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One-way Delay Measurement Based on Reference Delay
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Abstract

The end-to-end network one-way delay is an important performance indicator of the arising 5G network. One type of existing methods requires the end-to-end deployment of accurate clock synchronization mechanism, such as PTP or GPS, which results in relatively high deployment cost. Another type of existing methods uses round-trip delay measurements to estimate the one-way delay. However, since the delay of the downlink and uplink of the 5G network may be asymmetric, the accuracy is relatively low. This document introduces a method to accurately measure end-to-end network one-way delay using reference delay without deploying clock synchronization.

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1. Introduction

With the gradual promotion of new-generation network technologies (such as 5G networks) and their application in various industries, SLA guarantees for network quality become more and more important. For example, different 5G services have different requirements for network performance indicators such as delay, jitter, packet loss, and bandwidth. Among them, the 5G network delay is defined as end-to-end one-way delay of the network. Real-time and accurate measurement of the end-to-end one-way delay is very important for the SLA guarantee of network services, and has become an urgent and important requirement.

A common scenario for end-to-end one-way delay measurement, such as a 5G network HD video surveillance service scenario, is shown in figure 1. One end of the network is a high-definition surveillance camera, as shown in the wireless access side on the left in figure 1, and the other end of the network is a video server. The end-to-end one-way delay measurement of the above-mentioned network is the one-way delay from the surveillance camera to the video server, including wireless access network, optical transmission network, 5G core network, and IP data network. The delay is the sum of T1, T2, T3 and T4 as shown in figure 1.

```
           +--------+   +-------+   +-------+   +-------+
+------+   |Wireless|   |Optical|   |5G Core|   |  IP   |   +------+
|Camera+<->+ Access +<->+ Trans +<->+Network+<->+ Data  +<->+Server|
+------+   |Network |   |Network|   |       |   |Network|   +------+
           +--------+   +-------+   +-------+   +-------+

       |<---- T1 ---->|<--- T2 -->|<--- T3 -->|<--- T4 ---->|
```

Figure 1:A Scenario for End-to-end One-way Delay

The existing one-way delay measurement solutions are divided into two categories. The first type is a one-way delay measurement solution based on round-trip communication delay, such as TWAMP[RFC8186]. The second type of one-way delay measurement solution is based on accurate network time synchronization mechanism, such as NTP[RFC5905] or PTP[IEEE.1588.2008].

The one-way delay measurement solution based on the round-trip delay requires the deployment of network measurement probes on the source end, namely the surveillance camera side, and the destination end, namely the server side. The source sends the measurement packet; the destination reflects the received measurement packet; after the source receives the measurement packet reflected by the destination, the round-trip delay can be obtained. By dividing the round-trip delay by two, the end-to-end one-way delay can be approximated. However, because the uplink delay and downlink delay of an end-to-end network (such as a 5G network) are not equal, the accuracy of the end-to-end one-way delay approximated by the round-trip communication delay is low. It cannot meet the requirements for accurate end-to-end one-way delay measurement.

The one-way delay measurement solution based on precise network time synchronization requires the deployment of an end-to-end time synchronization mechanism. The current time synchronization accuracy based on the NTP protocol can only reach millisecond level, which cannot fully meet the measurement accuracy requirements, while the time synchronization accuracy based on the GPS module or the PTP protocol can meet the requirements. On the basis of end-to-end time synchronization, the source sends a measurement packet with an accurate egress timestamp; when the destination receives the measurement packet, the accurate ingress timestamp is marked. Since the source and destination have already performed end-to-end time synchronization, the ingress timestamp is subtracted from the egress timestamp to obtain the end-to-end one-way delay. However, for GPS module-based time synchronization solutions, in actual deployment scenarios, many data centers are located underground or in rooms without GPS signals,so GPS clock information cannot be continuously obtained for time synchronization. For time synchronization

solutions based on the PTP protocol, end-to-end deployment is required, which is to say, each device in the wireless access network, optical transmission network, 5G core network and IP data network must support the PTP protocol, which is unrealistic at the moment. So the one-way delay measurement solution based on precise end-to-end time synchronization is expensive and difficult to be deployed.

