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RATE ADAPTION TECHNIQUES FOR LOW-POWER AND LOSSY NETWORKS (LLNS) BASED ON LOSS DIFFERENTIATION AND SAMPLE RATE

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ABSTRACT

Proposed herein is a complete solution to choose the appropriate PHY mode for delivering packets between nodes based on loss differentiation and sample rate. With the proper PHY mode selection, the described techniques are capable of distinguishing between fading and collision as the source of poor network performance, which can greatly assist in decreasing the latency of frames in low-power and lossy networks (LLNs).

DETAILED DESCRIPTION

Internet-of-Things (IoT) solutions are widely used in smart utility network applications, such as advanced metering infrastructure (AMI) and Distribution Automation (DA). In some systems, the devices can form a mesh Personal Area Network (PAN) and communicate with each other through wireless links. Since the wireless links can be extremely variable, the packet delivery between devices is unreliable, which may lead to packet loss and poor network performance. Furthermore, in some IoT applications, since the amount of data volume is variable over time, flexibility may be needed to adapt to different data rate requirements.

When a wireless channel suffers from substantial attenuation or noise interference, which results in a higher Packet Loss Rate, the relevant nodes can switch to a lower data rate format to guarantee valid communication services. Conversely, the nodes can increase the data rate when the channel's signal quality improves. Therefore, one key requirement is to accurately measure the Packet Loss Rate during receipt of packets.

Due to the "hidden nodes" problem, packet collision may also occur, which can likewise result in a higher Packet Loss Rate. However, the impacted nodes cannot solve the problem of packet collision by switching the PHY format. Thus, another key requirement is to correctly distinguish the real reason of Packet Loss Rate as either being caused by packet collision or channel error.

IoT devices have the following characteristics compare with WiFi devices:

1) IoT devices have fewer resources to buffer packets;
2) IoT devices have limited selection on supported PHY modes; and
3) Some IoT wireless solutions adopt channel hopping, making CTS/RTS unavailable.

IEEE802.11 has two different kinds of rate adaption algorithms. One kind encompasses open-loop based approaches (e.g. ARF, AARF, AMRR, Onoe and SampleRate). Another encompasses closed-loop based approaches (e.g. CARA, RRAA, RBAR). The open-loop based approaches use consecutive packet transmission or packet delivery ratios in a time window to decide when to switch the data rate, which cannot work well if the lost packets are caused by network collisions. The closed-loop based approaches use the timely collected value to select an appropriate data rate and use the RTS/CTS to detect the collision. In at least some contexts, IoT solutions cannot use RTS/CTS frames because of channel hopping.

PHY mode "receiver sensitivity" is the lowest input power for which the packet error rate (PER) condition is met. If noise is also considered, a relationship between signal-to-noise ratio (SNR) and loss rate can be generated. "Transition range" is defined as the SNR range over which the frame losses increase from receiver sensitivity to 100%. For example, as shown in Figure 1, if the SNR falls below 18 dB, frame losses begin to occur, and if the SNR is less than 13 dB, frame loss increases to 100%. Thus, in this example, the transition range is about 5 dB (from about 13dB to 18 dB).

