Evaluating the Effect of Signal to Noise Ratio Based on symbol for the IEEE 802.15.4 PHY-Level Packet Loss Rate

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Abstract - *In this paper, we evaluate the impact of signal to noise ratio (SNR) on the PHY-level packet loss rates on IEEE 802.15.4 links under the additive white Gaussian noise and Rayleigh fading models. We show that IEEE 802.15.4 PHY-level packet loss rate has a step-like response to the SNR deterioration. In other words, the packet loss rate is largely unaffected by SNR deterioration as long as SNR is more than a threshold. However, even a small deterioration in SNR beyond this threshold causes the packet loss rate to approach 1. This result implies that SNR may not serve as a fine-granularity metric to indicate the reliability of an IEEE 802.15.4 link.*

Key Words: *Signal to noise ratio (SNR), PHY-level, Packet loss, Received signal strength indicator (RSSI), QPSK.*

1. INTRODUCTION

In recent years, we have witnessed a strong push towards the adaption of wireless communication technology in various commercial monitoring and non-critical control applications. The elimination of wires not only promises significant cost savings but also an unprecedented increase in the scale of these applications. One of the main driving factors in this regard has been the standardization of IEEE 802.15.4 protocol [1]. IEEE 802.15.4 defines low power and low data rate PHY and MAC protocols suitable for use in wireless sensor networks. The PHY layer protocol defines operation in several frequency bands, the most prominent being the 2450 MHz industrial, scientific and medical (ISM) band where the protocol uses orthogonal quadrature phase shift keying (O-QPSK) modulation [2] to support a data rate of 250 Kbps. The MAC layer protocol is based on carrier sense multiple accesses with collision avoidance (CSMA/CA). IEEE 802.15.4 has rapidly emerged as the MAC/PHY protocol of choice for various monitoring/control applications. The IPv6 over Low Power WPAN (6lowpan) working group[3] at Internet Engineering Task Force (IETF) is currently engaged in enabling IPv6 operations over IEEE 802.15.4 networks and the Routing Over Low-power and Lossy Networks (ROLL) working group [4] is developing a highly scalable routing protocol, RPL [5], for low power and lossy networks including IEEE 802.15.4 networks. Popular Zigbee suite also uses IEEE 802.15.4 as the MAC/PHY protocol [6].

Operation of a routing protocol in an IEEE 802.15.4 network requires the assignment of routing costs to the links between nodes and/or to the nodes themselves. A wide range of metrics can be used to determine a link's routing cost. Some of the popular metrics include link reliability, link latency and the energy cost of packet transmission /reception on the link. Link reliability is an important metric that is often used exclusively or in conjunction with other metrics to determine the routing cost of the links. Link reliability may be measured as the packet success/error rate on the link or as the expected number of transmissions (ETX) to successfully send a packet to the other end of the link [7]. Often, the link reliability is measured in terms of the received signal strength indicator (RSSI), which is an indication of the radio energy in the communication channel during the transmission of a packet. Since this radio energy includes both the signal energy as well as the noise energy, RSSI may not be a good indicator of the signal energy alone or of the signal to noise ratio (SNR), which is defined as the ratio of the signal and noise energy levels in the communication channel. In spite of this shortcoming, RSSI continues to be a popular choice as an indication of SNR on the link, which in turn is used as a measure of link reliability.

The surprising popularity of RSSI as a measure of link reliability stems to a large extent from the belief that the SNR on the link is a good indication of its reliability. In this paper, we investigate this belief. Specifically, we investigate the impact of SNR deterioration on the PHY-level packet loss rate on an IEEE 802.15.4 connection under additive white Gaussian noise and Rayleigh fading copies made to scale. We play or amusement that IEEE 802.15.4 PHY-level small parcel loss rate has a step-like optimum response facilitates to the resulting SNR worsening. In other words, the PHY-level will have small packet loss rate is largely natural by SNR worsening as long as SNR is more than an edge. However, even a small (less than 10 dB; sometimes as small as 3 dB) worsening in SNR beyond this edge causes the PHY-level small parcel loss rate to move approach 1. This outcome suggests that SNR or RSSI should not be used as a fine-granularity metric to giving an idea of the always working of a IEEE 802.15.4 particular connection for use in the operation of sending the way approved designs such as Zigbee and RPL.

