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# Multipath Transmission for 6LoWPAN Networks
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Abstract

This document provides a multipath transmission method for 6LoWPAN Networks, which can effectively provide the transmission redundancy for packets. It is suitable for high-reliability networks, especially for IPv6-based industrial wireless scenarios.

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## 1. Introduction

6LoWPAN can deploy large-scale and high-density wireless personal area network devices with its high popularity, applicability, and more address space. However, due to the low processing power, the limited energy and the poor communication environment of the 6LoWPAN network, packets are easily lost during transmission, which causes transmission failure. The use of multipath packet transmission technology in 6LoWPAN is of great significance for improving communication reliability and transmission performance. It is well known that RPL as a routing protocol standardized by IETF, is an efficient distance vector protocol for wireless sensor networks, which has designed a series of new mechanisms [RFC6550], and is widely used in 6LoWPAN. Aiming at the explicit requirement of multi-path packet transmission for 6LoWPAN, this document proposes an RPL-based multipath transmission method, which improves the success rate of packets transmission in uplink networks and further enhances the transmission reliability.

## 2. 6LoWPAN Multipath Header Format

6LoWPAN multipath header designed at the adaptation layer contains the multipath header type field, the sequence number field of the multipath package (SequenceNumber) and the path number field (PathCount) [RFC4944], as depicted in Figure 1.

```
 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 2
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Multipath   |         Sequence Number       |  Path Number  |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: 6LoWPAN Multipath Header Format

Field definitions are as follows.

Multipath: Different types of headers at the adaptation layer must have a length of 8-bit header type field. The multipath field is the header type field of 6LoWPAN Multipath Header that uses the Dispatch Value Bit Pattern of 11101000.

Sequence Number: This field contains the unique sequence number SequenceNumber of packets, and its length is 16 bits.

Path Number: This field includes the number of paths PathCount that needs to be filled in the packet, and its length is 8 bit.

## 3. Architecture

The following figure 2 shows the architecture of the 6LoWPAN protocol stack. In this architecture, the IP layer uses RPL to realize the multipath transmission. Moreover, at the adaptation layer, the multipath transmission entity is achieved by designing a multipath header. The encapsulation of multipath packets and the transmission of multipath packets can be implemented by using above methods.

```
          +----------------------------------------------------+
          |   COAP          Application Layer          XMPP |
          |----------------------------------------------------|
          |   UDP            Transport Layer                   |
          |----------------------------------------------------|
          |  ----------                          --------------|
          |  |RPL|IPv6|          IP Layer       |   Multipath||
          |  ----------                          |Transmission||
          |                                      --------------|
          |----------------------------------------------------|
          |                                  ------------------|
          |   Fragmentation Adaptation Layer|       Multipath||
          |   Header Compression            |Transport Entity||
          |                                  ------------------|
          |----------------------------------------------------|
          |   CSMA/CA            Mac Layer                     |
          |----------------------------------------------------|
          |   Channel Detection     Physical Layer             |
          +----------------------------------------------------+
```

Figure 2: 6LoWPAN Protocol Stack Architecture

Before the source node sends a message, it is necessary to determine the number of paths P according to reliability requirements. Then we need to assign one or more paths for each parent node at the IP layer through the rank value. The rank value is calculated according to the residual energy value and the hop value to the sink node from the source node [RFC6551], [RFC6552]. The number of paths is encapsulated into the multipath header of the message at the adaptation layer before sending the message to the parent node. In addition, each intermediate routing node forwards the message according to the above method until it reaches the sink node.

## 4. Number of Paths Destination

Before the source node sends packets, it is needed to first determine the number of transmission paths. By determining the number of suitable paths, the end-to-end transmission success rate can be effectively improved, and the transmission reliability of the network can be further improved.

ETX refers to the number of expected transmissions of a link and is an important criterion for evaluating the quality of links in the network. This paper uses ETX to confirm the number of paths and balance the link quality of each path. At the same time, it selects the path with better quality, thereby increases the transmission success rate of the network.

Assume that there are n paths in the network, each path has a, b, c, d,...links, then the total ETX value of path a can be calculated by following formula:

E1 = L1 + L2 + ... + La.

Similarly, the total ETX values of the path b, path c, and path d are

E2 = L1+L2+...+Lb, E3 = L1+L2+...+Lc, E4 = L1+L2+...+Ld, and so on.

Among them, li represents the ETX of the link i in each path, so the transmission success rate of the path a is

p1 = 1 / E1.

Similarly, the transmission success rate of the path b, path c, and path d are

p2 = 1 / E2, p3 = 1 / E3, p4 = 1 / E4, and so on.

Then, the transmission success rate of the entire network is the sum of the transmission success rates of all the paths, that is

p = p1 + p2 + p3 + ... + pi + ... + pn.

Where p represents the success rate of the entire network, and pi represents the transmission success rate of path i. Sort p1 to pn from largest to smallest, followed by p11, p12, p13,..., p1i,...p1n. In order to ensure the success rate of one transmission, calculating the following formula:

p = p11 + p12 + p13 + ... + p1i >= 1.

When the above formula is established, then i is the number of required path.

## 5. Multipath Distribution

If the required number of paths P is greater than the total number of parent nodes N in the collection of RPL parent nodes, multiple paths are assigned to each parent node according to the size relation among the rank values of all parent nodes. The following formula is used.

Pm = round (P/Rm/R)     where     R = 1/R1 + 1/R2 + ... + 1/Rn

Here, round() presents the rounding function, rounding for the calculation result of (P/Rm/R). P is the total number of paths. Pm shows the number of paths allocated for parent node m. Rm represents the Rank value corresponding to the parent node m (m=1,2,...n). The above situation is shown as Figure 3.

