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Bit Error Rate vs. Frame Error Rate in Wireless LANs

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Abstract

This paper presents a practical method for translating frame errors into bit errors while taking into account the frame size and other factors such as the Inter Frame Spacing. A method previously presented in May 95 PHY meetings, takes into account only frames of 112 octets for the purpose of Bit Error calculation from Frame Error Rate.

1. Introduction

One of the objectives of the IEEE 802.11 Medium Access unit is to provide a mean bit error rate at the MAC layer of less than one part in 10^{8}. As we all know, bits are grouped in frames, but unfortunately 802.11 does not specify a maximum frame error rate. From the MAC stand point FER is the measurement that makes sense, being the only thing it can measure. From the PHY standpoint BER makes more sense because the PHY deals with a bit stream and it is easier to measure.

The wireless LAN environment provides a number of additional challenges and differences versus models developed for the wired environment that usually assume Gaussian noise distribution. In the wireless LAN environment the channel is interference limited with bursty characterisitics, and the error rate depends on a complex combination of factors.

The issue is what performance are we trying to quantify. Are we looking at the performance of the radio only, the radio and the post detection processing, or the whole chain from the antenna to the output of the MAC. As defined today, 802.11 has only two points of access: the antenna and the top of the MAC. If we make the optimistic assumption that all nodes in the network have equal receiver sensitivity some of these factors are:

1. Number of active users on the same LAN, their transmitted power, their access statistics and distance.
2. Number of similar LANs in the same area , number of active users on each LAN, their transmitted power, their access statistics and distance.
3. Number of dissimilar devices transmitting in the same area and their transmission characteristics and statistics.

Unfortunately, in 802.11 we have not defined yet a channel model to offer a standardised method for performance measurement equal for all wireless LAN devices, and this adds another dimension to the complexity of the problem.

Availability of a PHY - MAC exposed (or reachable) interface would resolve the problem by allowing each part to measure errors utilising the most convenient method and then translate the effective error rate utilising one of the standard methods. However we don't have an agreed exposed MAC-PHY interface. Therefore I will try to offer a method that calculates BER from Frame Error rates wiht the desired level of confidence.

For the purpose of this presentation, it is assumed that errors detected in the MAC are not a result of factors other than PHY or channel performance. (For those interested in the PHY performance with an ideal channel -i.e Gaussian noise only- an isolated test environment will be required)
In addition to factors outlined above, the bit or frame error rates are definitely a function of:
- the length of the frame
- the spacing between frames
- the disturbance's characterisitics.

(note: in the following, I'll use the term disturbance for any factor that disturbes the received bit stream, such as noise, interference, colisions etc.)

Providing a system that meets any particular bit error rate in absolute terms is next to impossible because it would require transmission of an infinite number of bits. For that purpose (less accurate but acceptable) statistical methods based on finite experimental measurements have been developed. This document presents a techniques for calculating bit error rates based on measured frame error rates and frame length. I hope this will alleviate the controversy.

2. Noise Models

Though the wireless environments have multiple complex models I will try to classify the error models to only two by the effects produced by disturbances.

2.1 *Single Bit Errors (Model 1)*

The first model to be considered is based on short disturbances that cause single bits to be received incorrectly, i.e a logic zero is read as one and a logic one is read as zero. In this case we can assume a uniform distribution model. This model does not preclude multiple errors (i.e multiple consecutive single bit errors).
Single bit errors during (air) collisions with any signal (similar or dissimilar signals) seem not to be a problem. A single error per frame allows for a simple calculation of the BER. If frequent interference or collisions occur, the frame rate can be lowered to a level that will minimise interference effects (or collisions).

2.2 *Multiple Bit Errors (Model 2)*

When noise or collisions occur in long disturbances, the result will be totally different than the single bit model, depending on the length and position of the disturbance in relationship with the interframe gap. (In 802.11 we have to deal with several values of interframe gaps IFS,DIFS, SIFS.)

If the disturbance burst is short, relative to the interframe gap, the effect will be identical to the single bit errors and the frame will be rejected. If the burst is longer, it may cause not only multiple errors in a frame, but errors in multiple frames. The probability of multiframe destruction depends on the following factors:

1. Disturbance length
2. Interframe spacing
3. Frame length
4. Statistics of the disturbance

When the interframe spacing increases or frame size increases, the probability of a burst to affecting more than one frame decreases. On heavily loaded networks, the average interframe spacing will be small. In the average, the length of the disturbance is expected to be more than the average interframe gap, therefore the frame error rate will increase to reflect this situation. The increase can be approximated by :

$$\frac{\text{(Avg. disturbance length)} - \text{(Avg. Interframe spacing)}}{\text{(Avg. frame length)}}$$

As with single bit error model the frame error rate should be reduced by a factor to account for the collision rate. The collision rate and the probability that long disturbances will affect more than one frame will be both positively proportional to the network load.

3. Error Calculation Methods

3.1 *Direct Measurement*

At the Physical layer the bit error rate can be measured by directly comparing the received bits (after demodulation, data and clock recovery) with the bits transmitted. The easiest way to implement this type of test is without any framing. By transmitting a sufficiently large enough number of bits, the bit error rate can be proven with a very high probability. This method is very common in testing radio equipment on production lines and suitable for "non-bursty" evenly distributed errors.

However, this method does not represent the real life situation for the radio PHYs, the PLCP part is not accurately represented in this type of measurement and the environment is mostly bursty. Therefore, this method represents just a raw bit error rate measurement.

For a more realistic picture which will represent receiver's ability to synchronise and recover bits, a frame based test would seem to be more appropriate.

In order to represent real life, various frame lengths and various interframe spaces (i.e frames with various spacing) have to be transmitted for long enough to provide a good statistical probability.