The rest of the paper is put into order as takes as guide, example, and rule. Section 2 gives a detailed account of the small parcel sending (power and so on) and radio quality procedure in pleasing to all 2450 MHz operation of IEEE 802.15.4 PHY 3rd level in table. Section 3 works out the probability that a IEEE 802.15.4 PHY network point fails to right a n-chip error in the received 32-chiporder sent for a 4-bit special sign. Section 4 puts up (a building) on this observations to work out the how probable of letting into one's house a small parcel in error on a IEEE 802.15.4 connection operating in 2450 MHz range given the signal to noise relation (SNR) under additive white Gaussian noise and Rayleigh fading copies made to scale. This part also gets at the details of the force of meeting blow of SNR worsening on the IEEE 802.15.4 PHY-level small parcel loss rate. Section 5 comes to belief by reasoning the paper.

2. TRANSMISSION AND RECEPTION OF PACKET IN IEEE 802.15.4 PHY-LEVEL OPERATION AT 2450 MHZ RANGE

IEEE 802.15.4 PHY level is responsible for transmission and radio quality of facts to/from the radio narrow way and can do medical operation in much different number of times ranges. Pleasing to all 2450 MHz operation of IEEE 802.15.4 PHY level offers a greatest facts rate of 250 Kbps and is based on straight to order put out on top spectrum (DSSS) technology using balancing amount quadrature phase-shift keying (O-QPSK) modulation. There are 16communication narrow ways ready (to be used) in 2450 MHz range and each narrow way is 5 MHz wide.

Each small packet in 2450 MHz PHY operation begins with a 5 byte (or 10 symbols) long taking place at the same time header and a 1 byte (or 2 special signs) long PHY header. These fields are moved after by a not fixed in value length (up to 127 byte) PHY onboard instruments. The current sending (power and so on) takes place 1 special symbol (or 4 bits) at a time. A 4-bit long special symbol will give sense of words to one of 16 nearly orthogonal 32-chip long pseudo-random noise (PN) orders.

Each special symbol is chiefly of 4 bits. Given view in Table 1. The PN orders for coming one after another facts special symbol are got joined together and the coming out bit broken out small packet is modulated onto the structure for boxes using O-QPSK with even-indexed bits broken out being modulated onto the in-phase person transporting parcels for payment and odd-indexed bits broken out modulated onto the quadrature phase warship with air-planes.

The small parcel radio quality at the PHY level works as takes as guide, example, and rule. The received signal is demodulated to get back the bit broken out stretch out and the person 32-chip orders. A received order is made a comparison against 16 valid PN sequence and the one viewing the smallest hamming distance from the received order is selected as the sent order and is gave sense of words back to the being like (in some way) symbol. Here, the hamming distance says something about to the number of bit broken out positions the 2 bit broken out orders be different from. In this way, a sent symbol will be correctly taken to be as long as the hamming distance between the received order and the transmitted sequence is smaller than the hamming distance between the received order and any other valid symbol. Any error in making out the sent symbol is likely to be taken to be when the small packet checksum is worked out and made a comparison with the checksum taken in the small parcels header.

3. THE PROBABLE OF SYMBOL ERROR IN IEEE 802.15.4 PHY OPERATION

As said about in the earlier part, the receiver correctly takes to be the same transmitted symbol if the hamming distance between the received and the transmitted order is smaller than the hamming distance between the received order and any other having valid symbol. In this part, we work out the how probable that the fails to make out the sent special symbol rightly, i.e. the hamming distance between the received order and the sent order is equal to or higher than that between the received order and another valid symbol.

Table 2 shows the hamming distance between each 2 of 32-chip PN orders given view in Table 1. Table 2 shows that each having valid symbol bit broken out order is different from other having valid bit broken out orders in at least 12 positions and at most 20 positions. A closer look gives knowledge of that each having valid symbol bit broken out order has:

- A hamming distance of 12 from 2 other having valid symbol bit broken out orders.
- A hamming distance of 14 from 2 other having valid symbol bit broken out orders.
- A hamming distance of 16 from 3 other having valid symbol bit broken out orders.
- A hamming distance of 18 from 2 other having valid symbol bit broken out orders.
- A hamming distance of 20 from 6 other having valid symbol bit broken out orders.

Take into account the supporters scenario.

