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TECHNIQUES TO IMPROVE THE HIT RATE OF UNICAST NODE-TO-NODE (N2N) DELIVERY IN CHANNEL-HOPPING AND MULTI-HOP LOW-POWER AND LOSSY NETWORKS (LLNS)

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ABSTRACT

In a large scale wireless mesh network, such as a Wireless Smart Utility Network (Wi-SUN), there can be many losses. For example, a transmitter typically does not know the availability of a receiver when transmitting, which can create losses. In another example, link quality measurements, such as expected transmission count (ETX), may not be well represented for every channel. In one instance, this proposal provides an improved scheduling technique that leverages Broadcast Interval (BI) information to determine receive (RX) and transmit (TX) plans for child nodes. Child nodes can select an appropriate parent node according to received schedules, which can facilitate download traffic propagation. In another instance, this proposal provides for the ability to facilitate fine management of ETX evaluation to improve the successful rate of packet delivery. Techniques of this proposal not only leverage a central control method, but also introduce a free contention mechanism through which a central node can announce acceptable time slots to sub-nodes. The central node may avoid assigning smaller slots for each sub-node in order to allow the sub-nodes to compete for communications. Thus, techniques herein may combine various advantages for both deterministic networks and mesh networks.

DETAILED DESCRIPTION

Classical connected grid (CG) mesh systems are being evolved to implement Wi-SUN deployments in which Wi-SUN is an open standard typically provided for large-scale outdoor Internet of Things (IoT) wireless communication networks that can be configured to support a wide range of applications.

A Personal Area Network (PAN) of a Wi-SUN deployment often consists of massive wireless nodes and one 6LoWPAN (Internet Protocol version 6 (IPv6) over Low-

Power Wireless Personal Area Network) Border Router (6LBR). Such networks are often implemented via a tree-like topology in which frequency hopping and a multi-hop wireless network is provided per the Routing Protocol for Low-Power and Lossy Networks (RPL), as codified in Request For Comments (RFC) 6550. In such networks, a child node preferentially selects a preferred parent node from a candidate list having a 'good' link quality with the child node.

Determining whether a link quality is 'good' or 'bad' may involve different considerations. For example, RPL provides that Expected Transmission Count (ETX) is to be used to measure link quality. ETX is the number of expected transmissions of a packet necessary for the packet to be received without error at its destination. For each node in a Wi-SUN deployment, it is desirable that all transmissions could be received by recipients. However, 100% successful transmissions do not exist in actual deployment, due to the following major factors:

1. Radio interference,
2. Channel access competition (e.g., hidden stations problem),
3. Half-duplex RX/TX mechanisms of a Radio Frequency (RF) module for nodes, and/or
4. ETX deviation in different channels.

The first two factors can positively affect ETX because ETX should typically be increased when there is strong radio interference or high channel competition for a node such that the affected node could switch to another parent node that has a lower ETX, which can help to balance the network. However, current mechanisms do not handle the remaining factors (half-duplex operations and ETX deviation) that can affect successful transmissions, which can cause incorrect ETX measurements and redundant retransmissions.

Half-duplex operations typically performed by a node involve the RF chip and antenna for the node operating in a half-duplex mode such that signals cannot be received by the node while it is performing signal transmissions. Such operations can cause problem incorrect ETX measurements and redundant retransmissions by nodes. With regard to ETX deviations, consider that ETX embodies the average link quality between two nodes, but it has limitations in channel hopping networks. For simplicity, assume that a node only uses

2 channels (a) and (b) for frequency hopping and that all transmissions are successful when the node uses channel (a), but there are 50% failed cases when using channel (b). If the node uses channel (a) for 80% transmissions and channel (b) for the rest, its ETX will be 142. However, if the schedule is reversed, for example if the node uses channel (b) for 80% and channel (a) for the rest, the ETX will be 213. Thus, reversing the schedule can cause completely different results.

According to RPL, an endpoint choosing parent node depends on ETX and RANK, but if the ETX is easily changed, issues can arise with endpoint parent selection. For example, it may take multiple unnecessary failed transmissions before an endpoint can determine the actual ETX for a system.

Accordingly, this proposal provides techniques to address problems associated with half-duplex operation and ETX deviations. In particular, techniques herein involve a parent (coordinator) broadcasting TX and RX schedules for one or more Broadcast Intervals (BIs) based on throughput prediction. A child node can then adjust its transmission plane based on the most recently received RX/TX time schedule.

