A PROPOSAL FOR FH PHY CCA BASED ON THE HUMAN MODEL

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Introduction

The human model is the subconscious paradigm by which we communicate each day. This paper presents a proposal for a FH CCA based on this paradigm, using a hybrid approach of both energy and transition detectors which minimizes collisions, is fast and proven in practice. The benefits are threefold:

1. 50% faster than packet detect under synchronous conditions - maximizing throughput while minimizing collisions
2. 77% better hidden node detection due to lower CCA sensitivity
3. Ability to pass multiple parameters to MAC layer for higher quality decision with adaptive capabilities

The document commences with background information covering scenarios for single and multiple network topologies and then presents the classic approaches to CCA graphically. Secondly, the proposal for a more intuitive CCA approach based on the human model of 'listen before talk' is discussed . This model is then transformed into a CCA approach for WLANs by stepping through the cases which make up the model. A comparison of acquisition times between this and the classical methods is given. Finally, different data modulation types are discussed with their effects on acquisition times.

Single Network Scenarios

The purpose of Fig 1 is twofold:
1. Provide the reader with an appreciation of single network scenarios.
2. Highlight the benefits of a low sensitivity CCA with respect to hidden nodes.

The range of a single transceiver as a receiver is diagrammed in fig 1A and assumes isotropic antennas, ideal indoor propagation patterns, transmitters of equal power and a receive sensitivity of 80dBm for 10E-5 BER without fading [1]. Note the **2x** increase in range for a BER of 10E-1 versus 10E-5 and a **.5x** decrease in range for a power output of 10 dBm versus 20 dBm.

The usable range of a two node network is shown in fig 1B and is equal to the minimum range of either receiver (**1x** @ 100mw & 10E-5). Therefore the radius of a transceiver's range is equal to the diameter of the usable network range. Note that transceivers on the perimeter of the circle defined by the range diameter should use a power output of 20dBm whereas transceivers within a circle defined by 1/2 the range diameter could use the 10dBm output assuming a CCA sensitivity requirement for a BER << 10E-5.

Fig 1C shows the range of a multinode network with a hidden node. Although the node is hidden from all but its nearest neighbor at a BER of 10E-5, if a node is less than **2x** from any other network node, it is not hidden at a BER of 10E-1.

Fig 1D compares a network's range with its RF energy shadow. In set notation, the RF shadow is the union of all individual transceiver ranges whereas the usable network range is the intersection thereof. The **1x** dimension defines a network area without hidden nodes. The **3x** dimension defines an area where communication is possible with some nodes. The **5x** dimension defines the limit of any communication. Rayleigh fading will cause an additional 20dB of loss without antenna diversity (~12dB with diversity) in the network range.

Multiple Network Scenarios

The purpose of Fig 2 is twofold:

1. Provide the reader with an appreciation of on channel interference issues in multiple network scenarios, particularly reliability/throughput during collisions.
2. Highlight a benefit of antenna diversity in avoiding collisions.

The dimensions required for independent operation of two networks (any node to any node) on the same channel without fading is **2x**, as pictured in fig 2A. This spacing is analogous to cell repetition (i.e. spatial diversity) in cellular based systems. Figures 2B-D show progressively higher levels of network overlap with increasing levels of on channel interference. Adjacent and alternate channel levels are also affected to a lesser extent.

Although a FHSS network inherently provides tolerance to off channel interference, there is a requirement that the network remain operationally intact during on channel interference scenarios including collisions, if reliability and throughput are to be maintained [4]. Lab tests indicate that significant on channel and adjacent channel interference at a receiver is caused, when 2 nodes transmit on the same channel, if their received power is within 15 dBm (without antenna diversity and within 10dBm with diversity). This channel interference appears as a mix of data and noise transition widths and could easily be false detected as noise albeit at a relatively high RSSI level. A transceiver using packet detect CCA would most definitely false a clear indication and commence transmission, worsening the existing collision problem - 'I5 in the fog".

CCA Approaches Versus Received Power Level and BER

The purpose of Fig 3 is twofold:

1. Provide the reader with an appreciation of CCA methods with respect to the power level and BER.
2. Highlight the sensitivity of false detection for each method.

The diagram covers various approaches to CCA (ranging from a simple power detect to a rigorous packet detect) with respect to the required power level at the receiver and the approximate BER of the data received [2].
Three areas are important: 1) Probability of false sensing (false deferral), 2) Probability of missed sensing (false transmit or collision avoidance) and 3) Ability to detect collision.

