IEEE 802.11
Wireless Access Method and Physical Layer Specification

Title: **Proposal For the Use of Packet Detection in Clear Channel Assessment**

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Abstract: This submission addresses the topic of Listen Before Transmit, LBT, for 2.4 GHz Spread Spectrum Systems. Specifically, it speaks to critical issues associated with an important aspect of LBT, the process of Clear Channel Assessment, CCA. Four basic CCA approaches to developing a decision to either transmit or defer are listed and compared. The comparison includes the potential for needless deferment, etiquette with respect to other occupants of the ISM band, impact of CCA on the hidden node syndrome, communications delay, and compatibility with a modulation gear shift. The four basic methods of CCA are RF power detect, symbol rate detect, a hybrid of power and symbol rate detect, and packet detect. The conclusion of the submission is that packet detect CCA is the choice of preference.

Introduction

The goal of Clear Channel Assessment, is to provide the means of measuring the activity on a communications channel before a device begins the process of transmitting a packet of data. By doing so, a device might defer its transmission if the channel is busy thus improving the throughput for all users of the channel. When the channel is wireline, all potential transmitting devices have the ability to sense the transmissions of other devices. The utility of the LBT concept for wireline data communications is well established in its effectiveness in maximizing network capacity and throughput rate because CCA is unambiguous.

In the wireless environment of IEEE 802.11, there are two important differences from a wireline communications channel:

1. The path loss between devices varies widely so that any particular device may not be able to sense the presence of a transmission of another device on the same rf channel. Thus, interference might be present at a receiving device, for instance, half way between two transmitting devices which are too far apart to sense each others transmissions. Thus neither transmitting device defers when deferral is appropriate.
2. On a wireline communications channel there is reasonable assurance that all transmitting devices on the channel are authorized, compatible and interoperable. On a wireless ISM channel this is not necessarily the case. One of the occupants on the communications channel might not be a member of the communications net, such as a microwave oven. Such situations may lead to ill-advised deferrals, called false deferrals, in this submission.

Thus, the criteria used to evaluate CCA in a wireless system operating in the ISM is quite different than the criteria for a wireline system.

In this submission the concept of CCA will be reviewed and four fundamental CCA processes described. The four processes will then be compared on the following bases:

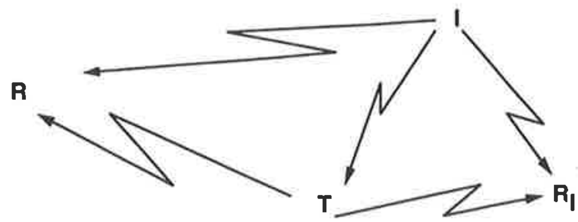
Propensity for false deferral,
Hidden node syndrome,
Communications delay,
Compatibility with modulation gear shift, and
Etiquette with respect to other occupants of the ISM band.

A chart is then developed to summarize these results. From this summary the conclusion is drawn that packet detect is the clear choice of preference.

The final aspect of this submission is a discussion of the fundamental problem of CCA in an RF system and why a packet detect based CCA minimizes the impact of this fundamental limitation.

Overview of CCA

Before describing the four basic types of CCA considered in this submission, a review of the simple operational diagram of Figure #1 may be useful in describing and understanding



Operational Diagram

Figure #1

CCA. Four communicating devices are depicted in this diagram, T, R, I and R_I. T is the device contemplating transmission of a packet of data and hence performing CCA. R is the device to which T will transmit. I is the device that may be emitting interference RF power. R_I is the device intending to receive the signal from I assuming that I is a communications transmitter, not an RF heater. Thus, before transmitting its packet, T evaluates the rf channel to determine if I (any I) is likely to interfere with the reception of its signal by R. In addition, a determination is made as to whether it is likely or not that a transmission from T would interfere with the reception of the signal from I by R_I.

If either possibility is likely, then a decision may be made by T to defer transmission because the system designers made the judgment that to defer under specified circumstances will, on the average, lead to faster, more reliable communications for all devices using the communications channel.

Basic Forms Of CCA

Four basic types of CCA are considered here. They are:

I. RF Power Detect CCA
The RF power criteria for CCA consist of measuring the level of received power at T (as in figure #1). If the RF power exceeds a threshold, then T defers. There are two criteria involved in this decision process. The first is the measurement period. For the purpose of IEEE 802.11 data packets, this period would be short, on the order of 50 microseconds. The second is the threshold. Based on the UPCS consideration of this same issue, a threshold of about 12 dB above sensitivity (BER = 10^{-5}) is reasonable. This leads to the result that T will defers to an I that is within about 1/2 of the range of T (assuming 12 dB per distance doubling and that all transmitting devices have the same ERP). T would not defer to an I that is rather remote.