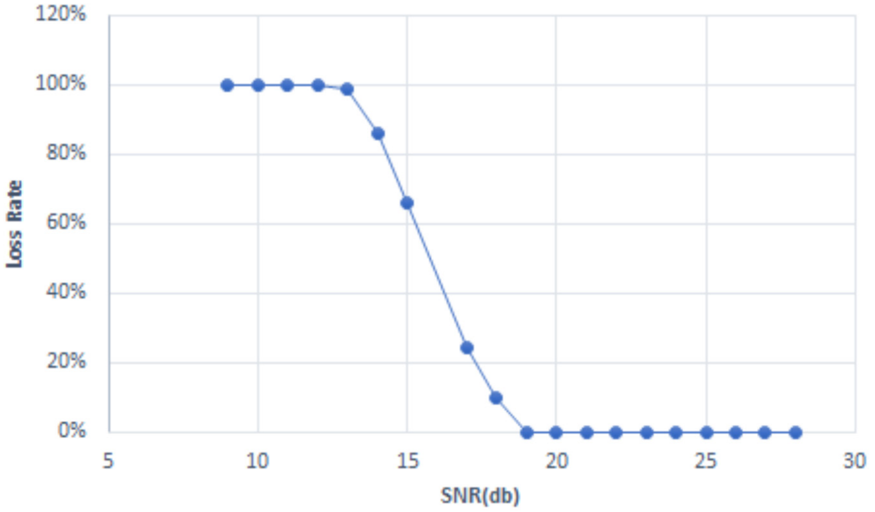

Figure 1 Loss Rate with different SNR

This proposal includes a first novel mechanism to select the proper alternative PHY modes based on loss rate differentiation and RF sensitivity differentiation by applying two rules. According to the first rule, the loss rate differentiation of two adjacent PHY modes in the transition range should be greater than a certain threshold. Each PHY specification provides several alternative PHY modes with different data rates. The transition ranges of different PHY modes may overlap.

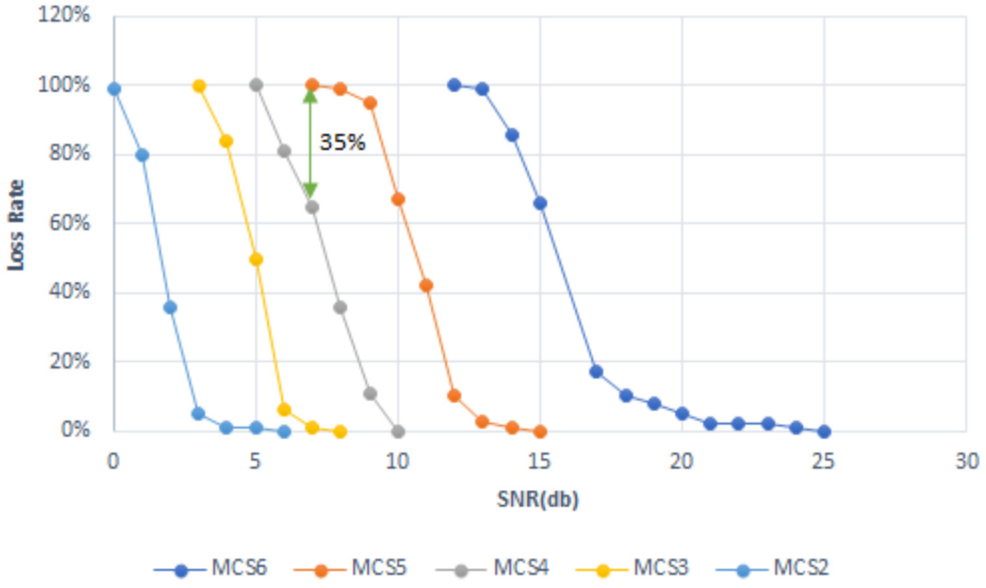

Figure2 OFDM option2 Loss Rate with different SNR

Figure 2 shows the RF sensitivity of IEEE802.15.4 SUN OFDM option2 MCS2 ~ MCS6. In this example, 50% is the empirical value for the least loss differentiation threshold (LDT), which is the threshold against which the loss rate differentiation of adjacent PHY modes in transition will be evaluated. Based on the selecting rule, MCS4 is not a good candidate because the loss rate of MCS4 is about 65% at an SNR of 7 dB, and the loss rate of MCS5 is 100% at an SNR of 7 dB. Further, the loss differentiation between MCS4 and MCS5 at an SNR of 7 dB is 35%, which is less than the required LDT of 50%. After MCS4 is excluded, all other PHY modes meet this rule.

