Composite Metrics for Routing in Low Power and Lossy Networks

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***Abstract*—IETF ROLL (Routing Over Low power and Lossy networks) Group proposes the RPL (IPv6 Routing Protocol for LLNs) for routing in low power and lossy networks. Though RPL is able to work on several routing metrics, the details of using these metrics are not completely specified in the standard. To meet different QoS requirements of the applications, adopting proper routing metrics is essential. In this paper, the ways of compositing metrics for routing in LLNs is presented. Simulation results show that the methods introduced in this paper feasibly work in LLNs.**

***Keywords*—LLN, RPL, Routing Metrics, Composite, QoS Requirement**

1. INTRODUCTION

Recently, the progress of network technology makes the applications of Internet of Things (IoTs) [1] possible. IETF Working Group proposes the 6LowPan [2] to integrate IEEE 802.15.4 and the IPv6. 6LowPan [2] aims at supporting a method for connecting the low-powered devices with the IP networks. Therefore, IETF ROLL (Routing Over Low power and Lossy network) Group introduces the RPL (IPv6 Routing Protocol for LLNs) [3] for routing in the new environment. RPL [3] defines the rules of building up the *Directed Acyclic Graphs* (DAG) [4]. That is, the ways of selecting the nodes as parent nodes. Also, ROLL introduces several metrics for routing in LLNs [5].

Though RPL is able to work on several routing metrics, the details of using these metrics are not completely specified in the standard. It is necessary to use different routing metrics to meet different QoS requirements of the applications. Thus, in this paper, the methods of combining metrics are presented for routing in low power and lossy networks. As will be shown in the simulations, the methods introduced in this paper can work well in LLNs.

This paper is organized as follows. In section 2, background and related work are introduced. The methods of compositing routing metrics are described in section 3. The simulations are given in section 4. Section 5 concludes this paper.

2. RELATED WORK

RPL [3][5][6][7] describes the ways of constructing a DAG. Each node computes the *rank* value according to the information carried in *Destination Information Object* (DIO) messages. A rank implies the location of a node in the *Destination Oriented DAG* (DODAG). And, each node selects the neighbor node with minimum rank value as its parent node. RPL [3][5][6][7] also introduces the concepts of *Object Function* (OF). OF describes the ways of computing the rank value using different metrics. A few studies [7][8][9] try to composite the routing metrics. The methods of combining these metrics either additively or lexically are addressed. The performance of the combinations of compositing routing metrics are presented in the study [7].

In this paper, three metrics, including path length, stability, and available energy; are additively composited to meet different application requirements.

3. COMPOSITE ROUTING METRICS

3.1. Problem Statement

In RPL, the OF can adopt kinds of routing metrics [5] including the *Hop Count* (HC) [5] (try to fine the path with least hop number), the available *Residual Energy* (RE) [5] (try to find the path with more residual energy), the *Expected Transmission Count* (ETX) [5] (try to find a stable path), and *OF0* [6] (try to find the node with minimum rank). Traditionally, single metric is used for selecting the path. However, it cannot satisfy the QoS requirements of different applications. Thus, a few proposals [7][8][9] propose the methods of combining kinds of metrics to meet the needs of applications. For example, *Hop Count* metric selects the path with least hop number while the *ETX* metric selects the path with better stability. However, these two methods possibly select a path being prone to failures due to depleted energy. In this paper, we composite a few routing metrics to meet different QoS requirements of various applications by assigning different weights to various metrics.

3.2. Selecting Parent Node in DODAG

Before going further, an example of calculating the rank and selecting the parent node in DODAG is given in Fig. 1. As introduced in [3], each node periodically broadcasts its DIO message to its neighbors. As shown in Fig. 1, when node *i* receives the DIO messages from node *j* and node *k*, node *i* re-computes the rank accordingly. Then, node *i* selects the node with smaller rank as its parent towards the root node.