2. Bit Or Symbol Rate Detect CCA
In order to provide some discrimination against RF sources for which the system designers would choose not to defer, bit or symbol rate detection is useful. For DSSS symbol rate might be either data or chipping rate. In this process, T determines if the received power from I has the same symbol rate as "like" devices in the T-R network of Figure #1. The principle criteria here is the method of measuring symbol rate. One might envision a device as simple as a filter to detect clock energy in the recovered baseband signal, or a process as sophisticated as a matched filter for the rf spectrum. From the standpoint of a standard, the criteria might be that a specified level of deviation of the Foundation format be detected. Product designers must translate that criteria into low cost implementations which might meet the criteria but may also tend to false as discussed below.

While one might envision a sophisticated data format measurement process, the assumption here is that the process of detecting clock energy would typically involve a tone filter and a level detector monitoring a squared version of the recovered baseband signal. The circuit to do this would be a derivative of the clock recovery process and therefore of little additional cost. For the Frequency Hop PHY, the threshold of detection would be low, on the order of what is usual for clock recovery. The probable sensitivity of such a detector would be in the range of 6 or 7 dB SNR or about 12 dB less than the 10^{-5} BER sensitivity of the receiver.

3. Hybrid Of Power And Symbol Rate Detect CCA
The third form of CCA is a hybrid of power detect and symbol rate detection as discussed at the last 802.11 meeting. With this CCA process, T would defer if it received interference that was greater than a threshold and if the interference had clock energy. The assumption is made here that the power threshold would be the same as the power detect CCA and thus about 12 dB above BER = 10^{-5}

sensitivity. Above this level, the device in question would defer if there was any reasonable level of clock energy in the baseband signal.

4 Packet Detect CCA

The fourth form of CCA is packet detect. This process requires T to defer if it senses one of the packets specified in the standard. For the purpose of this paper the assumption will be made that the packet is 24 bits. No attempt is made in this submission to suggest that this packet be PHY or Mac specific, just that it occur near the beginning of each transmission. The CCA would require that a device, T, that has just begun to monitor the channel do so for at least the maximum length data payload, say 5 to 10 mSec. Following the initial period, T would continue to monitor the channel for the occurrence of header packets. By doing so, there is little delay anticipated. The signal to noise ratio necessary to detect a 24 bit code with a high probability of detection, 75 %, is about 6 dB less than the signal to noise ratio to achieve the rated BER for the throughput data, i.e., BER = 10-5.

Performance Comparison Of CCA Alternatives

Having described the four alternatives for CCA it is appropriate to estimate and compare relative performance expectations. The categories of comparison are:

false deferral
hidden node syndrome
communications delay
compatibility with modulation gear shift, and
etiquette

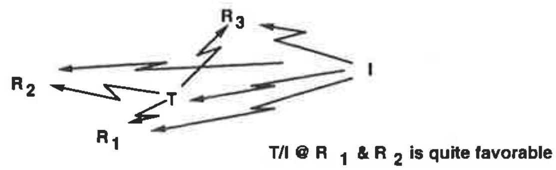
False Deferral

In this submission, the term "false deferral' will refer to either:

1) the decision to defer transmission of a packet when the interference sensed would in fact not interfere with intended reception of the packet, or
2) the decision to defer transmission of a packet when the transmission would in fact not interfere with the intended reception of the signal sensed as interference.

Near-Far CCA Scenario

In order to understand some of the false deferral issues associated with CCA, it is important to discuss the near-far aspect of CCA as it pertains to RF applications. Consider the physical layout described in Figure #2. In this figure, potential receiving devices for the



Near - Far Issue

Figure #2

transmitting device are shown as R_1, R_2 etc. From this figure it is clear that the transmitting device would be able to receive RF power from the interfering device, I, at a high level. Also evident from this figure is that many of the potential receivers of T's signal would not receive excessive interference from I. If T defers to I under these circumstances, then many of the potentially strong links would be needlessly abandoned, i.e., bandwidth and time would be wasted.

The near-far issue is of particular interest in considering the adjacent channel signals in Frequency Hop or DSSS systems.

False Deferral Propensity

In order to evaluate the propensity of the CCA approaches to produce false deferrals, a number of potential signal or interference sources are considered. The four CCA processes are power, clock, hybrid, and packet detect.

1. Microwave Ovens.
Ovens will cause the power CCA to false defer but not the other CCA systems. Clearly, there is no concern with the possibility of interfering with microwave oven signals. Less obvious, but also true, is that there is little utility from deferral to microwave ovens with respect to T to R throughput rate. This is true since there will be no race to retry and if the desired reception fails, retry is required anyway. One argument that deferral to microwave ovens is of benefit to the 802.11 device, is the possible scenario that a retry might begin sooner with deferral. This is a poor tradeoff against losing channels that would not be effected by the microwave oven interference.

