Claims

What is claimed is:

1. A mesh network, comprising:

a root node;

a child node in communication with the root node through other nodes in the mesh network; and

a plurality of parent nodes of the child node, each parent node in the plurality of parent nodes is associated with a route between the child node and the root node that passes through the parent node, the plurality of parent nodes comprising a primary parent node and one or more backup parent nodes;

wherein the child node is configured for:

transmitting regular data to the root node through a primary route associated with the primary parent node;

determining that there is a time-critical message to be transmitted to the root node;

selecting a subset of parent nodes of said plurality of parent nodes according to a route reliability criteria;

estimating a round trip time (RTT) for each route between the child node and the root node that is associated with one parent node of the selected subset of plurality of parent nodes, wherein the RTTs are estimated based on messages transmitted between the child node and each parent node of the selected subset of plurality of parent nodes;

selecting, among the selected subset of plurality of parent nodes, a parent node whose associated route has the lowest RTT;

transmitting the time-critical message to the root node through the selected parent node; and

after transmitting the time-critical message to the root node through the selected parent node, transmitting additional regular data to the root node through the primary route.

2. The mesh network of claim 1, wherein estimating the RTT for a route between the child node and the root node that is associated with one parent node of the selected subset of plurality of parent nodes comprises:

transmitting a unicast message to the root node through the one parent node;

recording a first timestamp associated with the transmitting of the unicast message;

receiving an acknowledgement message of the unicast message from the root node;

recording a second timestamp associated with receiving the acknowledgement message; and

calculating the RTT for the route between the child node and the root node that is associated with the one parent node as a difference between a second time point indicated by the second timestamp and a first time point indicated by the first timestamp.

3. The mesh network of claim 2, wherein the one parent node is configured for:

receiving the unicast message from the child node;

forwarding the unicast message to the root node through a route between the one parent node and the root node;

recording a third timestamp associated with forwarding the unicast message by the one parent node;

receiving the acknowledgement message of the unicast message from the root node;

recording a fourth timestamp associated with receiving the acknowledgement message at the one parent node;

forwarding the acknowledgement message of the unicast message to the child node; and

calculating an RTT for the route between the one parent node and the root node as a difference between a fourth time point indicated by the fourth timestamp and a third time point indicated by the third timestamp.

4. The mesh network of claim 3, wherein the mesh network implements a routing protocol of lossy medium (RPL) and the unicast message is a destination advertisement object (DAO) message.

5. The mesh network of claim 4, wherein:

the DAO message comprises a sequence number;

the acknowledgement message of the DAO message comprises the sequence number; and

the one parent node is configured to identify the third timestamp and the fourth timestamp based on the sequence number contained in the DAO message and the sequence number contained in the acknowledgement message, respectively.

6. The mesh network of claim 5, wherein the sequence number is comprised in a new IPv6 extension header or a hop-by-hop (HBH) option of an existing IPv6 header.

7. The mesh network of claim 1, wherein estimating the RTT for a route between the child node to the root node that is associated with one parent node of the selected subset of plurality of parent nodes comprises:

transmitting a neighbor unicast message to the one parent node;

recording a first timestamp associated with the transmitting of the neighbor unicast message;

receiving an acknowledgement of the neighbor unicast message from the one parent node;

recording a second timestamp associated with the receiving of the acknowledgement;

calculating a local RTT for a local route between the child node and the one parent node as a difference between a second time point indicated by the second timestamp and a first time point indicated by the first timestamp;

receiving a control message from the one parent node, the control message specifying an RTT of a route between the one parent node and the root node; and

calculating the RTT for the route between the child node and the root node that is associated with the one parent node as a sum of the local RTT and the RTT of the route between the one parent node and the root node.

8. The mesh network of claim 7, wherein the mesh network implements a routing protocol of lossy medium (RPL) and the control message is a DODAG information object (DIO) message, wherein the control message specifies the RTT of the route between the one parent node and the root node in an option of the DIO message.

9. The mesh network of claim 7, wherein the RTT of the route between the one parent node and the root node is an RTT of a route between the one parent node and the root node associated with a primary parent node of the one parent node.

10. The mesh network of claim 7, wherein the RTT of a route between the one parent node and the root node specified in the control message is a latest RTT or an averaged RTT calculated by the one parent node.

11. The mesh network of claim 1, wherein each of the child node and the selected subset of plurality of parent nodes is configured for maintaining the RTT for routes from the corresponding node to the root node.

12. A node of a network, comprising:

a processor configured to execute computer-readable instructions; and

a memory configured to store the computer-readable instructions that, when executed by the processor, cause the processor to perform operations comprising:

transmitting regular data to a root node of the network through a primary route associated with a primary parent node of the node, wherein the node has a plurality of parent nodes in the network comprising the primary parent node and one or more backup parent nodes, each of the plurality of parent nodes associated with a route between the node and the root node of the network;

determining that there is a time-critical message to be transmitted to the root node;

selecting a subset of parent nodes of said plurality of parent nodes according to a route reliability criteria;

estimating a round trip time (RTT) for each route between the node to the root node that is associated with one parent node of the selected subset of plurality of parent nodes, wherein the RTTs are estimated based on messages transmitted between the node and each parent node of the selected subset of plurality of parent nodes;

selecting, among the selected subset of plurality of parent nodes, a parent node whose associated route has the lowest RTT and is different from the primary route associated with the primary parent node;

transmitting the time-critical message to the root node through the selected parent node; and

switching back to the primary route to transmit additional regular data to the root node.