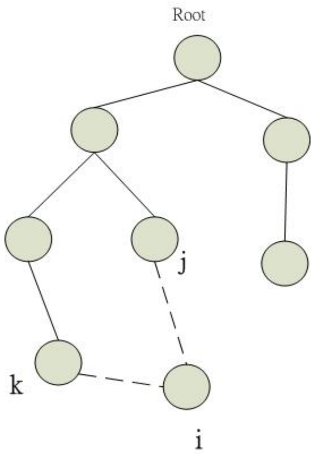

Fig.1: Selecting Parent Node in a DODAG

3.3. Routing Metrics

Hop Count (HC) metric [5][6] is widely used in many existed proposals. With this metric, the path with least hop count will be selected. As mentioned in the study [7], the HC metric is computed as in expression (1). It computes the hop count if node *i* selects node *j* as its parent node towards the root. Fig. 2 shows the snapshot of a route selected according to the HC metric by JSIM [10].

$$F_1 = \text{HopCount}_{i,j} \qquad (1)$$

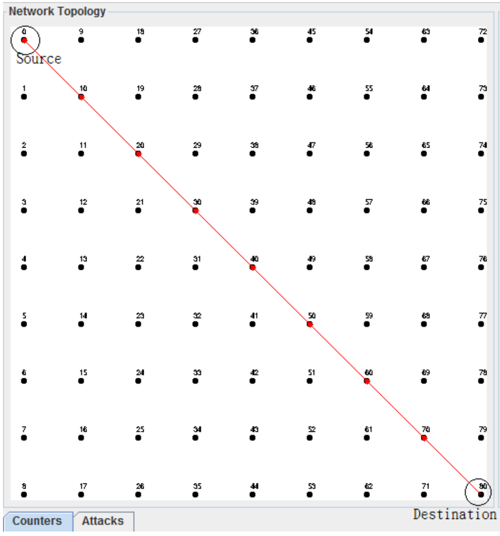

Fig. 2: Route Selected with Hop Count

Due to the special characteristics of LLNs, the stability of the path is necessary. The ETX metric [5][6] is used to indicate the stability of a path. As described in [7], the ETX metric is computed as in expression (2). Where, *s* is the number of packets successfully delivered while *f* is the number of packets sent out unsuccessfully. It can compute the ETX value if node *i* selects node *j* as its parent node towards the root. Fig. 3 shows the snapshot of a route selected according to the ETX metric by JSIM [10].

$$F_2 = \text{ETX}_{i,j} = ((s+f)/s) \qquad (2)$$

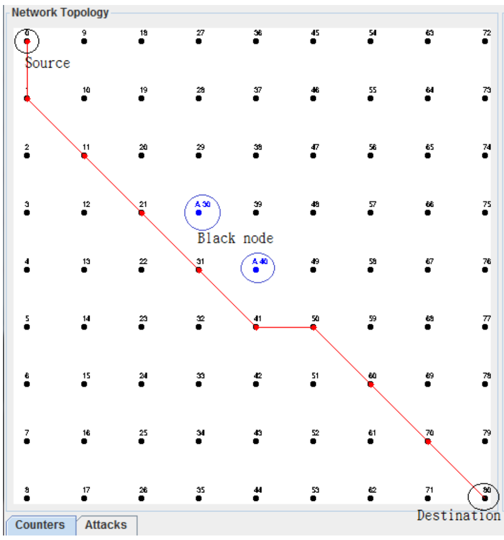

Fig. 3: Route Selected with ETX

In LLNs, the nodes are typically powered by the batteries. Thus, it is necessary to choose the nodes with more available energy for routing in LLNs. The *Residual Energy* (RE) metric [5][6] reveals available energy on a node. As introduced in [7], the RE metric is computed as in expression (3). Where, $V_{initial}$ and V_{now} are the initial energy and current energy of a node respectively. It computes the RE value if node *i* selects node *j* as its parent node towards the root. Fig. 4 shows the snapshot of a route selected according to the RE metric by JSIM [10].