At the output of the MAC the relevant real data bits will then be compared with the transmitted bits. The number of received frames will be counted. Frames with errors in the PLCP or in the body of the frame will be rejected.

If the disturbance bursts are very short, such as in the noise Model 1, then the continuos measurement method will provide a good indication of the effects of the disturbance on the network throughput. Each bit error will cause in average one frame loss and vice versa.

If the disturbances are long, such as in Model 2, then direct measurement will (exaggerate) amplify the effects of disturbance on the network throughput. If a noise burst for example, causes 50 consecutive bit errors (50 microseconds burst), it might destroy one frame but would be counted 50 times under the direct measurement. The distribution of the bit errors should be recorded and the equivalent frame error rate reduced accordingly. For bursts less than the interframe spacing , only one error should be counted. For disturbances longer than one interframe spacing, but less than an average frame size, n frame errors should be counted.

There are several potential problems with the direct measurement method: first, standard MAC controllers can not be used, second, any means (such as jabbers) that limit the length of transmissions would interfere with the measurement and need to be disabled (if possible). Most MAC designs would also have maximum frame size limitations. Another problem would be creating a “quiet” environment where no other devices utilise the medium. All these are hard to implement in an open “wireless” environment.

The only way the direct method can be utilised, is in an isolated environment and with the PHY separated from the MAC in a special test fixture providing all the necessary MAC controls and interfaces. This would be a challenge for the compliance testers.

3.2 *Indirect Measurement*

On the assumption that many of the MAC controllers will be similar with existing LAN controllers, they will be capable to record the number of received frames that contain errors. These errors usually fall in one of the following categories:

CRC errors: one or more bits have been received **incorrectly.**

Alignment Errors: One or more bits have been received incorrectly and the number of bits received does not correspond to an integer number of octets. Interference can cause extra bits to be received or create extra transitions in the signal stream.

Short Frame Errors: less than a minimum length frame was received. Although this typically is a result of a collision, noise or interference it can also wipe out enough bits to prevent reception of a minimum length frame.

The advantages of using the indirect measurement method are as following:

1. Standard MAC controllers can be used. Since they are part of the entire chain, the overall bit error rate of the system may be estimated.
2. Other activity on the network can continue and may even be encouraged to create realistic test environments.
3. The real Frame Error rate is measured.

The disadvantages of this method:

The calculated bit error rate is not as accurate as the direct continuous bit stream measurement.

3.2.1 **Calculating Bit Error Rate under Noise Model 1**

Assumptions:

1. For the simplification of this presentation it is assumed that bit errors are uniformly distributed throughout the frame (If errors distribution is significantly different, then the results can be multiplied with the function representing the distribution).
2. The bit error rate is much less than 1.0.

Definitions:

Bit	1 or 0
Octet	8 bits
Frame	64 to 1500 Octets
b	Bit error rate
f	Frame error rate
m	Number of bits per frame
n	Number of frames transmitted
P(n,i)	Probability of exactly i errors in n frames
S(n,i)	Cumulative probability of from 0 to i errors in n frames

The gross frame error rate will be :

$$f = 1-(1-b)^m \qquad [3\text{-}1]$$

During the test of n frames, the number of frame errors "i" is recorded. The value for i is in the range of 0 to n. For large "n" the probability of exactly i errors in n frames follows a Poisson distribution of the form:

$$P(n,i) = e\ {-v} * vi/i! \qquad [3\text{-}2]$$

where

$$v = n*f \qquad [3\text{-}3]$$

Note: "*" denotes multiplication.

Then the cumulative probability is calculated as:

$$S(n,i) = \sum_{z=0}^{i} P(n,z) \qquad [3\text{-}4]$$

The cumulative probability can then be used with the test results to prove Bit Error Rate to the desired accuracy. Tables for S(n,i) for various values of n,i and b cam be compiled and used during testing.

Example:

This example is used to demonstrate the approach:

Number of transmitted frames = 10^6
No of Frame errors= 85
Frame size 1500 octets.

In order to calculate the probability that the BER is equal or better than 10^{-8}
$b = 10^{-8}$.
m = 1500 * 8=12000

$i = 85$

$n = 10^6$

$f = 1-(1-b)^m = 1-(1-10^{-8})^{12000} = 1.19928 * 10^{-4}$

$v = n * f = (1.19928 * 10^{-4}) * (1 * 10^{-6}) = 1.9928 * 10^{2}$

$P(n,0) = e^{-v} * v^i/i! = e^{-119.928} * v^0/0! = 8.24 * 10^{-53}$

The same calculations are repeated for P(n,1), P(n,2)....P(n,85)

The probability that the bit error rate is less than or equal to 10^{-8} is provided by

$$1-S(n,i)=1-S(10^6, 85). \quad [3\text{-}5]$$

Calculation of S(n,i)

In order to calculate the cumulative probabilities a computer routine based on the following formula can be used.
Due to overflow limitation of computing machines it is highly desirable to utilise a natural logarithm formula:

$$\ln(P_{n,i}) = \ln(e^{-v} * v^i/i!) = \ln(e^{-v}) + \ln(v^i) - \ln(i!) \quad [3\text{-}6]$$

Note: "ln" denotes natural logarithm
after mathematical manipulations the formula becomes:

$$P(n,i)=\exp[-v+(i*\ln(v))-(\ln(1)+\ln(2)+..+\ln(i))] \quad [3\text{-}7]$$

Frame size considerations: as frame sizes vary, there is a small window in the PLCP preamble where a corruption of a few bits can be tolerated. Since this window is relatively small in relationship with the frame size, it can be neglected for the purpose of calculations.

4. SUMMARY

A practical method for translating the Frame Error Rate to Bit Error Rates has been shown. A similar method has been used for estimation of BER in wired LANs with good results.
Any improvements on the method are welcomed.