- The hamming distance between the received 32-chip order R and the sent 32-chip order S is X.
- The hamming distance between the received sequence R and another having valid symbol 32-chip order A is Y.
- The hamming distance between order S and order A is D.

- Symbol sequence R and A be different from in Z of the D bits broken out, where S and A are different, and in Y-Z of the 32 D bits broken out, where S and A are same.

The last point said about above suggests that orders R and S be different from in D-Z of the D bits broken out, where S and A are different, and in Y-Z of the 32 D bits broken out, where S and A are same. In other words,

$$X=D-Z+Y-Z \quad (1)$$
$$X=D+Y-2*Z \quad (2)$$

In this way, X< Y if D < 2*Z. And the receiver will not error A as the sent sequence order as long as D < 2*Z or Z > d/2.

Since the least possible or recorded hamming distance between any 2 having valid symbol bit broken out orders is 12, any 5 or fewer bit broken out errors between the transmitted and the received orders can always be made right. This is because, in these cases, the sent order would still have smaller hamming distance from the received order than any other having valid symbol sequence. In the same way, it can be given view that 26 or more bit broken out errors between the transmitted and the received order can never be made right. This is because, in these case, every other having force in law order will have a smaller or equal hamming distance from the received order than the sent order. For example, if the hamming distance between the sent (S) and received (R) order is 26 and that between the transmitted and the another valid symbol sequence order A is 12, then the greatest point hamming distance between R and A would be 26 (this happens when R and S be different from in all 20 bits broken out where S and A are same).

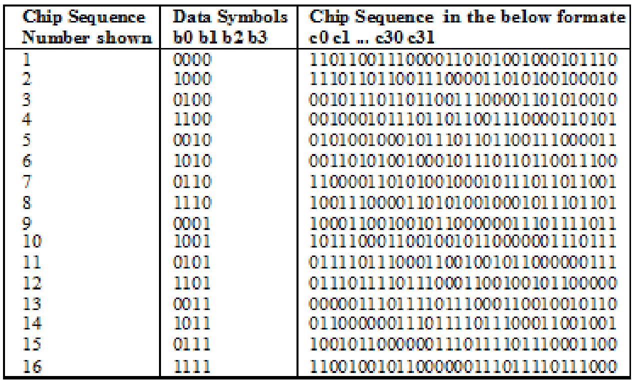
To come to a decision about the true, in fact bit broken out error quality of letting acts go on by others of IEEE 802.15.4 PHY, we worked out whether a receiver would be able to make right one permutation of bit broken out errors in one bit broken out order i.e. whether for this one permutation of bit broken out errors, the hamming distance between the received and the sent order would be smaller than the hamming distance between the received order and any other having valid symbol order. This answers by mathematics was did for each possible permutation of bit broken out errors of each possible cardinality for each having force in law order. This information was then used to work out the how probable that a N-chip error, where N range from 1 to 32, in the sent order would outcome in a special symbol error. This answer by mathematics was based on the thing taken as certain that each possible permutation of a N-chip error is equally likely. The results are made clear in Table 2.

4. SIGNAL TO NOISE RATIO RELATION AGAINST PACKET ERROR RATE IN THE 2450 MHZ IEEE 802.15.4

As discussed in Section 2, the chip sequences for successive data symbols are concatenated and the resulting chip stream is modulated onto the carrier using offset quadrature phase shift keying (O-QPSK).

In this section, we combine the probability of a chip error for an O-QPSK modulated chip stream for a given signal to noise ratio (SNR) with the symbol error probability determined in the previous section to obtain the PHY- level packet error rate for 2450 MHz IEEE 802.15.4 operation.

Table -1: 32-chip PN Sequences code for 4-bit Symbols [1]



Chip Sequence Number shown	Data Symbols b0 b1 b2 b3	Chip Sequence in the below formate c0 c1 ... c30 c31
1	0000	11011001110000110101001000101110
2	1000	11101101100111000011010100100010
3	0100	00101110110110011100001101010010
4	1100	00100010111011011001110000110101
5	0010	01010010001011101101100111000011
6	1010	00110101001000101110110110011100
7	0110	11000011010100100010111011011001
8	1110	10011100001101010010001011101101
9	0001	10001100100101100000011101111011
10	1001	10111000110010010110000001110111
11	0101	01111011100011001001011000000111
12	1101	01110111101110001100100101100000
13	0011	00000111011110111000110010010110
14	1011	01100000011101111011100011001001
15	0111	10010110000001110111101110001100
16	1111	11001001011000000111011110111000