```
+-----------------------------------------------------+
|  rank2=500 P2=1                                     |
| +------------->(R1)----> .....                      |
| |                                                   |
| |                                                   |
| |               /---->(R3)---->(R4)----> .....\     |
| |rank1=100 P1=5/                               \    |
|(S) ----------->(R2).....--->(R5)--->(R6)---> ...(D)|
| |P=8           \                               /    |
| |               \---->(R7)---->(R8)----> ...../     |
| |                                                   |
| |rank3=200 P3=2     /----> .....                    |
| +----------------->(R9)                             |
|                     \----> .....                    |
+-----------------------------------------------------+
```

Figure 3: The Transmission Process of P>N

If the number of paths P is less than or equal to the total number of parent nodes, P rank values are selected according to the rise order of rank values, and one path is assigned to the parent node corresponding to each rank value, as shown in Figure 4.

```
+---------------------------------------------------+
|   rank2=500 P2=1                                  |
| +--------------->(R1)---->(R2)---->(R3)......... |
| |                                              | |
| | rank1=100 P1=1                               | |
| | /-------------->(R4)---->(R5)---->(R6)......\ | |
| |/                                            \| |
|(S)P=3                                         (D)|
| .\rank3=200 P3=1                              /. |
| . \-------------->(R7)---->(R8)---->(R9)....../ . |
| .                                              . |
| . rank4=600 P4=0                               . |
| .................(10)....(R11)....(R12)......... |
|                                                   |
+---------------------------------------------------+
```

Figure 4: The Transmission Process of P<=N

## 6. Packet Replication and Elimination

The process of packet multipath transmission also includes packet replication and elimination. A detailed description is given as following five steps.

1) When the multipath transport entity of the adaptation layer receives the packet from the upper layer of the protocol stack, it first confirms the total number of paths P of the transmission packet according to the reliability requirements of the packet. When P is less than or equal to 1, it indicates that the packet does not need to use multipath transmission, then the packet can be forwarded directly.

2) When the total number of paths P is larger than 1, the number of the replicated packets PathCount that needs to be forwarded by each parent node in the collection of RPL parent nodes is allocated using the multipath packet allocation method [I-D.ietf-detnet-architecture], [I-D.ietf-detnet-problem-statement].

3) For the parent node that PathCount is greater than or equal to 1, the multipath transport entity replicates the packet and adds the multipath header at the adaptation layer, and then sends the packet to the parent node. In this case, the packet sequence number SequenceNumber of the multipath header in all replicated packets must be concurrent and it can be accumulated when the next new packet is sent. The path number field is filled with the corresponding number of copies PathCount. For the parent node whose

number of copies PathCount is less than 1, the source node does not send the packet.

4) After the intermediate routing node receives the packet including the multipath header, it judges whether the number of paths PathCount is equal to 1 in the multipath header. If PathCount is equal to 1, the intermediate node sends the packet directly with the value of each field in the multipath header constant. If PathCount is greater than 1, the node replicate PathCount copies of the packet and distributes them to multiple paths. Repeating step 2 and 3, and in step 2, P is equal to PathCount. In step 3, the new multipath header is not added, the SequenceNumber of the packet is unchanged, and the path number field is filled with the new corresponding number of copies.

5) When a destination node receives a packet containing the multipath header, it can distinguish whether the packet has been received according to the source address and the packet sequence number in the multipath header. If the destination node has not received the packet before, the node forwards the packet to its upper layer protocol directly. Otherwise, the node discards the packet [I-D.ietf-detnet-architecture], [I-D.ietf-detnet-problem-statement].

## 7. Security Considerations

This document does not add any new security considerations other than what is already mentioned in the referenced technology.

## 8. IANA Considerations

This document creates an IANA registry for 6LoWPAN Multipath Header Type, and assigns the following dispatch type values:

11101000: for 6LoWPAN Multipath Header Type.

## 9. References

### 9.1. Normative References

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