ROLL
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RPL-based Clustering Routing Protocol
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Abstract

The IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) is one of the emerging routing standards for multi-hop Wireless Sensor Networks (WSNs). RPL is based on the construction of a Destination-Oriented Directed Acyclic Graph (DODAG), which offers a loop-free topology to route data packets. But due to the tree topology, the upper nodes in tree topology are easy to run out of energy. Moreover, the hop count and ETX are the only route metrics for which standards related to their usage in RPL are published. Due to the seriously resource-constrained character, we take nodes' residual energy into account. Here we present an RPL-based clustering scheme and detailed description of Objective Function.

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1. Introduction

Low power and Lossy Networks (LLNs) consist of numerous constrained nodes (with limited processing power, memory, and sometimes energy). For such low-power lossy network characteristics, IETF ROLL working group developed RPL (Routing Protocol for Low-Power and Lossy Networks). RPL is a distance-vector routing protocol and organizes networks as one or more Directly Acyclic Graph (DAG).

Furthermore, Wireless Sensor Network (WSN) consists of hundreds or thousands of nodes scattered in an environment of interest, although network topology built by RPL protocol can better ensure network stability, because of the tree topology, when the nodes are distributed densely and in a large scale, the topology depth will be deeper. Sensor nodes in the network topology whose relative position is near the sink are not only responsible for collecting sensor information themselves, but also undertake the task of forwarding packets, which make them easier to deplete energy. Once the sensor nodes in relative top position are invalid, the entire network will have a great concussion.

This document proposes a hierarchical routing mechanism based on the RPL routing protocol.

2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. The whole routing protocol

In wireless sensor networks, after the routing topology is basically established, first of all, the network is hierarchized. In each layer, a cluster head is selected according to specific rules and a certain percentage (See Section 5).

The nodes elected as cluster head will broadcast "office information" to other nodes in the same layer, which invite other nodes to join the clusters. After receiving the message, nodes decide whether to join in the cluster in accordance with rules. If deciding to join, the cluster member node will add its cluster head into the routing table as the sub-optimal parent. Otherwise the node will restart the process of selecting cluster head. Thus, until all the nodes repeat the above process, the whole network process is completed.

In the packet forwarding, the cluster member node sends its own collection of information directly to the cluster head node and data fusion processed by the cluster head node. If a node receives packets from lower layer which have been integrated, it will forward the integrated massages directly to the original optimal parent rather than the cluster head. So the node can keep two parents, one is the original optimal parent and the other is the cluster head which is the sub-optimal parent. In other words, packets without fusion are forwarded to the cluster head, and the fusion data are forwarded along the original path. Thereby, this method can reduce the packet flow, balance node energy consumption and increase network reliability.

Route establishment process is as follows: Cluster head node broadcasts DIOs that carry with cluster information. After cluster members receive the DIOs, they will judge whether they are in the same layer. If in the same layer, it will compare cRank (Rank for Cluster) which is a new route metric in the cluster and defined by EXT and RE(Remaining Energy)(See Section 5). Only if the cRank is less than itself, node will send DAO to request to join the cluster. The cluster head receives the request message and judges whether it is in the same layer. If in the same layer, cluster head replies CH-

Ack to the node. Cluster member will get the CH-Ack and if its cluster head agrees to be joined, then it will update information table and add the cluster head to parents list as the sub-optimal parent. This process is shown in figure 1.

```
        cluster head             cluster member
                |                            |
                |                            |
                |------------DIOC----------->|
                |                            |
                |                            |
                |                            |
                |                            |
                |<------------DAOC-----------|
                |                            |
                |                            |
                |                            |
                |                            |
                |----------CH-Ack----------->|
                |                            |
```

Figure 1 Route establishment

4. Packet formats

This document defines three kinds of messages and two among them are derived from RPL control massage which is defined in RFC 6550.The packet formats are defined as follow:

1)DODAG Information Object for Cluster (DIOC)

The DODAG Information Object for Cluster carries information that allows a node to discover a RPL Instance and cluster, learn its configuration parameters, select a DODAG parent set, and maintain the DODAG and the cluster.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| RPLInstanceID | Version Number|           Rank                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|G|0| MOP | Prf |       DTSN    |     Flags     |   Reserv      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                           DODAGID                             +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Option Type  | Option Length |           cRank               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Msg Type    |       N       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2. Format of DIOC

Option Type: 0X99, 8-bit unsigned integer indicating cluster massage.

