IEEE 802.11
Wireless Access Method and Physical Specification

Title: **32-Bit CRC Performance with Burst Errors and Proposed FH Packet Formatting**

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Abstract

Errors undetected by the CRC occurs when an error pattern superimposed on a valid transmitted codeword (packet) results in another valid codeword. The MAC then passes up to the LLC a packet containing undetected errors. Burst errors due to the noisy wireless environment will be the primary cause of undetected errors. In the ISM band, microwave ovens, non-standard systems, multipath fading, edge of range operation, and hidden terminal collisions will be the key sources of burst errors. This paper evaluates an estimate of the maximum probability of undetected errors due to burst errors of an assumed "typical" wireless LAN with the IEEE 802 standard 32-bit CRC.

A packet formatting method to minimize data DC bias was presented in P802.11-94/069. The undetected error probability due to this FH packet formatting method is calculated in this submission. The error rate due to the formatting is shown to be small compared to the error rate due to the bursty nature of the wireless environment.

Several questions are posed that will determine if a 32-bit CRC is sufficient. Finally, options for improving the undetected error performance are addressed.

Introduction

The referenced article by Raj Jain [1] evaluated the probability of undetected error for the FDDI standard. A previous article by the same author concluded that a 32-bit CRC was necessary for FDDI which also required that each fiber segment have a bit error probability of 2.5×10^{-10}. He also assumed in his analysis that burst errors did not occur.

Both the ISM and IR wireless environment is a tad bit worst than FDDI's channel. Although the operational maximum bit error probability is 1×10^{-5}, the guaranteed worst case bit error probability in any given time segment is 0.5, e.g., during burst errors. Standard radio design practice is to specify and measure the BER in the absence of interferers and other burst error sources which are difficult to quantify for all situations. Thus, the BER performance of a wireless system is essentially independent of the burst error rate.

Burst error events are segments of time in which the bit error probability is significantly higher than the overall average. Burst errors will occur with varying probability depending on the application environment and will range from seldom to continuous for periods of time. Microwave ovens, non-standard systems, multipath fading, edge of range operation, and hidden terminal collisions are some of the causes of burst errors that are common in the indoor wireless environment. Hardware methods to detect some burst errors are possible but nowhere near foolproof.

There will likely be many situations in which the preamble and header is received correctly, but the signal drops out or is corrupted in portions of the subsequent data. In this scenario, the received length and/or the CRC may be correct, but there are bursts of errors in the data.

Probability of Undetected Errors Due to Burst Errors in the Wireless Environment

The 32-bit CRC can detect up to three random bit errors in a given packet. Thus, a burst error event - for the purposes of CRC performance analysis - consists of a combination of four or more bit errors in a single packet. The duration of a burst error event is defined as the time or number of bits between the first bit in error and the last bit in error, within the constraints of the packet length. If the burst error duration is 32 bits or less, regardless of the actual number of errors within the 32-bit duration, the 32-bit CRC guarantees error detection. If the burst error duration is greater than 32 - regardless of the number of bit errors beyond four - the probability of an undetected error with a 32-bit CRC is 2^{-32}. Thus, a minimum (but not sufficient) condition for undetected errors in a packet is that there are four or more errors that span 33 bits or more within a single packet.

Assume for a "typical" environment that the probability of burst errors longer than 32 bits due to all sources occur with a frequency of 0.01, or one in a hundred packets. Obviously, it could get better or worse in any given environment.

Making certain assumptions for average packet size and network efficiency, the maximum **number of packets/year** that a fully loaded wireless LAN with one AP will transmit is:

=	data rate/second	(1 Mbps)
x	1/(average packet size)	(1/100 bytes = 1/800 bits)
x	network efficiency	(0.5)
x	seconds/year	(3600 x 24 x 365)
=	1.97×10^{10} packets/year	

The **number of packets/year with burst errors** is:

=	number of packets/year	(1.97×10^{10})
x	probability of burst error	(0.01)
=	1.97×10^{8} packets/year	

The **rate of occurrence of undetected errors** for a single wireless LAN is:

=	number of packets/year with burst errors	(1.97×10^{8})
x	probability of burst error causing undetected error	(2^{-32})
=	4.59×10^{-2} undetected errors/LAN/year	

The **mean time between undetected errors** for a single wireless LAN is:

= 1 / (rate of occurrence of undetected errors)

= 1 undetected error in 21.8 LAN*years

Thus, an average of one undetected error will pass the 32-bit CRC check per year in a group of 22 separate wireless LANs. As a point of reference, the author of the referenced article [1] considered a mean time between undetected error events of 10^{12} LAN*years as "acceptable for most applications."