In one instance, techniques involving Fibonacci retracement to predict the future throughput of broadcast (BCAST) slots for a node in LLNs can be enhanced to predict future TX throughput over one or more future BI slots for LLN nodes. Once a node determines future TX throughput, the time needed for transmitting in a BI can be easily determined.

Figure 1, below, illustrates example details associated with techniques of this proposal in which a parent node divides the unicast (UCAST) duration (UD) of a BI into two partitions, similar to a superframe (SF) structure including 1) an Active Portion, and 2) an Inactive Portion.

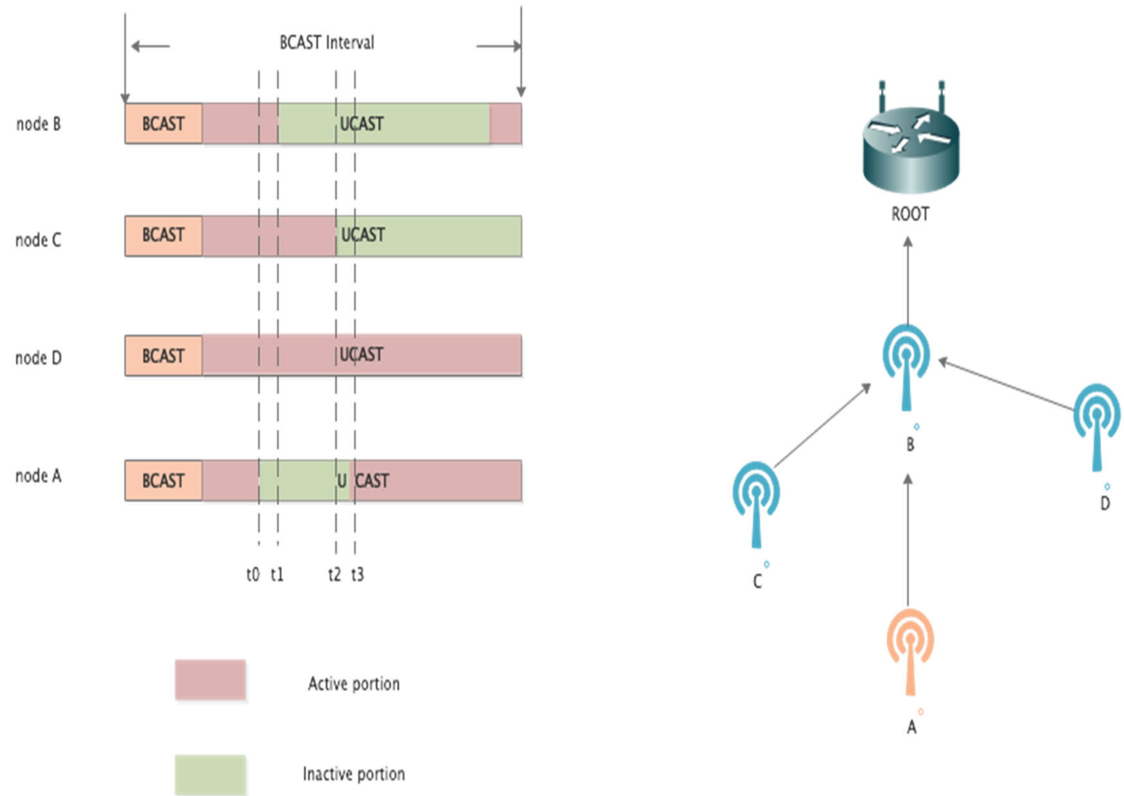

Figure 1: UCAST Duration Partitioning Details

For the Active portion as shown in Figure 1, the parent node is open to receive transmissions for all child nodes and, for the Inactive portion the parent node can plan to transmit its own packets.

For this proposal, consider that each parent node broadcasts its TX/RX schedule within a broadcast (BCAST) duration, and the child nodes refresh this content within a neighbor information table as long as the information is received. However, if every node shares its schedule within a BCAST slot, this, in itself, can cause many collisions and loss at the same moment.