$$F_3 = RE_{i,j} = (V_{initial}/V_{now}) \tag{3}$$

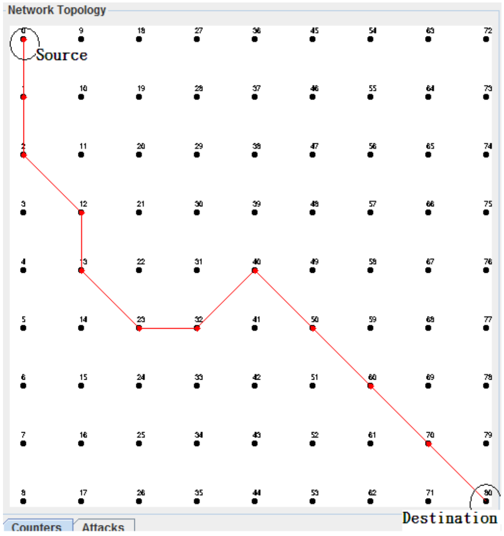

Fig. 4: Route Selected with RE

3.4. Compositing the Metrics

To study the effects of different combination of weights assigned to the routing metrics on the network lifetime, the simulations are carried out. In this paper, the routing metrics are combined to meet different QoS requirements of different applications. In the study [7], a few metric combinations are tried. In this paper, three metrics, including the HC, the ETX, and the RE, are additively combined. As shown in expression (4), different weights (i.e. α , β, and γ; α + β + γ=1) are assigned to these metrics.

$$W_{i,j} = \alpha * F_1 + \beta * F_2 + \gamma * F_3 \tag{4}$$

The rank value of node *i* thence is re-computed as in expression (5). The node with least rank value is selected as the parent nodes of *i*.

$$Rank_i = Rank_j + W_{i,j} \tag{5}$$

4. SIMULATIONS

In this paper, a few simulations are implemented in JSIM [10]. The experimental environment is arranged as follows. Some (20, 40, 60, or 80) nodes are deployed in a 1000m*1000m area. The source node periodically yields packets and delivered towards the destination node. In the simulations, 3000 packets are delivered. The transmission rage is 150m. IEEE 802.15.4 and RPL are used for MAC layer and network layer protocol respectively. Initial energy of each node is 3.5V. The parameter settings are collected in Table 1.

TABLE 1

PARAMETER SETTINGS

Parameter	Value
Simulation Time	6000s
Area	1000m*1000m
Number of nodes	20, 40, 60, and 80
Transmission Range	150m
Network Protocol	RPL: Composite metrics
MAC Protocol	802.15.4
Energy Value	3.5V
Number of Packets	3000

As shown in Fig. 5, the network lifetime increases when the number of nodes increases. Apparently, the distance of two neighbor nodes decreases when the number of nodes increases. Thus, the energy consumption of a single node reduces when the distance of a single hop increases. Also, it seems obvious that the network lifetime increases when the weights assigned to the RE metric increase.

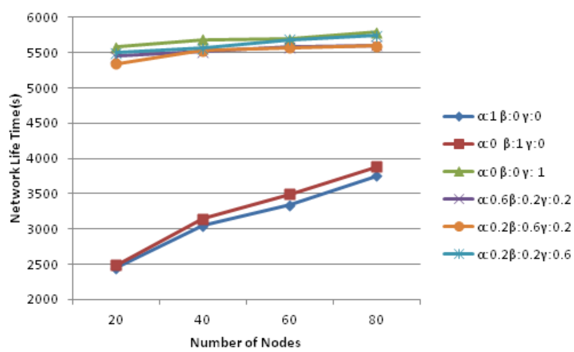

Fig. 5: Network Lifetime

5. CONCLUSIONS

Though RPL is able to work on several routing metrics, the details of using these metrics are not specified. It is critical to use correct metric for routing to meet the QoS requirements of the applications. In this paper, the methods of compositing metrics are presented for routing in LLNs. As suggested in the simulation results, the methods introduced in this paper feasibly work in LLNs.

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