2. Non 802.11 Transmitters.
This consideration is the same as the microwave oven discussion assuming that the non 802.11 device has a different modulation format.

3. Other 802.11 PHYs
Etiquette for/with other IEEE 802.11 PHYs is an interesting issue which is discussed below. The conclusion with respect to CCA, however, is the same as for #1 and #2 above.

4. Remote, But Same 802.11 PHY
This is the scenario where a signal from another cell of the same overall RLAN is detected. Since such a signal has the correct symbol rate and modulation format, power, symbol rate, and hybrid CCAs are all prone to false defer on such

interference. Because of its greater sensitivity, the symbol rate CCA is prone to false deferral from much weaker sources of interference than the power or hybrid CCAs.

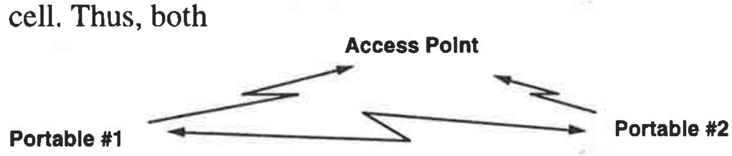
It is the position of this submission that deferral to signals from other cells is typically not desirable. Since the interference signal propagates from a transmitter in another cell, it is in general not likely that the interference signal would be strong at both the intended receiver, R and at the device making the CCA decision, T. In addition, the spread spectrum nature of frequency hop and DSSS provides processing gain for the intended receiver to help avoid interference from a like PHY transmitters in other cells. For the frequency hop case, the affected receiver will change to a new frequency on a different hop sequence from the interferer within one dwell period, i.e., the interference would be short lived. The processing gain for a DSSS system is more immediately in minimizing the impact of interference. The same argument that deferral is not warranted for signals from other cells is true in both directions, i.e., T is not likely to interfere with R_I.

5. Same Phy On An Adjacent Channel
Neither the DSSS nor the Frequency Hop PHYs provide significant selectivity at adjacent channels. Assuming modest sophistication in the symbol rate detection process, power, symbol rate, and hybrid CCAs are prone to false defer on adjacent channel signals from the same PHY. Because of its greater sensitivity, the symbol rate CCA is prone to false deferral from much weaker sources of interference than the power or hybrid CCAs. It is the position of this submission that deferral to signals on adjacent channels is typically not desirable.

6. Strong And Same Channel Signals Producing An On Channel IM Product
A high capacity system application with many users in many cells will provide the opportunity for IM products to be developed and appear as interference. These are not desirable causes for deferral. The power, symbol rate and hybrid CCA systems are prone to false deferral based on such artificial forms of interference. Because of its greater sensitivity, the symbol rate CCA is prone to false deferral from much weaker sources of interference than the power or hybrid CCAs.

Hidden Node Syndrome

Consider two portable transmitters attempting to transmit to an Access Point, as illustrated in Figure #3. The two portable transmitters are on different sides of the cell. Thus, both portables are within range of the Access Point, but not necessarily within range of each other. If the portables are not



Hidden Node Syndrome

Figure #3

within range of each other, then with respect to CCA, they cannot defer to each other. In the case of the power and hybrid CCAs, the CCA sensitivity is 12 dB worst than the Data sensitivity. Packet sensitivity is 6 dB more sensitive than Data sensitivity. Thus, the packet CCA would be 12 + 6 dB or 18 dB more sensitive than power or hybrid CCAs and far more likely to defer as desired and thus avoid the hidden node syndrome. The symbol rate CCA is 6 dB more sensitive than the packet CCA and thus has a 24 dB advantage relative to the power or hybrid systems.

The packet detect and symbol rate detect CCAs are far more effective in avoiding the hidden node problem than the power or hybrid CCAs.

Delay

Power, hybrid and symbol rate CCAs are all fast CCAs algorithms. The argument could be made that the packet detect CCA is slower because a transceiver with a packet to transmit would have to wait at least the period of the maximum length packet to be sure that no deferral is required. A 10 mSec. delay might result. This is true, but only for the initial period that a transceiver is monitoring the RF channel. From that initial period on, the transceiver in question would be monitoring the RF channel and would recognize header packets which occur at the beginning of each transmission, record the fact that the channel is active for what expected period. Thus, no delay is encountered after the initial packet. On an overall basis, therefore, the delay associated with packet detect CCA is minimal.

