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NOVEL TECHNIQUES TO DISTINGUISH FADING FOR ADAPTIVE MODULATION IN A LOW POWER AND LOSSY NETWORK (LLN)

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ABSTRACT

Techniques are described herein to distinguish fading for adaptive modulation in a Low power and Lossy Network (LLN). The techniques include splitting large frames into small fragments at the physical (PHY) or Media Access Control (MAC) level. Fragments are possibly acknowledged (e.g., using draft-ietf-6lofragment-recovery), which gives a bitwise signature of a transmission. Those signatures are appended to one another in a bit stream. In that bit stream, scattered losses mean fading whereas continuous losses for a brief time indicate a collision. In the former case, a node can increase power or decrease modulation and/or speed; however, in the latter case, it must not do so since this can aggravate the situation.

DETAILED DESCRIPTION

Internet-of-Things (IoT) devise 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 are extremely variable, the packet delivery between devices can be unreliable, which might lead to packet loss and/or 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 great attenuate 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. On the other hand, the nodes can improve the data rate when the channel becomes better. Therefore, one key factor is to accurately measure the Packet Loss Rate during the received packets.

Due to the "hidden nodes" problem, packet collision may also occur, which can also result in a higher Packet Loss Rate. However, the relevant nodes should not switch the PHY format, which can't solve the problem of packet collision. Thus, another key factor is to correctly distinguish the real reason of Packet Loss Rate as either being caused by packet collisions or channel errors.

This proposal includes a first novel mechanism to measure Packet Loss Rate more accurately using a packet fragmentation method. Typically, information of only Packet Loss Rate is not enough to distinguish perfectly because the performances of collision and fading are almost the same. Therefore, this proposal provides a packet fragmentation method to check the corruption of each segment. Considering the compatibility, this proposal could take advantage of the 802.15.4k protocol to transmit MAC Protocol Data Unit (MPDU) fragments.

Note that in a number of implementations the PHY activity is hidden above the MAC and the knowledge below is obfuscated to the code that decides which modulation should be used. This is the case for connected grid (CG) mesh systems and an alternate proposal for such systems is to use Internet Protocol version 6 (IPv6) over Low-Power Wireless Personal Area Networks (6LoWPAN) recoverable fragments (such as described in draft-ietf-6lo-fragment-recovery) as opposed to PHY level fragments to achieve the exact same results. Of course, "fragments probing" may only be sent if the Packet Loss Rate is high. Advantages of this first novel mechanism may include the overhead being relatively low, no more MAC headers for fragments, and it is standard.

In order to reduce the loss of efficient data rate, an Immediate Acknowledgement (I-ACK) policy can be set to '2' in the MPDU Fragment Sequence Context Description Information Element (IE), where the I-ACK may be generated only when the last expected fragment is received or if the timeout has elapsed. An I-ACK contains the bitmap which indicates the successful received fragments.

Each fragment may have its own Frame Check Sequence (FCS) that should be transmitted in a short interval. The sender can check the I-ACK validation field to mark the received fragments and loss fragments. With this field, this mechanism may provide more acknowledgement of Packet Loss Rate to significantly improve the accuracy of distinction. An example packet fragmentation and I-ACK policy is illustrated below in Figure 1.

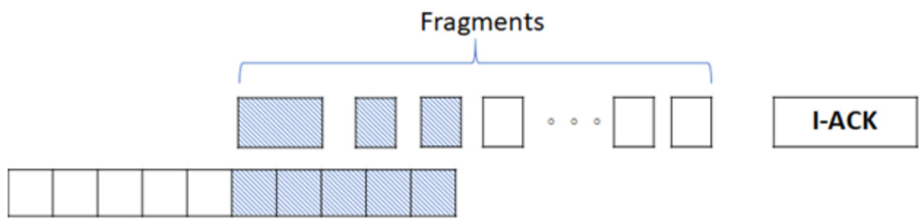

Figure 1 – Packet Fragmentation and I-ACK Policy

For CG mesh implementations, as discussed above, techniques of this proposal may be performed at Layer 2.5 (L2.5) using 6LoWPAN fragmentation in which a frame is separated into several fragments using 6LoWPAN recoverable fragments (Rfrag). Each fragment has its own FCS, a datagram tag, and a sequence. The sequence is an offset in the ACK bitmap.

