detailed understanding of the invention may be had from the following description of a preferred embodiment, given by way of example, and to be understood in conjunction with the accompanying drawings wherein:

0022 FIG. 1 is a flowchart of an energy detection threshold optimization process in accordance with a first method of the present invention;

0023 FIG. 2 is a block diagram of an apparatus embodying the process shown in FIG. 1;

0024 FIG. 3 is a diagram showing the signaling between an AP or STA and another AP or STA to implement a second method in accordance with the present invention; and

0025 FIG. 4 is a diagram showing the signaling between an AP and a STA to implement a third method in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

0026 The present invention describes methods to dynamically optimize the EDT parameter that is used for CCA in WLAN systems.

### TABLE 1

<table>
<thead>
<tr>
<th>Symbol/Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N_F)</td>
<td>Number of packets over which the transmitted packet error rate is calculated.</td>
</tr>
<tr>
<td>(N_R)</td>
<td>Number of packets over which the received packet error rate is calculated.</td>
</tr>
<tr>
<td>(PER_{\text{MAX}})</td>
<td>The target maximum transmitted packet error rate.</td>
</tr>
<tr>
<td>(PER_{\text{MAX}})</td>
<td>The target maximum received packet error rate.</td>
</tr>
<tr>
<td>(DR_{\text{MAX}})</td>
<td>The target maximum deferral rate.</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>Weighting factor for received packet error rate.</td>
</tr>
<tr>
<td>(\beta)</td>
<td>Weighting factor for transmitted packet error rate.</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>Weighting factor for deferral rate.</td>
</tr>
<tr>
<td>(\Delta)</td>
<td>EDT basic step size.</td>
</tr>
</tbody>
</table>

### TABLE 2

<table>
<thead>
<tr>
<th>Symbol/Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(PER)</td>
<td>The transmitted packet error rate. This measurement is calculated using a sliding window of (N_F), last transmitted packets.</td>
</tr>
<tr>
<td>(PER_{\text{RX}})</td>
<td>The received packet error rate. This measurement is calculated using a sliding window of (N_R), last received packets.</td>
</tr>
<tr>
<td>(DR)</td>
<td>Deferral rate. This is a measurement that represents the percentage of time that the AP is carrier locked by an out-of-BSS packet and has at least one packet to transmit.</td>
</tr>
</tbody>
</table>

0027 A flowchart of a CCA optimization process 100 using a first method in accordance with the present invention is shown in FIG. 1. The process 100 can be applied both at the AP and at individual STAs. This CCA optimization process addresses the determination of the proper level of the EDT. The CCA mode is preferably set so that it indicates busy if the received signal is above EDT and a WLAN signal is sensed. Alternatively, the CCA mode may be set so that it indicates busy if the received signal is above EDT only.

0028 Triggering

0029 The EDT optimization process 100 is triggered on any of the following conditions:

0030 1. \(PER_{\text{TX}} < PER_{\text{TX MAX}}\) and at least \(N_F\) packets have been transmitted since the last EDT update.

0031 2. \(PER_{\text{RX}} < PER_{\text{RX MAX}}\) and at least \(N_R\) packets have been received since the last EDT update.

0032 3. Expiration of a periodic triggering timer, i.e., \(T_{\text{ELAPSED}} > T_{\text{PERIODIC}}\) and at least \(N_F\) packets have been transmitted and at least \(N_R\) packets have been received since the last EDT update. \(T_{\text{ELAPSED}}\) is the elapsed time since the last EDT update.

0033 When triggered according to condition 1, the optimization process 100 attempts to solve the insufficient deferral problem. One cause for excessive packet errors in the downlink (DL) is an overly high EDT setting; the AP does not sense the channel as busy while STAs are carrier-locked on
neighboring BSS transmissions. A minimum number of transmitted packets are imposed to ensure that a problem really exists.

When triggered according to condition 2, the optimization process 100 attempts to solve the exceedingly sensitive AP problem. One cause for excessive packet errors in the uplink (UL) is an overly low EDT setting; the AP locks onto neighboring BSS packets, causing it to miss packets from its own STAs. An UL packet error generally occurs when a STA transmits a packet while the AP is already carrier-locked on a neighboring BSS transmission. A minimum number of received packets are imposed to ensure that a problem really exists.