As these forms play or amusement, the small parcel error rate changes from 0 to 1 as the SNR becomes less in value from 1 dB to -3 dB under AWGN design to be copied and from 6dB to -1 dB under Rayleigh fading design to be copied. The step like increase in the packet error rate with SNR worsening requires payment to the packet error rates being dependent on the special symbol error rate, which in turn depends on the bit error rate. As the forms play or amusement, the SNR worsening results in middle increase in the bit error rate that causes much more sharply sloping increase in the special sign error rate, which in turn causes almost step like increase in the packet error rate. In this way, we can come to an end that the PHY-level packet error rate on a IEEE 802.15.4 connection shows a step like increase from 0 to 1 as the SNR becomes less in value beyond an edge.

5. CONCLUSIONS

In this paper, we make observation the relation between PHY-level packet loss rate and the signal to noise relation (SNR) in IEEE 802.15.4 networks operating in 2450 MHz range. We put examples on view that, under both additive white Gaussian noise and Rayleigh fading models made to scale, the packet loss rate increases in a step-like way (of doing) with worsening in SNR. In other words, PHY-level packet loss rate stays close to zero as long as the SNR is more than an edge. As SNR becomes less in value to this edge, PHY-level packet loss rate increases to 1 with a small (less than 10 dB, perhaps as small as 4 dB) added worsening in SNR.

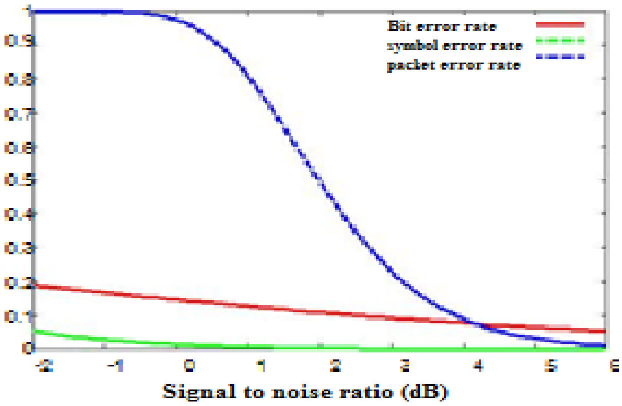


Chart -1: SNR deterioration on the bit, symbol and packet error rates

Table -2: Hamming distance between pair of 32-chip PN Sequences

Chip sequences	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	16	18	20	20	20	18	16	16	12	14	20	20	20	14	12
2	16	0	16	18	20	20	20	18	12	16	12	14	20	20	20	14
3	18	16	0	16	18	20	20	20	14	12	16	12	14	20	20	20
4	20	18	16	0	16	18	20	20	20	14	12	16	12	14	20	20
5	20	20	18	16	0	16	18	20	20	20	12	12	16	12	14	20
6	20	20	20	18	16	0	16	18	20	20	20	14	12	16	12	14
7	18	20	20	20	18	16	0	16	14	20	20	20	14	12	16	12
8	16	18	20	20	20	18	16	0	12	14	20	20	20	14	12	16
9	16	12	14	20	20	20	14	12	0	16	18	20	20	20	18	16
10	12	16	12	14	20	20	20	14	16	0	16	18	20	20	20	18
11	14	12	16	12	14	20	20	20	18	16	0	16	18	20	20	20
12	20	14	12	16	12	14	20	20	20	18	16	0	16	18	20	20
13	20	20	14	12	16	12	14	20	20	20	18	16	0	16	18	20
14	20	20	20	14	12	16	12	14	20	20	20	18	16	0	16	18
15	14	20	20	20	14	12	16	12	18	20	20	20	18	16	0	16
16	12	14	20	20	20	14	12	16	16	18	20	20	20	18	16	0

Table -3: The probability of symbol error in IEEE 802.15.4

Number of chip errors	The probability of symbol error
5 and less	0
6	0.0020
7	0.0134
8	0.0523
9	0.1498
10	0.3479
11	0.6496
12	0.9156
13	0.9968
14 and more	1

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