Note that the 6LoWPAN ACK bitmap is not the sequence of bits on which the continuous loss is assessed. Rather, another sliding window of bits can be built that is independent on which packet the fragment comes from, but is sequential with the transmission of fragments. In general, the size of the can be varied but is may be big enough to detect high frequencies in loss. The sender could make an internal arbitration based on the received Rfrag-ACK, which is the 6LoWPAN equivalent of I-ACK. With 6LoWPAN Rfrags, the fragments are acknowledged in a bitmap per datagram so it can be determined which ones are received. As long as there is an overlap between two transmissions, contiguous error will occur with high probability during the overlap. It may not be guaranteed that there will be no false positives or false negatives using techniques described herein; however, the probability of contiguous error is much higher for collision than fading.

This proposal further includes a second novel mechanism to leverage some algorithm such as Fast Fourier Transform (FFT) to enlarge the difference between collision and fading. Consider, for example, that a long packet could be considered as a combination of segments in which "+1" represents a successful transmission for the segments and "-1" represents a failure. For this second mechanism, consider that A and B are two nodes with the same parent in which different performances between collision and fading using the FFT algorithm can be analyzed.

1. Collision Analysis

If the packet loss is caused by collision, continuous segments will be corrupted because of the overlap of transmission time, as shown in Figure 2, which illustrates a distribution of segments for a collision.

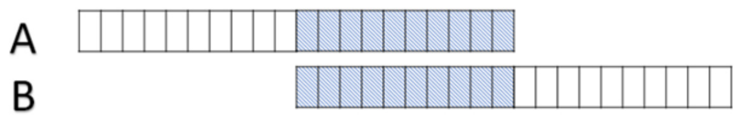

Figure 2 – Distribution of Segments for Collision

After marking each segment with '+1' and '-1', a time wave can be obtained, as shown in Figure 3.

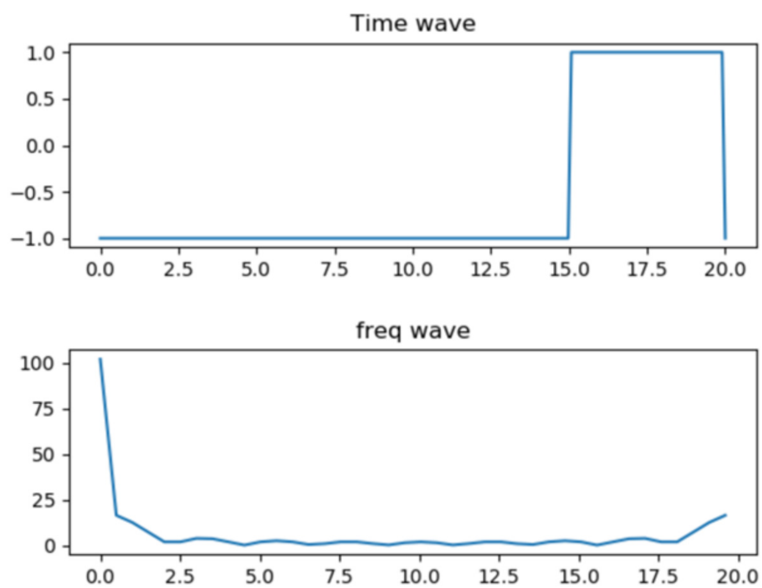

Figure 3 – Collision Situation

An FFT-based method is proposed to analyze the time wave that first includes up-sampling the time wave with the sinc() function interpolation technique. Then the signal could be converted from the time domain to the frequency domain using an FFT algorithm to obtain the resultant frequency (freq) wave, as also shown in Figure 3. From the frequency wave, it can be determined that the lower-frequency component is a lot more than the high-frequency component. As a contrast, the fading situation could also be analyzed using an FFT-based method, discussed below.

2. Fading Analysis

If packet loss is caused by fading, the distribution of segment corruption is random, as shown in Figure 4as Fig. 4 shows.

Figure 4 – Distribution of Segment for Fading

After up-sampling and performing the FFT conversion, the time wave and frequency wave signals are as shown in Figure 5.