Thus, this proposal further provides that each node spreads schedule information for the following 'N' number of BI slots in which N is an even number, e.g., 2, 4, ..., 2*m. Using this technique, only 1/N nodes may need to spread their schedule information per BI, which can reduce networking maintenance during the same BI. However, this proposal goes further in providing that more than 1/N nodes may broadcast their schedule information per BI in order to avoid some child nodes missing these messages.

For example, that there are 100 nodes in a PAN and each node spreads its RX/TX schedule every 10 BIs. In this example, only 10 nodes may broadcast their schedules in the same BCAST slot. Each schedule may contain 20 BIs to ensure the child nodes receive the schedules twice before a previously transmitted schedule is consumed.

As shown in Figure 2, below, the hop 1 node spreads its following 20 BIs' schedules in the 0th, 10th, . . ., 40th, etc. BI slot to the hop 2 node and the hop 2 node spreads its schedules in the 1st, 11th, . . ., 41st, etc. BI slot to two hop 3 nodes. Further, both the hop 3 nodes exchange their schedules with each other in a different BI slot. For example, the hop 3a node broadcasts its schedules in 0th, 10th, . . ., 40th, etc. BI slot and the hop 3b node spreads within the 3rd, 13th, . . ., 43rd, etc. BI slot. Thus, each node has two chances to update neighbors' schedules before they consume the old schedules. In some implementations, schedule information could be injected into any BCAST messages as an additional payload information element (IE) of an Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 frame, such as a Destination Oriented Directed Acyclic Graph (DODAG) Information Object (DIO), or by creating an independent BCAST message to spread this information periodically.

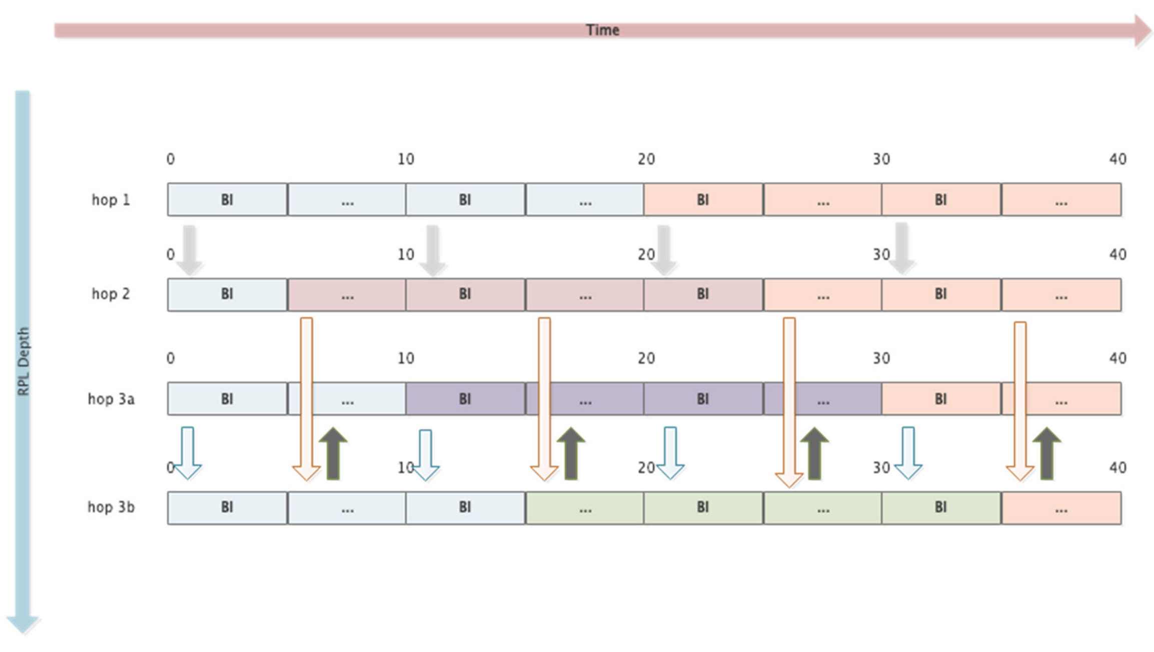

Figure 2: Example Schedule Transmission Details

A random offset for arranging TX and RX time in one BI slot for each node can be utilized to reduce collision risk. For example, after determining the rate of TX and RX in one BI, the TX or RX time could simply be set at the beginning of one BI. However, doing this would cause all nodes to enter the TX mode at the same time. In some instances, neighboring nodes could be arranged into a reasonable working mode in which one is in an RX mode while the other is in a TX mode.