Option Length: 0X05, 8-bit unsigned integer indicating length of option.

cRank: 16-bit unsigned integer indicating node's relative position in the cluster (See Section 5).

N: 8-bit unsigned integer indicating that node's in the Nth layer.

Msg Type: 8-bit indicating the type of message.

Msg Type	Meaning
0x01	Cluster head
0x02	Cluster member
0x03	Cluster pre-head

Figure 3. Msg Type Encoding

2) Destination Advertisement Object for Cluster (DAOC)

The Destination Advertisement Object for Cluster (DAOC) is used to propagate destination information upwards along the DODAG.

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | RPLInstanceID |K|D|  Flags    |   Reserved    |  DAOSequence  |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   +                                                               +
   |                                                               |
   +                            DODAGID*                           +
   |                                                               |
   +                                                               +
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | Option Type   | Option Length |    Msg Type   |       N       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | Node Status   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4. Format of DAOC

Option Type: 0X99, 8-bit unsigned integer indicating cluster massage.

Option Length: 0X03, 8-bit unsigned integer indicating length of option.

N: 8-bit unsigned integer indicating that node's in the Nth layer.

Msg Type: 8-bit indicating the type of message (See Figure 3).

Node Status: 8-bit indicating the node current status.

Node Status	Meaning
0x01	joined
0x02	unjoined

Figure 5. Node Status Encoding

3)CH-Ack

ACK of cluster head is used to reply to cluster members whether to agree to serve.

```
 0                   1                   2
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Msg Type     |    Status     | DODAG Versioin|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6 Format of CH-Ack

Msg Type: the same in DIOC and DAOC.

Status: 8-bit indicating cluster head whether agrees to be joined.

Node Status	Meaning
0x01	agree
0x02	not agree

Figure 7. Status Encoding

DODAG Versioin: 8-bit, recording DODAG version of cluster head node.

5. Objective Function

Objective Function (OF), which uses routing metrics to select node's preferred parent among neighbors. Different criteria, also called routing metrics, are defined to capture link or node characteristics on the path for parent selection. They could be node attributes: hop count, node residual energy, or link attributes: throughput, latency, link quality level or expected transmission count (ETX).

Most protocol implementations use expected transmission count as the routing metric focusing on the link reliability. As the battery recharging of sensor nodes is practically very difficult, we hope that the data can be transmitted with the minimum energy consumption. Thus the routing metric has to consider energy awareness. In this document, we organize routing topology based on node's ETX and battery power level.

To avoid loop in the network, every node uses a scalar values, called cRank, to record its relative position to other nodes with regard to cluster head. The cRank is not a path cost, although its value can be derived from and influenced by path metric. The calculation method is as follows: Once a node (say M) has chosen its preferred parent (P), node computes its own cRank from preferred parent's cRank.

$$cRank(M)=cRank(P)+RankIncrease \qquad (1)$$

RankIncrease=*RankIncrease_ETX+*RankIncerase_RE (2)

RankIncease_RE=step+MinHopInc   (3)

where Step=MAX_energy-Node_energy

These formulas ensure the monotonic property of the rank which increases by at least one point (MinHopRankIncrease) between node and its preferred parent, when child node has a full battery level. Root rank is set to the same value as MinHopRankInc. RankIncrease_ETX is increase of ETX metric while RankIncerase_RE is increase of residual energy metric. MAX_energy, Node_energy, RankIncrease_ETXare defined in RFC6551.

After computing the path cost for all reachable candidate neighbors, a node selects the preferred parent. A node MUST select the candidate neighbor with the lowest path cost as its preferred parent. The specific rules is described in [RFC 6550] Section3.5.

6. References

6.1. Normative References

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7. Acknowledgments

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