March 2020

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Recommended Citation
Jiang, Caijun; Zhang, Xiaopu; Wang, Zhanwu; and Zhu, Dapeng, "FAST FORWARDING ROUTING MECHANISM BASED ON NETWORK TOPOLOGY FOR WIRELESS SENSOR NETWORK", Technical Disclosure Commons, (March 20, 2020)
https://www.tdcommons.org/dpubs_series/3037

FAST FORWARDING ROUTING MECHANISM BASED ON NETWORK TOPOLOGY FOR WIRELESS SENSOR NETWORK

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ABSTRACT

Techniques are described herein for dynamically adjusting a transmit sequence based on a coefficient collision table. A fast forwarding routing mechanism may search a routing table when traffic enters the data plane, and fill the output buffer of a corresponding interface. Furthermore, if the data plane detects large amounts of short packets destined for the mesh, compression into one packet can be achieved if they belong to a common parent.

DETAILED DESCRIPTION

Recently, Wireless Sensor Networks (WSNs) have been widely recognized as a promising technology which has wide applicability in Field Area Network (FAN) solutions, such as Advanced Metering Infrastructure (AMI) and Distributed Automation (DA) Gateways, which enable forming network connectivity for a FAN.

Figure 1 below illustrates an example overview of a connected grid mesh network (CG-MESH) that includes a Connected Grid Router (CGR), thousands of Connected Grid Endpoints (CGEs), and cloud management servers. CGR is a key component of the FAN solution, offering a reliable communications platform for smart metering, DA, and remote workforce automation. For example, a CGR can support outdoor wired and WSNs. It supports a variety of communications interfaces, such as Ethernet, serial, cellular, Radio Frequency (RF), and Power Line Communications (PLC). The mesh nodes are aggregated at a CGR mounted on pole tops or in secondary distribution substations.

Figure 1. Overview of connected grid mesh network

In the FAN solution, Internet Protocol version 6 (IPv6) over Low-power Wireless Personal Area Networks (6LoWPAN) and IPv6 Routing Protocol for Low-power and Lossy networks (LLNs) (RPL) has accelerated the integration of WSNs and smart objects with the Internet.

LLNs communicate using low data rate links (e.g., IEEE 802.15.4g and 1901.2). Because the communication over a physical medium is strongly affected by environmental conditions that change over time, congestion and collision are critical issues during upward and downward traffic flow. Upward traffic may reduce the collision by adjusting the sample sequence, but downward traffic is impossible to predict.

Figure 2 below illustrates a typical collision case in which downward traffic to zones A and B collide in nodes 1, 2, and 19. Collisions can be prevented by propagating packets alternately to zone A and zone B, but there is no proper mechanism and routing algorithm to implement this optimization.

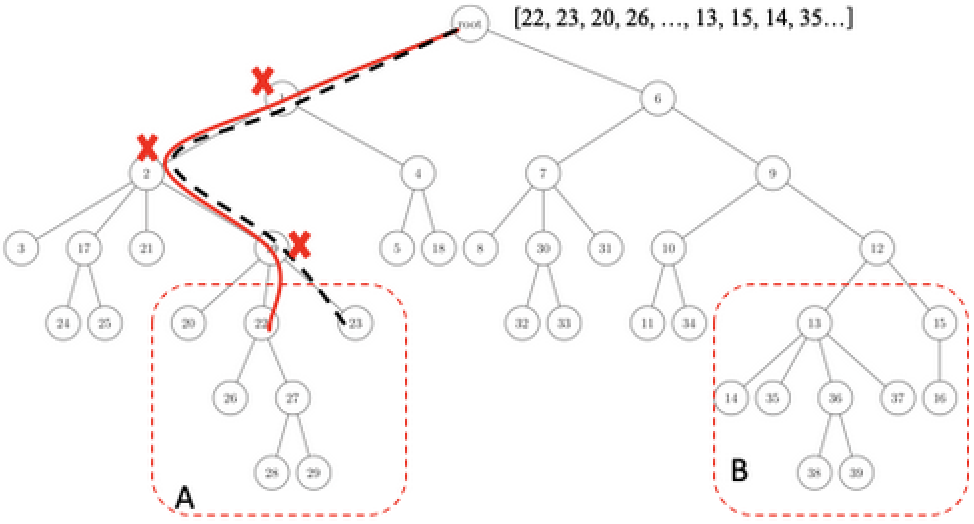

Figure 2. typical collision case that downward traffic to zone A and B

In addition, congestion on CGR is another issue that needs to be resolved. CGR Ethernet, Wi-Fi®, and 4G modular use the highest common speed between the sending and receiving devices, ranging from 10Mbits/s to 100Mbits/s or even more. But LLN transceivers typically provide very low throughput (e.g., frequency hopping provides only 75Kbits/s for thousands of nodes). The mismatch of transmit speeds to mesh networks can lead to significant congestion and packet loss, resulting in the decline of Quality of Service (QoS) parameters such as transmission delay and throughput. Limiting the transmission rate can alleviate congestion, but a more effective solution may improve the transmission capacity of the mesh network.