Etiquette

Etiquette is an issue of particular importance to the UPCS band at 1.9 GHz. Here CSMA and CCA form the basis of the etiquette. In the ISM band, however, there is another very important aspect to the etiquette profile. Here, the FCC has devised a set of rules which are intended to allow different RF devices with very different application and system designs to operate in an intermingled fashion with minimal and manageable interference. This is the function of the mandated spread spectrum. The processing gain of spread spectrum, for both frequency hop and DSSS provide the etiquette for the ISM band. Note that in the UPCS band, spread spectrum is not required, and therefore another form of etiquette is required. The overhead of additional etiquette is neither required or desirable in the ISM band. Spread spectrum is the means by which commercial devices of all types share the ISM without frequency planning or coordination. This process should holdover to the 802.11 use of the ISM band for Data communications. It is the position of this submission that power detect CCA is, in effect, an etiquette criteria which is not required and undesirable in conjunction with spread spectrum. To a lesser extent the same is true of clock rate and hybrid CCAs. Packet detect can be controlled to provide the required system coordination without the confusion of an etiquette.

Gear Shift

Some members of the IEEE 802.11 committee have been pursuing the possible option of a higher data rate format for the frequency hop PHY. This option might be considered as a stand alone PHY or as an option on the Foundation modulation format of 1 Mb/s 0.5 GFSK. The implicit suggestion of the later is that a packet transmission would begin with the foundation modulation format for an initial header and then switch to a different modulation format having a higher data rate. At the November, 1993 meeting, this author proposed two alternatives for performing the required change of modulation. There was general agreement in the PHY group that performing the gear shift itself was straight forward. The problem envisioned was the potential impact of the optional modulation format on the CCA and system operation.

Assume, for instance, that the optional modulation was some form of QPSK operating at a symbol rate of 700 KHz. If the CCA criteria was clock detect or the hybrid system, then the baseline transceivers designed to operate at 1 Mb/s would not be able to recognize the optional system symbol or clock rate and would therefore not defer as desired. Thus, customers who paid for an upgrade to the higher data rate system would suffer reduced throughput and market confusion would result. The power detect and the packet detect CCAs are compatible with the modulation gear shift option.

Summary Table Of CCA Comparisons

CCA TYPE ISSUE	POWER	CLOCK	HYBRID	PACKET
*False Deferral				
uwave ovens	poor	good	good	good
non 802.11	poor	good	good	good
other 802.11	poor	good	good	good
remote/same 802.11 PHY	poor	very poor	poor	good
same/adj ch 802.11 PHY	poor	very poor	poor	good
same PHYs/IM	poor	very poor	poor	good
*Hidden Node Syndrome	poor	best	poor	good
*Delay	good	good	good	almost as good
*Etiquette	adds to SS[1]	adds to SS[1]	adds to SS[1]	relies on SS[1]
*Gear Shift Support	yes	no	no	yes

1. SS means spread spectrum

The Fundamental Problem Of CCA

The fundamental problem associated with CSMA or Listen Before Transmit, LBT, is that the transmitting device must make a judgment about the interference level present at the intended receiver. In an indoor RF world where all transmitters have about the same ERP (even microwave ovens are in the 100 mWatt range), CCA is thus an imprecise process at best.

To the extend that CCA fails to predict an interference scenario, spread spectrum provides a significant measure of protection from interference. Frequency hop spread spectrum, provides a significant measure of protection from persistent interference from sources of RF outside the immediate cell of concern. It is quite useful if the CCA function is very sensitive to devices that are members of the same cell or group of cells. Packet detect CCA is unique in its ability to provide that selectivity at very good sensitivity.

Conclusions

This submission has considered four forms of CCA:

- power detect
- symbol of clock rate detect
- hybrid of clock and power detect
- packet detect

The following criteria have been used to compare the expected performance of these CCAs with the following conclusions:

- Propensity for false deferrals
- Hidden node Syndrome
- Communications Delay
- Compatibility with modulation gear shift
- Etiquette

Specific Conclusions

1. It is concluded that Packet Detect CCA is superior to the other forms of CCA in terms of its ability to avoid false deferrals.

2. Packet Detect CCA is superior to power and hybrid CCAs with respect to the hidden node syndrome. The clock rate detect CCA is more sensitive than the packet detect CCA and thus performs better in the hidden node scenario. The improved sensitivity, however, is a major disadvantage to the clock rate detect CCA with respect to the first criteria of false deferral.

3. Packet detect and power CCAs are compatible with modulation gear shift. Clock rate and hybrid CCAs are not.

4. The time delay of packet detect CCA is negligible on an overall basis.

5. Packet detect does not provide an effective etiquette format. In the ISM band, however, spread spectrum provides the etiquette. Additional etiquette from the CCA is not required or desirable.

Summary Conclusion

Packet detect is the appropriate CCA basis for the IEEE 802.11 standard.