According to the second rule, the RF sensitivity differentiation of two adjacent PHY modes should be in a certain range. Because of the capture effect, under the same conditions, a node with lower data rate could get a better bit error rate (BER) than a node with a higher data rate when collision happens. This effect will ultimately influence the frame loss rate if the differentiation of RF sensitivity is over a certain threshold. This threshold depends on different PHY specifications. From IEEE802.15.4 SPEC, PER for RF sensitivity is 10%. Based on experimentation, a suitable threshold for RF sensitivity differentiation is about 10 dB.

For example, as shown in Figure 2, the sensitivity of MCS6 is 16 dB, and the sensitivity of MCS5 is 11 dB, so the differentiation is 16 - 11 = 5 dB which is acceptable. But considered the situation between MCS2 and MCS6, the differentiation is about 13 dB (16 - 3), which violates the second rule relating to RF sensitivity differentiation between two adjacent PHY modes. Consequently, it would be unacceptable to make MCS2 and MCS6 as adjacent PHY modes, and it would be necessary under the second rule to insert MCS3 or MCS5 between MCS2 & MCS6 (MCS4 was already excluded under the first rule).

This proposal further includes a second novel mechanism to provide collision awareness based on the loss differentiation of different PHY modes. According to the rules of the first novel mechanism, a set of PHY modes are selected. The second mechanism is based on the concept that collisions can be identified based on the loss differentiation of the current PHY mode and a potentially better PHY mode. If frame loss is caused by collision, a PHY mode with a lower data rate will be probed. The possible scenarios are as follows:

1. Each node probes a PHY mode with a lower data rate. It is apparent that transmission in a lower data rate will require more time, which causes more severe congestion. Therefore, the loss rate will be even higher. Consequently, if the loss rate increases when the PHY mode with lower data rate is probed, collision should be the main reason for frame loss.

2. Some nodes probe a PHY mode with lower data rate. Due to the capture effect, the loss rate may decrease if the node probes a PHY mode with a next lower PHY mode. But as a result of the constraint in the second rule of the first mechanism described above, the loss differentiation is limited.

Thus, if the loss rate significantly decreases after the next lower PHY mode is probed, the main reason for frame loss should be channel fading. Otherwise, it is caused by collision with a high probability. The LDT selected in the first rule of the first mechanism is the judging condition for the loss differentiation of two adjacent PHY modes.

For instance, consider three alternative PHY modes A, B, and C. The current PHY mode is C. With the loss rate shown below, the next potential PHY mode is B which has the next lower data rate compared with PHY mode C. Further, the loss differentiation is higher than the LDT (loss differentiation threshold, for example 50%). Consequently, the frame loss is most likely caused by channel fading.

	Data Rate (kbps)	Loss Rate (%)
A	200	0
B	400	10
C	600	70

According to another scenario, the loss rate of the current PHY mode C is 40%, but the loss differentiation between C and B is only 5%, which is much lower than the LDT, which is a common scenario when the frame loss is caused by collision.

	Data Rate (kbps)	Loss Rate (%)
A	200	30
B	400	35
C	600	40

This proposal further includes a third novel mechanism, which is a PHY mode switch based on the combination of loss differentiation and sample rate. SampleRate is one of the popular frame-based rate adaptation algorithms. At a high level, SampleRate computes the average loss rate at various data rates and picks the rate with the highest throughput. Based on the second novel mechanism described above, collision and fading can be distinguished. But this provides only a PHY mode switch tendency. In the first example above, it is apparent that frame loss is caused by fading. But because the current PHY mode has higher data rate, a throughput comparison is still necessary before deciding to make a PHY mode switch.

A popular, well-accepted throughput calculation equation is DataRate * (1 - PER). However, this calculation may not be suitable for a mesh network. The third mechanism proposes a punishment score based on Expected Transmission Count (ETX). Score = (1 / DataRate) * (ETX ^2). A lower score indicates lower latency. It can ideally fit a latency curve compared with the standard equation.