In accordance with techniques described herein, once a router receives a Destination Advertisement Object (DAO) from the mesh, the control plane may construct the RPL routing parameters and download them to the data plane. Meanwhile, the coefficient collision table may update in real time. This can be used to adjust the transmit sequence of the output buffer to reduce the collision in LLNs. When traffic enters the data plane, a fast forwarding module may look up the routing table and fill the output buffer of the corresponding interface. The transmit sequence can then be adjusted dynamically based on the coefficient collision table described herein. Furthermore, if the data plane detects large amounts of short packets destined for the mesh, compression into one packet can be achieved if they belong to a common parent. The compression sequence can adopt this algorithm as well.

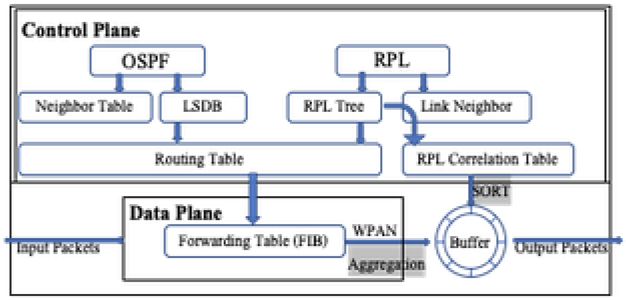

Figure 3 Component Dependency Hierarchy

Transmission sequence may be controlled to reduce packet collisions based on network topology. In LLNs, any traffic from the root nodes is transmitted downward hop-by-hop. In RPL storing mode, all non-root nodes store downward routing tables for their sub - Destination Oriented Directed Acyclic Graph (DODAG), which contains information obtained from the DAO messages. In non-storing mode, nodes do not store routing tables for their sub-DODAG. Instead, nodes transmit downward packets by using source routes populated by a DODAG root.

The RF module in the network is in the half-duplex working state, so the node cannot send and receive data simultaneously or receive data of multiple neighbor nodes. In addition, due to the shared communication medium, if IPv6 over the Time Slotted Channel

Hopping (TSCH) mode of the IEEE 802.15.4 standard is enabled, the probability of interference conflict can be expressed as the reciprocal of the number of channels.

Figures 4.1-4.3 below illustrate calculation and treatment of correlation coefficients for an example RPL topology. In Figure 4.1, the line connecting the parent and child node is the preferred path of the downstream route. The dotted line connects every two link neighbors in which the connected nodes can interfere with each other. As shown, packets from node B to node G are interfered with by node C to node I if the channel matches.

Figure 4.2 illustrates the probability array of every combination of two nodes with a maximum of four transmitting intervals. The correlation coefficient of each combination of two nodes can be represented as = $C_{ij}=[P_{ij}^{(1)}, P_{ij}^{(2)}, ..., P_{ij}^{(h)}]$, composed of the collision possibility in different transmitting intervals or time slots. h represents the interval, and $P_{ij}^{(h)}$ represents the collision possibility of propagating packets to node j after node i. For example, $C_{AB} = [0, 0, 0, 0]$ indicates that the CGR that sends packets to node A after node B will not conflict in the mesh in any sequences. In array C_{OI}, the second element is 2/n, and packets sent to node I will be sent after two time slots. Meanwhile, packets sent to node O have already arrived at node I. In the next time slot, sending node I will interfere with receiving node C if nodes C and N are in the same channel. After another time slot, similar interference occurs again on receiving node I. Thus, the probability is 1/n + 1/n.

Figure 4.3 illustrates the matrix that includes an array of all C_{ij}. This array assumes that the packets transmitted in hop four will not interfere with the packets in hop 1. Under this assumption, each element in the array that has a multiple of n can be compressed into an unsigned 32-bit integer. For example, $C_{OI} = 0*2^{24} + 2*2^{16} + 1*2^{8} + n*2^{0}$. Finally, the matrix may be sent down to the data plane.