A previous CCA paper described some classic methods and focused particularly on propensity to false deferral but said little about the positive benefits of collision avoidance and detection. Collision avoidance (CA) is important to keep the network throughput high and is best achieved with the lowest CCA sensitivity level (i.e. fewest hidden nodes) [3,4]. Collision detection (CD) is important for network reliability and can be achieved with a power detect of moderate level in conjunction with a detector looking for a simple data pattern (like sync). The obvious effect of no CD is "I5 in the Fog" - most data would be corrupted and the network would be down until the next channel slot. The benefit of CD is that the fewer transmitters involved, the more likely that transmissions will get to their destinations uncorrupted (Data at the destination receiver is likely to be corrupted if the received power is within 15dBm without diversity and 10dBm with diversity).

Table 1 - CCA method vs Sensitivity to Missed Sensing

	Power	Clock	Hybrid	Sync	Packet
avoidance	poor	best	poor	good	fair
detection	good	good	best	fair	poor

Although a higher level has been suggested (12 dBm above 10E-5), the power detect method shown has a more conservative -75 dBm level to better avoid collisions (It still has the worst collision avoidance of these methods) and is inherently efficient at collision detection. The power level can be determined in conjunction with antenna diversity with a 10 bit increase in acquisition time.

The clock detect has the lowest required energy for acceptable performance including the best collision avoidance, the best acquisition time but only fair collision detection.

The hybrid version shown combines power detect AND clock detect in an undesirable way which may aggravate an existing collision. A proposal for a hybrid "human model" CCA with much better characteristics, will be discussed in the next section.

The SYNC method requires more energy and more time but implies a higher false deferral confidence factor than clock detect alone. Likewise packet detect takes even higher energy, BER ~ 10E-4 and significantly more time particularly during asynchronous operation. Table 3 compares the acquisition times for these methods.

A look at these methods gives some insight into desirable CCA characteristics:

1. A CCA approach with the minimum detection level has the greatest ability to detect hidden nodes [3]. As shown in Fig 1, the 10E-1 BER level had a range large enough to detect all hidden nodes for a network.
2. A CCA should attempt to avoid collisions to keep the throughput high and detect collisions to keep the network reliability intact [4].
3. The quicker the method, the more opportunity (slots) for access without collisions during the contention period. There is an added benefit of power savings for applications which are generally asynchronous in nature.

Proposed Hybrid Method of Clear Channel Assessment

A combination of energy and transition detectors would determine channel assessment in P bit times - where P is a protocol factor to allow time for clock recovery, synchronization and framing using different data encoding methods (about 36 bits for NRZ/16). Further M, the maximum run length in bits must be less than P (17 bits for NRZ/16 [5]). Diversity would increase the probability of a correct assessment in a total time less than 52 bits (16 bits for diversity + 36 bits for transition) [3]. Table 2 shows a wireless CCA model as compared to the six case "Listen before Talk" human model. Figures 4 - 9 step through the 6 cases.

TABLE 2 - Proposed Hybrid Method Based on LBT Human Model

Human Model		Wireless Model		
Case. Observation	Action	Observation	Action	CCA Detection Method
1. quiet	Speak	minimal RF energy	Tx	ED < TH1
2. sounds	Speak	Th1< non802 < Th3	Tx	Th1 < ED < Th3 &TD = No trans
3. background noise	Speak	AWGN	Tx	Th1 < ED < Th2 &TD = Noise
4. foreground voices	Defer	possible collision	Scan	Th2 < ED < Th3 &TD = Noise
5. voice	Defer	Th1< 802 Data < Th3	Scan	Th1 < ED < Th3 &TD = Data
6. loud racket	Defer	RF energy above Th3	Scan	ED > Th3

NOTES:

1. The Tx/Scan terminology used in the text and diagrams means "clear to transmit" and "channel busy" and is one of several indications/parameters which the MAC layer may use to determine whether to Transmit or Defer. Parameters from the transition detector would be Data, Noise, Notrans and from RSSI would be the power level.
2. N is the number of bits detected - one less than the number of transitions detected.

where:

ED = Energy Detect with **example** programmable thresholds:

Th1 = -85 dBm Set based on an extremely low ambient RF (data or noise) signal level which indicates that traffic is distant (BER<<10E-5) or nonexistent.
Analogy would be traveling a deserted desert highway.

Th2 = -50 dBm Set based on a high ambient RF noise signal level unlikely to occur during normal loads and signifies a possible collision already in progress.
Analogy would be flares/skid marks on freeway indicating an accident.

Th3 = -20 dB Set based on a desensitizing signal level and is intended to avoid potential collisions which may occur when strong RF signals are present.
Analogy might be poor visibility at an airport .