Still, considering this factor in which all nodes could potentially enter the TX mode at the same time, this proposal provides for injecting a random offset for TX time in each BI. For example, consider Figure 1, above, in which node A may desire to send packets to its parent node B from t0 to t3, but it detects node B will turn to TX mode when time is t1 according to received schedule information. As a result, node A can turns candidate node C from t1 to t2 and candidate node D from t2 to t3.

In addition to the above techniques, this proposal further provides for using an Extended Directed Frame Exchange (EDFE) for probing if a recipient is available for receiving, even if it is in a TX portion of its schedule. For example, sometimes a transmitter may not find any possible parent nodes from its neighbor information table because all of them may be in a TX mode at that a given moment. As shown in Figure 3, below, consider that node A has no available parent node from time t2 to t3 because all of the parent nodes are busy with transmissions.

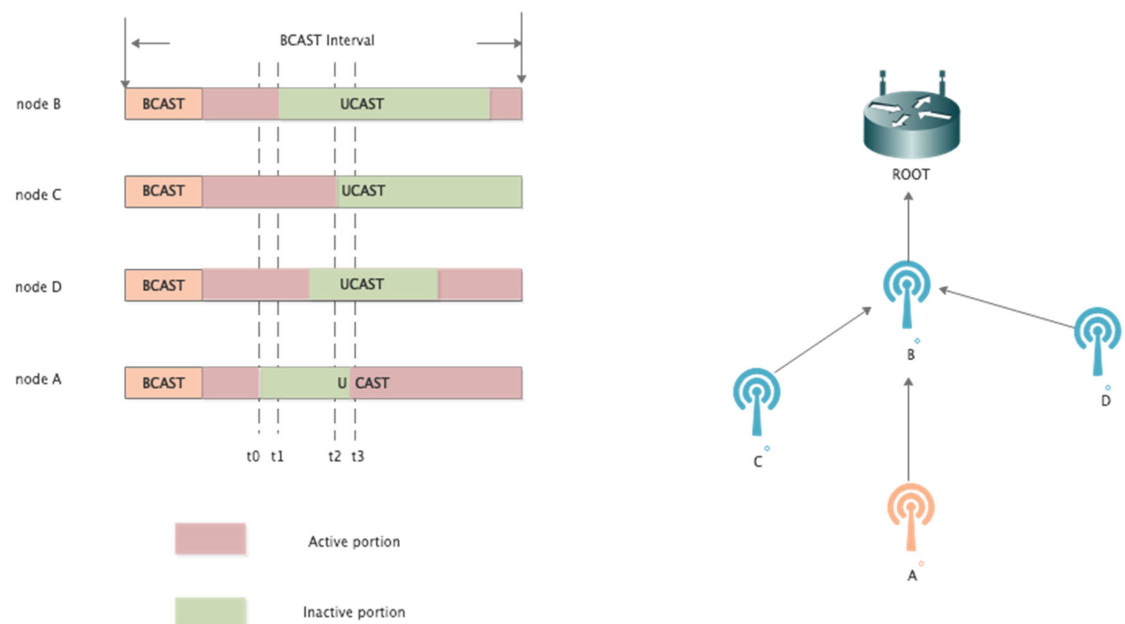

Figure 3: EDFE Example Scenario

For the example illustrated in Figure 3, node A has two options for handling such a situation. For a first option, node A may stop transmitting immediately, i.e., the node switches to RX mode when time is t2, and then sends the rest packets in next BI.

For a second option, node A may select a parent node to send an EDFE in order to request an extended transmission time slot. Because the TX time slot (which is marked with GREEN) is evaluated using Fibonacci retracement method, the results are not completely accurate. Consequently, this may mean that some of the parent nodes are not in the TX mode at that moment. Based on this principle, it is proposed that node A sends an EDFE to a selected parent node (e.g., node B, C or D) in which the following transmissions will be successful if they are available. Otherwise, the wasted overhead may be very small because the initial EDFE frame is simple and short. Another benefit of this option is that other siblings will not compete for this time slot because they consider the slot to be a TX mode slot. Thus, collisions may not exist, except for other nodes that may be utilizing an EDFE probe.