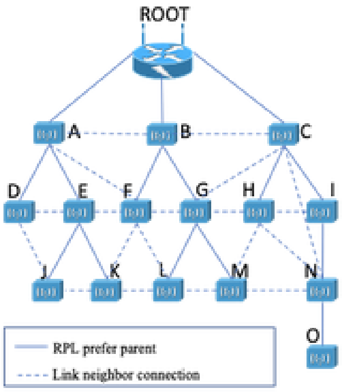

Figure 4.1 RPL topology in CG-MESH Router

$$
\begin{aligned}
C_{AB} &= [0, 0, 0, 0];\\
C_{AD} &= [0, 0, 0, 0];\\
C_{AF} &= [0, 0, 0, 0];\\
C_{AH} &= [0, 0, 0, 0];\\
C_{DE} &= [1, 0, 0, 0];\\
C_{DF} &= [\tfrac{1}{n}, 0, 0, 0];\\
&\dots\\
C_{OC} &= [1, \tfrac{1}{n}, \tfrac{1}{n}, 0];\\
C_{OI} &= [1, \tfrac{2}{n}, \tfrac{1}{n}, 0];\\
C_{OL} &= [\tfrac{1}{n}, 0, 0, 0];\\
C_{OM} &= [\tfrac{2}{n}, 0, 0, 0];\\
C_{ON} &= [1, \tfrac{3}{n}, \tfrac{1}{n}, 0];\\
&\dots
\end{aligned}
$$

$$
\begin{aligned}
C_{AB} &= [0, 0, 0, 0];\\
C_{DA} &= [1, 0, 0, 0];\\
C_{FA} &= [\tfrac{1}{n}, 0, 0, 0];\\
C_{HA} &= [0, 0, 0, 0];\\
C_{ED} &= [1, 0, 0, 0];\\
C_{FD} &= [\tfrac{1}{n}, 0, 0, 0];\\
&\dots\\
C_{CO} &= [0, 0, 0, 0];\\
C_{IO} &= [1, 0, 0, 0];\\
C_{LO} &= [\tfrac{1}{n}, 0, 0, 0];\\
C_{MO} &= [\tfrac{1}{n}, \tfrac{1}{n}, 0, 0];\\
C_{NO} &= [1, \tfrac{1}{n}, \tfrac{1}{n}, 0];\\
&\dots
\end{aligned}
$$

Figure 4.2 calculation of correlation coefficient

$$
\begin{bmatrix}
0 & 0 & \dots & 0 & 0 & 0\\
0 & 0 & \dots & 0 & 0 & 0\\
\dots & \dots & \dots & \dots & \dots & \dots\\
0 & 0 & \dots & 2^8 + n & 1 & 2\\
0 & 0 & \dots & 2^8 + n & 2^8 + n & 2^{16} + 3 \cdot 2^8 + n\\
0 & 0 & \dots & 2^8 + 1 & 2^{16} + 2^8 + 1 & 2^{16} + 2 \cdot 2^8 + n
\end{bmatrix}
$$

Figure 4.3 Matrix of correlation coefficient

In the data plane, packets may locate the output interface after looking up the routing table. Due to the low transmit rate in LLNs, traffic may fill into the buffer while it is still full, or may even be dropped. Thus, the packet sequence may be dynamically adjusted in the buffer based on the collision-reducing algorithm. The QoS policy that prioritizes critical traffic may be satisfied first. The following traffic should be prevented from collisions therewith based on the RPL correlation table.

Packet aggregation may also be performed based on the RPL tree. Downward traffic generally includes control commands or data requests in which the packet length remains short. In LLNs, every transition will require a time slot and some Clear Channel Assessment (CCA) detection. Hence, a large number of massive short IPv6 packets may reduce the throughput of LLNs and worsen congestion. Accordingly, some short packets that belong to a common parent may be merged and then filled into the buffer to be restored. The merging sequence can also follow this mechanism. The common parent may send the downward traffic in sequence after unpacking the merging packet.

In summary, techniques are described herein for dynamically adjusting a transmit sequence based on a coefficient collision table. A fast forwarding routing mechanism may search a routing table when traffic enters the data plane, and fill the output buffer of a corresponding interface. Furthermore, if the data plane detects massive short packets destined for the mesh, compression into one packet can be achieved if they belong to a common parent.