This document introduces a one-way delay measurement solution based on reference delay. The end-to-end one-way delay of a reference packet with a stable delay is used as the reference delay, which is known in advance and has extremely low jitter. For example, next generation networks are gradually supporting deterministic network[RFC8655] and end-to-end network slicing technologies, which are characterized by bounded end-to-end delay and extremely low jitter of transmitted packets, which are ideal for reference packets. We can use the reference delay provided by the reference packet to indirectly measure the one-way delay of other packet streams under measurement.

2. Conventions Used in This Document

2.1. Terminology

NTP Network Time Protocol

PTP Precision Time Protocol

TWAMP Two-Way Active Measurement Protocol

SLA Service Level Agreement

2.2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14[RFC2119][RFC8174] when, and only when, they appear in all capitals, as shown here.

3. The method of One-way Delay Measurement Based on Reference Delay

The end-to-end one-way delay of a reference packet with a stable delay in the network can be used as a reference delay, denoted as Dref, which is known in advance and has extremely low jitter. This section will describe in detail the end-to-end one-way delay measurement method based on reference delay of the reference packet. Assume that the end-to-end one-way delay from the sender to the

receiver is measured, as shown in figure 2. The intermediate network devices other than the sender and receiver are hidden in the figure.

```
       +------------+                    +------------+
       |            |   Clock Offset     |            |
       |   Sender   | +----------------> |  Receiver  |
       |            |                    |            |
       +------------+                    +------------+

Reference  +-----+          Dref          +-----+
  Packet:  | Ts1 |  +-------------------> | Tr1 |
           +-----+                        +-----+

 Target    +-----+         Dtarget        +-----+
 Packet:   | Ts2 |  +-------------------> | Tr2 |
           +-----+                        +-----+
```

Figure 2:Topology of One-way Delay Measurement

3.1. One-way Delay Measurement Method

The measurement steps are shown in figure 3, which describe the measurement steps at the sender side and receiver side respectively. For the sender side, a reference packet is sent. In the first step, the sender gets ready to send a reference packet; in the second step, the sender marks an egress timestamp Ts1 for the reference packet; in the third step, the sender encapsulates the egress timestamp of the reference packet in the measurement header of the reference packet; in the fourth step, the sender sends the reference packet. For the target packet, the sender side procedures are the same,we omit it for simplicity. The sending time of the target packet is according to the traffic model of real applications. On the other hand, the sender can send the reference packet according to a fixed frequency or adjust the sending frequency according to the link usage rate, so that the target packet can always find a nearby reference packet to make sure that the sending time interval between the reference packet and the target packet is small.

For the reference packet, the processing steps at the receiver are shown in figure 3. In the first step, the reference packet arrives at the receiver, and the receiver receives the reference packet; in the second step, the receiver timestamps the reference packet at the entrance, which is denoted as Tr1; in the third step, the receiver decapsulates the measurement header of the reference packet to obtain the sender side timestamp Ts1; in the fourth step, the receiver records the timestamp information of Ts1 and Tr1; in the fifth step, the receiver uses the source/destination pair obtained by decapsulation in the third step as the search key, queries the

reference delay table and records the reference delay search result, denoted as Dref.

For the target packet, the processing steps at the receiver are also shown in figure 3. In the first step, the target packet arrives at the receiver, and the receiver receives the target packet; in the second step, the receiver timestamps the target packet at the entrance, which is denoted as Tr2; in the third step, the receiver decapsulates the measurement header of the target packet to obtain the sender side timestamp Ts2; in the fourth step, the receiver records the timestamp information of Ts2 and Tr2; in the fifth step, the receiver calculates the target one-way delay, which we want to measure, according to the recorded timestamp information Ts1, Ts2, Tr1, Tr2 and reference delay information Dref. The target one-way delay of the target packet is recorded as Dtarget.

```
Sender Side Procedures for both Reference and Target Packet:

+-------+   +------------+   +-------------+   +-------+
|Sender |   |Sender Side |   |Sender Side  |   |Sending|
|Ready  +-->+Timestamping+-->+Encapsulation+-->+ Packet|
|       |   |            |   |             |   |       |
+-------+   +------------+   +-------------+   +-------+

Receiver Side Procedures for Reference Packet:

+---------+  +-------------+  +-------------+  +---------+  +---------+
|Reference|  |Receiver Side|  |Receiver Side|  |Timestamp|  |Query for|
|Packet   +->+Timestamping +->+Decapsulation+->+Recorded +->+Reference|
|Arrival  |  |             |  |             |  |         |  |  Delay  |
+---------+  +-------------+  +-------------+  +---------+  +---------+

Receiver Side Procedures for Target Packet:

+-------+  +-------------+  +-------------+  +---------+  +-----------+
| Target|  |Receiver Side|  |Receiver Side|  |Timestamp|  |  One-way  |
| Packet+->+Timestamping +->+Decapsulation+->+Recorded +->+   Delay   |
|Arrival|  |             |  |             |  |         |  |Calculation|
+-------+  +-------------+  +-------------+  +---------+  +-----------+
```