An additional aspect of this proposal includes using EDFE for probing if a recipient is available for receiving during an asynchronous (ASYNC) duration. As illustrated above, ASYNC schedules can be triggered by a trickle timer with randomness, and the durations can be particularly long in relation to a single BI duration. In order to avoid such long unconnected periods, this proposal provides for attaching a new IE to a current ASYNC message that indicates when the next ASYNC message is to occur and a corresponding length for the message. As long as the child node receives this message, it marks the time to avoid sending data to the parent node during that period. Similar to the above, this technique involves using an EDFE to detect the availability of a selected parent node during an ASYNC period if transmissions cannot wait to the next BI window.

Finally, techniques herein provide for utilizing an asymmetric channel notch as a solution to the ETX deviation problem. In particular, this proposal provides for creating several independent ETXs for each channel or several successive channels rather than a single ETX, which typically denotes the average degree of link quality for all channels.

As we discussed above, different channels can have a different link quality status. Although a currently measured ETX could represent the average link quality in a very long period because every channel may have an equal opportunity to be used for transmitting, it is desirable for re-transmissions to be minimized if it is known that some channels may not be good channels to utilize for some specific neighbors.

The Wi-SUN protocol provides for the ability to delete one or more low link quality channel(s). This is typically referred to as "channel notch." However, a channel might not be good for only one parent node or may not be workable during one specific period. Thus, deleting such a channel may unnecessarily waste bandwidth.

Thus, rather than using single a ETX to evaluate current link quality to a neighbor, this proposal provides for creating several independent ETXs for a single channel or successive channels in a group. A threshold can be defined in advance such that if a current channel ETX exceeds this threshold, the transmitter can re-select another neighbor that has an acceptable ETX in this channel with which communications can be exchanged.

For example, as shown in Figure 4, below, consider that the node A has different ETXs in different channels to the same neighbor. In accordance with this proposal, further consider that there is a threshold that can be used to determine whether or not to perform a transmission. In one instance, if the ETX threshold is set 300, then for the present example node A can transmit packets to node B with channels 1 and 3 and channel 2 may be used to transmit packets to node C rather than node B.

	CH 1	CH 2	CH 3	...
node B	128	400	196	...
node C	156	256	128	...
node D	134	134	256	...

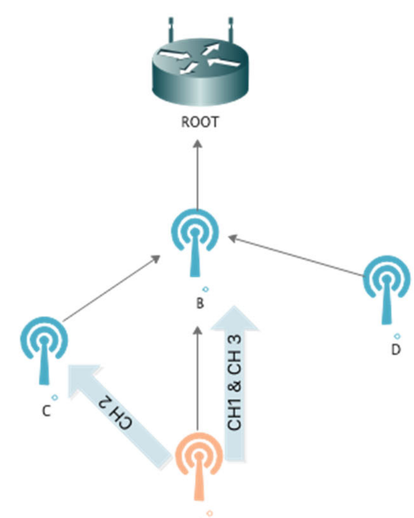

Figure 4: Example ETX Deviation Solution Details

In one instance, this technique may be characterized as a "single side channel notch" or "asymmetric channel notch" in which bad ETX channels can be avoided for packet transmissions and a transmitter could change to another parent node in order to utilize a UCAST slot. This may not only keep a channel from being used by other neighbors, but may also improve the hit rate of successful UCAST packet delivery.

In some instances, maintaining a separate ETX per channel may create heavy burdens for the limited resources of a node, thus, this proposal further provides for allowing several successive channels to share an ETX. For example, an implementation may provide for channels 0-4 sharing one common ETX, channels 5-9 sharing another ETX, and so on. Accordingly, such an implementation may provide fine management for ETX evaluation.

In summary, provided herein are improved scheduling techniques that leverage BI information to determine RX and TX plans for child nodes. Child nodes can select an appropriate parent node according to received schedules to facilitate download propagation. Additionally, techniques herein provide fine management of ETX evaluation to improve the successful rate of packet delivery. Thus, this proposal not only leverages centrally controlled techniques, but also introduces free contention techniques such that a central node can announce acceptable time slots to all sub-nodes and not assign smaller slots for each node. In response, each node can compete for communication rights among themselves, which may combine advantages of both deterministic networks and mesh networks.