TD = Transition Detect with programmable jitter tolerance and % of occurrences:

Data = 1.0us x N +/- Jt (Jitter tolerance]) for N < M (maximum run length in bits)

Noise = % of occurrences of invalid vs valid data widths (0 % indicates data)

No trans = 0 or 1 transition within M bits

For all cases, energy detection is obtained as part of the antenna diversity decision. The existing antenna is sampled, converted and compared to the second antenna level. The higher level is stored and the antenna switched in less than 15 us. The transition detector is about 500 gates and uses programmable transition timings (jitter tolerance and percentage of occurrences) to determine either data, noise or no transitions as defined above. For NRZ data, the acquisition times are shown in Table 3. Other data modulation methods can significantly shorten these times.

Case 1 - Low Power Threshold

This case says clear to transmit below this threshold. This level is more of a reference point than a fixed value since other cases will cover both higher and lower energy levels.

Case 2 - Non 802 Communications

This case says clear to transmit if the channel does not look like 802 FH data. It is the equivalent of speaking in spite of a dog barking or jet overhead (i.e. intelligent life not inanimate noise). The transition detector sees less than two transitions over the run length window M. The peak power outputs of a microwave fall into this category.

Case 3 - RF Noise

This case says clear to transmit if the channel looks like noise. It is the equivalent of speaking in spite of the wind blowing or a cooling fan. The transition detector sees a higher percentage than that programmed for non valid vs valid data widths.

Case 4 - Potential 802 collision detected

This case says scan if the channel looks like noise and is above some moderate energy threshold. It is the equivalent of deferring when several people speak at once. The transition detector sees a higher percentage than that programmed for non valid vs valid data widths AND the power is above a potentially moderate level. Our research shows this is a viable case and would avoid **"I5 in the fog".**

Case 5 - 802 data detected

This case says scan if the channel looks like data. It is the equivalent of deferring when another person speaks. The transition detector sees a lower percentage than that programmed for non valid vs valid data widths.

Case 6 - Extreme Interferer detected

This case says scan if the channel energy is quite high. It is the equivalent of deferring when next to a jet engine or at the rock concert! The energy detector sees a high desensitizing radio level which may cause CCA miscues in the network. The reliability of the network is in jeopardy unless "the airport closes for a limited time" (until the next channel hop). The MAC layer may desire to adjust the level over time for an adaptive type CCA.

Table 3 - CCA Bit Delay vs Method

Assumptions: NRZ data bit stuffed as indicated, 80 bit mark/space sync pattern, 16 bit frame, 32 bit header

faster -->

CCA Method	NRZ32 (async)	NRZ32 (sync)	NRZ16 (async)	NRZ16 (sync)	^ (faster) ^
Energy	4	4	4	4	
Energy w/ div.	16	16	16	16	
CK	71	2	35	2	
SYNC	71	9	35	9	
* TD = DATA	71	9	35	9	
* TD = NOISE	71	9	35	9	
* TD = Notrans	71	9	35	9	
FRAME	80+16	80+16	80+16	80+16	
PACKET	10ms	80+16+32	10ms	80+16+32	

Notes:

1. All units are bit times unless noted
2. TD = Transition Detector as defined on page 6.
3. Synchronous operation assumes CCA detect during preamble
4. Other data modulation methods can have considerably shorter times for asynchronous operation
5. MAC CCA Target ~ 50us

Other Modulation Types

Data modulation encoding other than NRZ may be used to limit the run length between transitions (reducing variable M) and thus reduce the acquisition time (P > 2 x M), particularly with respect to asynchronous operation. A modulation run length limited to 8 bits would need at least 2 times 8 bits to guarantee at least 2 transitions (1 valid bit duration = 1.0us x N +/- Jt). There are modulation types which limit run length to 2 bits for any data stream and provide positive benefits for radio operation as well.

Summary

This paper presented/discussed three desirable characteristics for CCA:

1. An approach with the minimum detection level has the greatest ability to detect hidden nodes [2].
2. The ability to avoid and detect collisions keeps the network throughput and reliability intact [4].
3. At the MAC layer, the faster the CCA acquisition, the more access slots are available during the contention period.

The proposal for a hybrid FH CCA based on the human model using energy and transition detectors provides three major benefits:

1. Very fast acquisition time (sync or async).
2. Maximum hidden node detection.
3. Higher quality decision by obtaining/passing multiple parameters (A singular CCA decision could be made in Phy or Mac layer)

Conclusion

The Hybrid human model is an appropriate CCA for the 802.11 standard.

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