Probability of Undetected Errors Due to Packet Formatting Burst Errors

If we use the FH packet formatting method proposed in 94/069 with a stuff/inversion block size of 16 bits, a bit error in one of the stuff bit locations will cause a 16-bit block error. Recalling that the CRC detects all burst errors of length 32-bits or less, one block error alone - or even two consecutive block errors - would be detected by the 32-bit CRC. It will take a minimum of one block error and one other bit error at least 16 bits away from the nearest error in the block to result in a potential undetected error.

Assuming first that the average bit error rate (not including burst errors) is 10^{-5}, the **probability of a block error** in a packet is:

=		average packet size	(100 bytes)
	x	number of stuffing bits per byte	(0.5)
	x	probability of bit error	(10^{-5})
=		2.5×10^{-4} /packet	

The **probability of one other bit error** more than two bytes away is:

=		remaining bytes at least two bytes away	(100 - 6 = 94)
	x	number of bits per byte	(8)
	x	probability of bit error	(10^{-5})
=		7.52×10^{-3} /packet	

The **probability of a burst error/packet** due to the packet formatting is:

=		probability of a block error	(2.5×10^{-4})
	x	probability of one other bit error	(7.52×10^{-3})
=		1.88×10^{-6} /packet	

The **number of packets/year with burst errors** due to the packet formatting is:

=		number of packets/year	(1.97×10^{10})
	x	probability of a burst error/packet	(1.88×10^{-6})
=		3.70×10^{4} packets/year	

The **rate of occurrence of undetected errors** due to the packet formatting is:

=		number of packets/year with burst errors	(3.70×10^{4})
	x	probability of burst error causing undetected error	(2^{-32})
=		8.62×10^{-6} undetected errors/LAN/year	

The **mean time between undetected errors** due to the packet formatting is:

= 1 undetected error in 1.15×10^{5} LAN*years

At an average BER of 10^{-4}, the **mean time between undetected errors** due to the packet formatting is:

= 1 undetected error in 1.15×10^{3} LAN*years

Thus, at 10^{-4} and 10^{-5} BER, the mean time between undetected errors due to the packet formatting is nearly two and four orders of magnitude greater than that due to the "typical" burst error environment.

Issues on Acceptability of 32-bit CRC

First and foremost, will the IEEE 802 recognize the tougher environment of the wireless LAN and allow a relaxed undetected error rate requirement? The undetected error rate due to burst errors calculated earlier are significantly higher than wired systems, but is it good enough?

The undetected error rate with 32-bit CRC's may be sufficient for most mobile user applications. The types of transactions of some mobile user applications do not require high reliability of data. Other applications could add their own data validation if higher reliability is required.

In general, however, we cannot rely on the transport or application layers to provide additional error checking. If WLAN systems are targeted as lower cost substitutes for wired LANs, applications would not necessarily know that a WLAN is being used or have been set up to provide additional error checking.

Options for Improving Performance

Two possible solutions that are practical for implementation are given below.

Longer CRC for packets, e.g., 48-bit or 64-bit.

This would clearly improve the undetected error rate by 2^{16} for a 48-bit CRC and 2^{32} for a 64-bit CRC over the current 32-bit CRC.

Concatenated Codes, e.g., fragmentation of packets with separate CRCs on each segment in addition to the overall packet 32-bit CRC.

Given that the 802 32-bit CRC is generated from a primitive polynomial, a separate smaller CRC on each segment of a fragmented packet, preferably also primitive, would improve the probability of a burst error causing an undetected error. For example, a CRC generated from a 16th order polynomial could provide over four orders of magnitude improvement in the overall undetected error rate. This should be analyzed more carefully before being adopted.

References:

[1] Raj Jain, "Error Characteristics of Fiber Distributed Data Interface (FDDI)", IEEE Transactions on Communications, Vol. 38, No. 8, August 1990.