13. The node of claim 12, wherein estimating the RTT for a route between the node and the root node that is associated with one parent node of the selected subset of plurality of parent nodes comprises:

transmitting a unicast message to the root node through the one parent node;

recording a first timestamp associated with the transmitting of the unicast message;

receiving an acknowledgement message of the unicast message from the root node;

recording a second timestamp associated with receiving the acknowledgement message; and

calculating the RTT for the route between the node and the root node that is associated with the one parent node as a difference between a second time point indicated by the second timestamp and a first time point indicated by the first timestamp.

14. The node of claim 13, wherein the one parent node is configured for:

receiving the unicast message from the node;

forwarding the unicast message to the root node through a route between the one parent node and the root node;

recording a third timestamp associated with forwarding the unicast message by the one parent node;

receiving the acknowledgement message of the unicast message from the root node;

recording a fourth timestamp associated with receiving the acknowledgement message at the one parent node;

forwarding the acknowledgement message of the unicast message to the node; and

calculating an RTT for the route between the one parent node and the root node as a difference between a fourth time point indicated by the fourth timestamp and a third time point indicated by the third timestamp.

15. The node of claim 12, wherein estimating the RTT for a route between the node to the root node that is associated with one parent node of the selected subset of plurality of parent nodes comprises:

transmitting a neighbor unicast message to the one parent node;

recording a first timestamp associated with the transmitting of the neighbor unicast message;

receiving an acknowledgement of the neighbor unicast message from the one parent node;

recording a second timestamp associated with the receiving of the acknowledgement;

calculating a local RTT for a local route between the node and the one parent node as a difference between a second time point indicated by the second timestamp and a first time point indicated by the first timestamp;

receiving a control message from the one parent node, the control message specifying an RTT of a route between the one parent node and the root node; and

calculating the RTT for the route between the node and the root node that is associated with the one parent node as a sum of the local RTT and the RTT of the route between the one parent node and the root node.

16. A method for transmitting time-critical messages in a mesh network, the method comprising:

transmitting, by a node in the mesh network, regular data to a root node of the mesh network through a primary route associated with a primary parent node of the node, wherein the node has a plurality of parent nodes in the mesh network comprising the primary parent node and one or more backup parent nodes, each of the plurality of parent nodes associated with a route between the node and the root node of the mesh network;

determining, by the node, that there is a time-critical message to be transmitted to the root node;

selecting a plurality of parent nodes of said plurality of parent nodes according to a route reliability criteria;

estimating, by the node, a round trip time (RTT) for each route between the node to the root node that is associated with one parent node of the selected subset of plurality of parent nodes, wherein the RTTs are estimated based on messages transmitted between the node and each parent node of the selected subset of plurality of parent nodes;

selecting, by the node and among the selected subset of plurality of parent nodes, a parent node whose associated route has the lowest RTT;

transmitting, by the node, the time-critical message to the root node through the selected parent node; and

switching, by the node, back to the primary route to transmit additional regular data to the root node.

17. The method of claim 16, wherein estimating the RTT for a route between the node and the root node that is associated with one parent node of the selected subset of plurality of parent nodes comprises:

transmitting a unicast message to the root node through the one parent node;

recording a first timestamp associated with the transmitting of the unicast message;

receiving an acknowledgement message of the unicast message from the root node;

recording a second timestamp associated with receiving the acknowledgement message; and

calculating the RTT for the route between the node and the root node that is associated with the one parent node as a difference between a second time point indicated by the second timestamp and a first time point indicated by the first timestamp.

18. The method of claim 17, wherein the mesh network implements a routing protocol of lossy medium (RPL) and the unicast message is a destination advertisement object (DAO) message.

19. The method of claim 16, wherein estimating the RTT for a route between the node to the root node that is associated with one parent node of the selected subset of plurality of parent nodes comprises:

transmitting a neighbor unicast message to the one parent node;

recording a first timestamp associated with the transmitting of the neighbor unicast message;

receiving an acknowledgement of the neighbor unicast message from the one parent node;

recording a second timestamp associated with the receiving of the acknowledgement;

calculating a local RTT for a local route between the node and the one parent node as a difference between a second time point indicated by the second timestamp and a first time point indicated by the first timestamp;

receiving a control message from the one parent node, the control message specifying an RTT of a route between the one parent node and the root node; and

calculating the RTT for the route between the node and the root node that is associated with the one parent node as a sum of the local RTT and the RTT of the route between the one parent node and the root node.