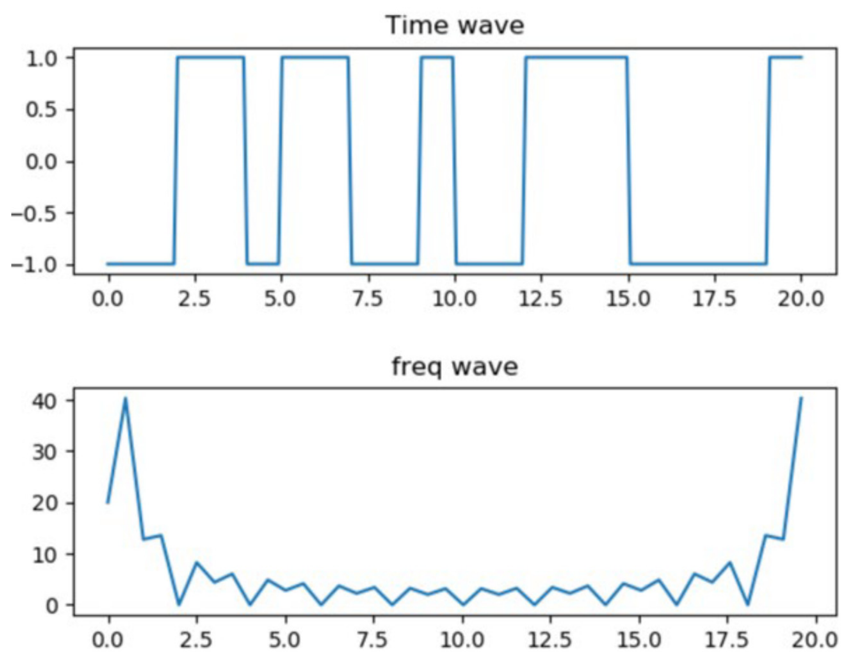

Figure 5

The frequency wave of Figure 5 reveals that the high frequency component becomes more compared with that in the collision situation as shown in Figure 3. Therefore, the difference of the frequency waves between collision and fading could make it possible to distinguish them. In some implementations, a cumulative distribution function (CDF) may be used to make the decision to distinguish between collision and fading.

Thus, this proposal further includes a third novel mechanism in which a cumulative distribution function (CDF) is applied in the final decision strategy. The signal of the frequency waves for collision and fading could be recognized as the random variable due to the random channel and the CDF can be used to determine the probability of change from lower-frequency to higher-frequency, as illustrated in Figure 6 in which the green curve is associated with collision and the blue curve is associated with fading.

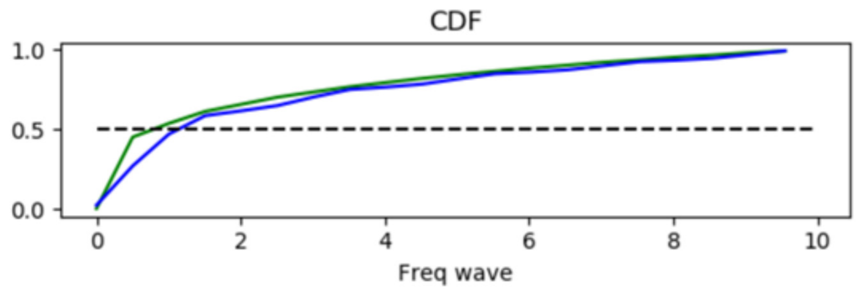

Figure 6 – CDF Curves (Green Curve is Collision, Blue Curve is Fading)

By analyzing Figure 6, it can be determined that the points of 50% probability have a distinct gap between the CDF curves of collision and fading, which can set a threshold to distinguish between collision and fading very well. In general, a stiffer CDF curve of collision means it has more low frequency component than fading. So it doesn't present the probability of happening in common, but the probability variation trend about the frequency component from low frequency to high frequency.

Although the techniques described above involve the comparison of the high-frequency component between collision and fading, other comparisons could be utilized in accordance with techniques described herein.

Accordingly, this proposal provides a first novel mechanism for implementing a packet fragmentation method to make the Packet Loss Rate more accurate and then provides a second novel mechanism based on the FFT algorithm to enlarge the difference between collision and fading. Finally, this proposal provides a third novel mechanism in which a CDF function and a probability threshold are applied to make a final decision of distinction between collision and fading.

Thus, this proposal provides new techniques to distinguish collision from fading on Layer 2 (L2) based on limited information about the PHY, which may be applicable to both

802.11 and LLN environments, as well as more general environments. In particular, techniques described herein operates on elements that are visible above the MAC and does not require a change in the PHY. Fragments can be error checked (Layer 2 / 2.5, e.g., 6LoWPAN) to distinguish collision from fading over a sliding window of fragments, which may be generated from a same packet or of multiple packets, including interleaved retried fragments from previous packets.

In summary, techniques are described herein to distinguish fading for adaptive modulation in a LLN. The techniques include splitting large frames into small fragments at the PHY or MAC level. Fragments are possibly acknowledged (e.g., using draft-ietf-6lofragment-recovery), which gives a bitwise signature of a transmission. Those signatures are appended to one another in a bit stream. In that bit stream, scattered losses mean fading whereas continuous losses for a brief time indicate a collision. In the former case, a node can increase power or decrease modulation and/or speed; however, in the latter case, it must not do so since this can aggravate the situation.