Condition 3 is for general optimization purposes. The optimization process 100 is triggered periodically, once enough packets have been transmitted and received to have collected significant statistics.

The triggering parameters should be selected so that the optimization process 100 reacts quickly to an excessive packet error situation. For example, the optimization process 100 could trigger periodically once per second, once sufficient statistics have been collected. If a minimum of 100 packets is required for triggering, a 10% error rate results in 10 errors.

Determining EDT Bounds

The optimization process 100 begins by determining upper and lower bounds for the EDT parameter (step 102). An upper bound on the EDT parameter, EDT\text{MAX}, is determined as follows:

$$\text{EDT}_{\text{MAX}} = P_{\text{STA}}(RNG_{\text{base}} + RNG_{\text{adj}})$$

where RNG\text{adj} is a range adjustment value determined by the Power Control algorithm. The EDT parameter should be set so that the AP can at least sense all packets originating from its own BSS. EDT\text{MAX} corresponds to the signal level at which a transmission from a STA located at the cell edge is received.

The calculated value of EDT\text{MAX} is compared to the maximum value allowed by the 802.11 standards, and the lower of the two values is taken. The maximum EDT value allowed by the standard is based on the AP’s transmission power, P\text{AP}. EDT\text{MAX} is dynamically calculated as RNG\text{base} + RNG\text{adj}. P\text{STA} can be modified by the Power Control algorithm at any time, and is updated whenever there is a change to RNG\text{base} + RNG\text{adj} or P\text{STA}.

The lower bound on the EDT parameter, EDT\text{MIN}, is set to the AP receiver sensitivity level, RS\text{AP}.

The EDT parameter is calculated based on its current value, the received and transmitted packet error rates, and the deferral rate (step 104):

$$\text{EDT} = \text{EDT} + \frac{\alpha}{P_{\text{STA}}} \left( \frac{\text{PER}_{\text{TX}}}{\text{PER}_{\text{TX}}^{\text{MAX}}} - \beta \frac{\text{PER}_{\text{RX}}}{\text{PER}_{\text{RX}}^{\text{MAX}}} + \gamma \frac{\text{DR}}{\text{DR}^{\text{MAX}}} \right)$$

The default values for the weighting factors is 1, and can be optimized based on the deployment of the system (i.e., the layout of the APs and the STAs).
may not allow direct communication between STAs in an infrastructure BSS. In that case, this method would be usable by the AP only.

The request must contain the addresses of the optimizing station 302 and the requested station 304. In an 802.11 WLAN, this information would already be in the MAC header. Optionally, the request may contain a time limit for the requested station 304 to respond. The requested station 304 sends back an acknowledgment just after correct reception of the packet containing the request (just as any other packet directed to a specific station). In this way, the optimizing station 302 knows that the requested station 304 has properly received the request, and can retransmit the packet containing the request if it did not receive an acknowledgment within a certain time.

A second possibility is for the optimizing station 302 to send a general request directed to all surrounding stations 304. This can be done by transmitting a broadcast message specifying only the basic service set (BSS) identity, in which case only the STAs belonging to the specified BSS would respond. This can also be done by transmitting a multicast message specifying the addresses of all STAs from which it is desired to have the CCA parameters reported.

In a third possibility, a STA (non-AP) may request the AP to which it is associated for the CCA parameters of one or more STA(s) associated to this AP, instead of directly requesting the parameters from the STA. This request would contain the address of the STA(s) from which it is desired to have the CCA parameters reported, or a special flag indicating that the CCA parameters from all STAs in the BSS are requested. Following this request, the AP may respond with the CCA parameters of the requested stations 304. The AP may already have this information, or it may need to request the information (using one of the mechanisms described above) from the STAs prior to responding to the optimizing station 302.

For any STA that successfully receives a CCA parameters request according to one of the mechanisms described above, that STA reads the values of the CCA parameters it is currently using (step 312). These values (CCA mode and EDT) can be normally found in the management information base (MIB) of the requested station 304. After having read the CCA parameters, the requested station 304 (after gaining access to the medium according to the usual 802.11 protocol) transmits a CCA parameters report (step 314). This report may be a broadcast to all STAs in the BSS (in which case no acknowledgment is expected) or, preferably, may be a unicast directed at the optimizing station 302. In the latter case, an acknowledgment is expected from the optimizing station 302 and the requested station 304 can retransmit in case of failure. The report contains the values of the CCA parameters.