Figure 3: Measurement steps for Sender and Receiver Respectively

Now we describe the fifth step of the receiver procedures for the target packet in figure 3, that is, calculating the one-way delay Dtarget of the target packet based on the recorded timestamp information Ts1, Ts2, Tr1, Tr2 and the reference delay information Dref. The calculation method is the core of this solution. For the

reference packet, leveraging the receiver timestamp minus the sender timestamp, we can get Equation 1.

Equation 1: Tr1 - Ts1 = Dref + Offset1

where Offset1 is the time offset between the sender and the receiver when the reference packet transmission occurs. Similarly, for the target packet, we can get Equation 2 using the same method.

Equation 2: Tr2 - Ts2 = Dtarget + Offset2

where Offset2 is the time offset between the sender and the receiver when the target packet transmission occurs. Assuming that the sending time interval between the reference packet and the target packet is very small, we can get that Offset1 = Offset2. By (Equation 2 - Equation 1), we can get Equation 3.

Equation 3: Dtarget = (Tr2 + Ts1) - (Tr1 + Ts2) + Dref

So the one-way delay of the target packet can be calculated by Equation 3.

3.2. Packet and Measurement Header Format

The sender encapsulates the timestamp information and sender-receiver pair information in the measurement header of the sent packet, as shown in figure 4. The position of measurement header is in the option field of the TCP protocol header. Detailed measurement header format is shown in figure 5. The Kind value can be 253 or 254, and the Length value is 8, which is in accordance with TCP option[RFC4727]. The sender ID is one octet, and the receiver ID is also one octet. The sender side timestamp is 4 octets, which can store accurate timestamp information.

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   |                    Ethernet header (14 octets)                |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   |                       IP header (20 octets)                   |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   |                       TCP header (20 octets)                  |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            Measurement Header in TCP option (8 octets)        |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            Data                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: Format of Reference or Target Packet

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |      Kind     |    Length     |  Sender ID    | Receiver ID   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |               Sender Side Timestamp (4 octets)                |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: Detailed Measurement Header Format

4. Acquisition of Reference Delay

The end-to-end one-way delay includes three parts, namely the transmission delay, the internal processing delay of the network devices, and the internal queueing delay of the network devices. Among them, fixed parts of the delay include transmission delay and internal processing delay. The transmission delay is related to transmission distance and transmission media. For example, in optical fiber, it is about 5ns per meter. With transmission path and media determined, it is basically a fixed value. The internal processing delay of a network device includes processing delay of the device's internal pipeline or processor and serial-to-parallel conversion delay of the interface, which is related to in/out port rate of the device, message length and forwarding behavior. The magnitude of the internal processing delay is at microsecond level, and it is basically a fixed value related to the chip design

specifications of a particular network device. Variable part of the delay is the internal queueing delay. The queueing delay of the device internal buffer is related to the queue depth, queue scheduling algorithm, message priority and message length. For each device along the end-to-end path, the queueing delay can reach microsecond or even millisecond level, depending on values of the above parameters and network congestion state.

With the continuous development of networking technologies and application requirements, a series of new network technologies have emerged which can guarantee bounded end-to-end delay and ultra small jitter. For example, deterministic network[RFC8655], by leveraging novel scheduling algorithms and packet priority settings, can stabilize queuing delay of network device on the end-to-end path. As a result, the end-to-end one-way delay is extremely low and bounded. So packets transmitted by a deterministic network with delay guarantee can be used as reference packets, and their end-to-end one-way delay can be used as reference delays. The acquisition method of reference delay is not limited to the above method based on deterministic network technology.

5. Security Considerations

TBD.

6. IANA Considerations

TBD.

7. Normative References

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