Once the optimizing station 302 has received CCA parameters reports from all requested stations 304 (or after a certain period of time has elapsed since the transmission of the requests, at the discretion of the optimizing station 302), the optimizing station 302 calculates the new CCA parameters it will use for itself (step 316).

A simple method for determining CCA parameters is to use those of the most sensitive STA from which CCA parameters were received (i.e., the STA with the lowest setting of the EDT parameter). If path loss information is available, the EDT parameter can be calculated to be as sensitive as the most sensitive reporting STA. For example, an AP could set its EDT parameter such that it is as sensitive to external transmissions as its most sensitive STA is. The AP could achieve this by setting its EDT parameter lower than the sensitive STA’s EDT parameter by an amount equal to the difference in path losses to the most dominant external interferers.

After the optimizing station 302 has calculated the new CCA parameters it should use, it can immediately apply the new setting. Optionally, it may send a CCA parameters notification to other requested stations 304 to inform them of the new setting now used by the optimizing station 302 (step 318). This message may be directed to specific STAs (unicast) or multiple STAs (multicast or broadcast).

A diagram of a CCA optimization process 400 using the third method is shown in FIG. 4. This method is preferably used by the AP in an infrastructure BSS, although use by a non-AP station is not precluded (e.g., in an independent BSS). The AP using the method is referred to as “controlling” station 402. The controlling station 402 computes or estimates the optimal CCA parameters for itself and other STAs in the same BSS (“controlled” stations 404; step 410). This determination may or may not be performed using the method 100 disclosed above.

After having determined the optimal CCA parameters for every STA (these may or may not be different from one controlled station 404 to another depending on the algorithm), the controlling station 402 requests the controlled stations 404 to modify their CCA parameters ("CCA parameters control request"; step 412). If the CCA parameters are the same for all controlled stations 404, the controlling station 402 may transmit a broadcast message containing the BSS identity along with the values of the CCA parameters, and optionally a time limit for responding. It may also transmit a multicast message containing the addresses of all controlled stations 404 along with the values for the CCA parameters. Preferably, the controlling station 402 transmits a unicast message (with acknowledgment) separately to each controlled station 404 with its new CCA parameters. When the new CCA parameters are different from one controlled station 404 to another, multicast or unicast messages are mandatory.

Following successful reception of the CCA parameters control request message, a controlled station 404 determines whether it is possible to apply the new CCA parameters requested by the controlling station 402 (step 414). Applying the new parameters may not be possible, depending on the capabilities of the controlled station 404 (e.g., radio sensitivity or the availability of the requested CCA mode). If the modification is possible, the controlled station 404 immediately modifies its CCA parameters (step 416) and transmits a response ("CCA parameters control response") as a unicast message to the controlling station 402 (preferred) or as a broadcast message to all STAs in the BSS (step 418). This message contains a flag indicating the success or failure of the CCA parameters modification. In case of failure, the message may optionally contain a "cause" field that specifies the reason for the failure (such as unavailable CCA mode or requested EDT value too low or too high). It may also contain the values of the CCA parameters currently in use by the controlled station 404.

After receiving the responses from all controlled stations 404 (or after a certain period of time has elapsed since the transmission of the requests, at the discretion of the controlling station 402), the controlling station 402 may decide to
do nothing until the next scheduled activation of the optimization algorithm, in a manner similar to that described in the method 100. The controlling station 402 may also decide to repeat the transmission of requests to the controlling stations 404 in case some of them did not transmit back a response.

While the present invention is described herein in connection with a WLAN, the principles of the present invention can be applied to other types of wireless communication systems. In such circumstances, the STA could include, but is not limited to, devices such as a wireless transmit/receive unit (WTRU), a user equipment, a fixed or mobile subscriber unit, a pager, or any other type of device capable of operating in a wireless environment. Similarly, the AP could include, but is not limited to, devices such as a base station, a Node B, a site controller, or any other type of interfacing device in a wireless environment.

Although the features and elements of the present invention are described in the preferred embodiments in particular combinations, each feature or element can be used alone (without the other features and elements of the preferred embodiments) or in various combinations with or without other features and elements of the present invention. While specific embodiments of the present invention have been shown and described, many modifications and variations could be made by one skilled in the art without departing from the scope of the invention. The above description serves to illustrate and not limit the particular invention in any way.

What is claimed is:

1. A method for optimizing clear channel assessment (CCA) parameters in wireless communications, comprising:
   - receiving a CCA parameter request from an optimizing station;
   - reading a current CCA parameter;
   - transmitting the current CCA parameter to the optimizing station;
   - receiving from the optimizing station a notification of an optimized CCA parameter to be used by the optimizing station.

2. The method according to claim 1, wherein the optimizing station is an access point (AP).

3. The method according to claim 1, wherein the optimizing station is a station (STA).

4. The method according to claim 1, wherein the receiving a parameter request, the reading, the transmitting, and the receiving a notification all occur at an access point (AP).

5. The method according to claim 1, wherein the receiving a parameter request, the reading, the transmitting and the receiving a notification all occur at a station (STA).

6. A method for optimizing clear channel assessment (CCA) parameters in wireless communications, comprising:
   - receiving a calculated optimal CCA parameter from an optimizing station;
   - receiving a request to change a current CCA parameter to the optimal parameter;
   - determining whether the change can be made;
   - changing the current CCA parameter to the optimal parameter on a condition that the change can be made and transmitting a message reporting whether or not the change has occurred.

7. The method of claim 6, wherein the optimizing station is an access point (AP).

8. The method according to claim 6, wherein the optimizing station is a station (STA).

9. The method according to claim 6, wherein the receiving a calculated optimal CCA parameter, the receiving a request to change a current CCA parameter, the determining, the changing, and the sending all occur at an access point (AP).

10. The method according to claim 6, wherein the receiving a calculated optimal CCA parameter, the receiving a request to change a current CCA parameter, the determining, the changing, and the sending all occur at a station (STA).

11. A wireless communications station, comprising:
   - a receiver configured to receive a clear channel assessment (CCA) parameter from an optimizing station;
   - reading circuitry configured to read a current CCA parameter;
   - a transmitter configured to transmit the current CCA parameter to the optimizing station;
   - the receiver further configured to receive from the optimizing station a notification of an optimized CCA parameter to be used by the optimizing station.

12. The wireless communications station of claim 11 configured to act as an access point (AP).

13. The wireless communications station of claim 11 configured to act as a station (STA).

14. The wireless communications station of claim 11 configured to function on a condition that the optimizing station is an access point (AP).

15. The wireless communications station of claim 11 configured to function on a condition that the optimizing station is a station (STA).

16. A wireless communications station, comprising:
   - a receiver configured to receive a calculated optimal CCA parameter from an optimizing station and to receive a request to change a current CCA parameter to the optimal parameter;
   - determining circuitry configured to determine whether the change can be made;
   - changing circuitry configured to change the current CCA parameter to the optimal parameter on a condition that the change can be made; and
   - a transmitter configured to transmit a message reporting whether or not the change has occurred.

17. The wireless communications station of claim 16 configured to act as an access point (AP).

18. The wireless communications station of claim 16 configured to act as a station (STA).

19. The wireless communications station of claim 16 configured to function on a condition that the optimizing station is an access point (AP).

20. The wireless communications station of claim 16 configured to function on a condition that the optimizing station is a station (STA).

21. An integrated circuit for optimizing clear channel assessment (CCA) parameters in wireless communications, comprising:
   - a receiver configured to receive a clear channel assessment (CCA) parameter from an optimizing station;
   - reading circuitry configured to read a current CCA parameter;
   - a transmitter configured to transmit the current CCA parameter to the optimizing station;
the receiver further configured to receive from the optimizing station a notification of an optimized CCA parameter to be used by the optimizing station.

22. An integrated circuit for optimizing clear channel assessment (CCA) parameters in wireless communications, comprising:

- a receiver configured to receive a calculated optimal CCA parameter from an optimizing station and to receive a request to change a current CCA parameter to the optimal parameter;
- determining circuitry configured to determine whether the change can be made;
- changing circuitry configured to change the current CCA parameter to the optimal parameter on a condition that the change can be made; and
- a transmitter configured to transmit a message reporting whether or not the change has occurred.

* * * * *