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Deterministic networking for radio access networks
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Abstract

This document describes requirements for deterministic networking in cellular radio access and transport networks context. The requirements include time synchronization, clock distribution and ways of establishing time-sensitive streams for both Layer-2 and Layer-3 user plane traffic using IETF protocol solutions.

Status of This Memo

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1. Introduction and background

The recent developments in telecommunication networks, especially in the cellular domain, are heading towards transport networks where precise time synchronization support has to be one of the basic building blocks. While the transport networks themselves have practically transitioned to all-AP packet based networks to meet the bandwidth and cost requirements, a highly accurate clock distribution has become a challenge. Earlier the transport networks in the cellular domain were typically time division and multiplexing (TDM) -based and provided frequency synchronization capabilities as a part of the transport media. Alternatively other technologies such as Global Positioning System (GPS) or Synchronous Ethernet (SyncE) [SyncE] were used. New radio access network deployment models and architectures may require time sensitive networking services with strict requirements on other parts of the network that previously were not considered to be packetized at all. The time and synchronization support are already topical for backhaul and midhaul packet networks [MEF], and becoming a real issue for fronthaul networks. Specifically in the fronthaul networks the timing and synchronization requirements can be extreme for packet based technologies, for example, in order of sub +-20 ns packet delay variation (PDV) and frequency accuracy of +0.002 PPM [Fronthaul].

Both Ethernet and IP/MPLS [RFC3031] (and PseudoWires (PWE) [RFC3985] for legacy transport support) have become popular tools to build and manage new all-IP radio access networks (RAN) [I-D.kh-spring-ip-ran-use-case]. Although various timing and synchronization optimizations have already been proposed and implemented including 1588 PTP enhancements [I-D.ietf-tictoc-1588overmpls][I-D.mirsky-mpls-residence-time], these solution are not necessarily sufficient for the forthcoming RAN architectures or guarantee the higher time-synchronization requirements [CPRI]. There are also existing solutions for the TDM over IP [RFC5087] [RFC4553] or Ethernet transports [RFC5086]. The really interesting and important existing work for time sensitive networking has been done for Ethernet [TSNTG], which specifies the use of IEEE 1588 time precision protocol (PTP) [IEEE1588] in the context of IEEE 802.1D and IEEE 802.1Q. While IEEE 802.1AS [IEEE8021AS] specifies a Layer-2 time synchronizing service other specification, such as IEEE 1722 [IEEE1722] specify Ethernet-based Layer-2 transport for time-sensitive streams. New promising work seeks to enable the transport of time-sensitive fronthaul streams in Ethernet bridged networks [IEEE8021CM]. Similarly to IEEE 1722 there is an ongoing standardization effort to define Layer-2 transport encapsulation format for transporting radio over Ethernet (RoE) in IEEE 1904.3 Task Force [IEEE19043].

As already mentioned all-IP RANs and various "haul" networks would benefit from time synchronization and time-sensitive transport services. Although Ethernet appears to be the unifying technology for the transport there is still a disconnect providing Layer-3 services. The protocol stack typically has a number of layers below the Ethernet Layer-2 that shows up to the Layer-3 IP transport. It is not uncommon that on top of the lowest layer (optical) transport there is the first layer of Ethernet followed one or more layers of MPLS, PseudoWires and/or other tunneling protocols finally carrying the Ethernet layer visible to the user plane IP traffic. While there are existing technologies, especially in MPLS/PWE space, to establish circuits through the routed and switched networks, there is a lack of signaling the time synchronization and time-sensitive stream requirements/reservations for Layer-3 flows in a way that the entire transport stack is addressed and the Ethernet layers that needs to be configured are addressed. Furthermore, not all "user plane" traffic will be IP. Therefore, the same solution need also address the use cases where the user plane traffic is again another layer or Ethernet frames. There is existing work describing the problem statement [I-D.finn-detnet-problem-statement] and the architecture [I-D.finn-detnet-architecture] for deterministic networking (DetNet) that eventually targets to provide solutions for time-sensitive (IP/ transport) streams with deterministic properties over Ethernet-based switched networks.

This document describes requirements for deterministic networking in a cellular telecom transport networks context. The requirements include time synchronization, clock distribution and ways of establishing time-sensitive streams for both Layer-2 and Layer-3 user plane traffic using IETF protocol solutions.

2. Network architecture

Figure Figure 1 illustrates a typical, 3GPP defined, cellular network architecture, which also has fronthaul and midhaul network segments. The fronthaul refers to the network connecting base stations (base band processing units) to the remote radio heads (antennas). The midhaul network typically refers to the network inter-connecting base stations (or small/pico cells).

Fronthaul networks build on the available excess time after the base band processing of the radio frame has completed. Therefore, the available time for networking is actually very limited, which in practise determines how far the remote radio heads can be from the base band processing units (i.e. base stations). For example, in a case of LTE radio the Hybrid ARQ processing of a radio frame is allocated 3 ms. Typically the processing completes way earlier (say up to 400 us, could be much less, though) thus allowing the remaining time to be used e.g. for fronthaul network. 200 us equals roughly 40 km of optical fiber based transport (assuming round trip time would be total 2*200 us). The base band processing time and the available "delay budget" for the fronthaul is a subject to change, possibly dramatically, in the forthcoming "5G" to meet, for example, the envisioned reduced radio round trip times, and other architecural and service requirements [NGMN].

The maximum "delay budget" is then consumed by all nodes and required buffering between the remote radio head and the base band processing in addition to the distance incurred delay. Packet delay variation (PDV) is problematic to fronthaul networks and must be minimized. If the transport network cannot guarantee low enough PDV additional buffering has to be introduced at the edges of the network to buffer out the jitter. Any buffering will eat up the total available delay budget, though. Section Section 3 will discuss the PDV requirements in more detail.

```
              Y (remote radios)
               \
           Y__  \.--.                   .--.       +------+
              \_(    `.     +---+     _(Back`.     | 3GPP |
       Y------( Front  )----|eNB|----(  Haul  )----| core |
             ( `  .Haul )   +---+   ( `   .  )  )   | netw |
             /`--(___.-'      \      `--(___.-'    +------+
          Y_/     /            \.--.       \
               Y_/            _( Mid`.      \
                             (   Haul )      \
                            ( `  .  )  )      \
                             `--(___.-'\_____+---+    (small cells)
                                   \         |SCe|__Y
                                  +---+      +---+
                               Y__|eNB|__Y
                                  +---+
                                Y_/   \_Y ("local" radios)
```

Figure 1: Generic 3GPP-based cellular network architecture with Front/Mid/Backhaul networks

3. Time synchronization requirements

Cellular networks starting from long term evolution (LTE) [TS36300] [TS23401] radio the phase synchronization is also needed in addition to the frequency synchronization. The commonly referenced fronthaul network synchronization requirements are typically drawn from the common public radio interface (CPRI) [CPRI] specification that defines the transport protocol between the base band processing - radio equipment controller (REC) and the remote antenna - radio equipment (RE). However, the fundamental requirements still originate from the respective cellular system and radio specifications such as the 3GPP ones [TS25104][TS36104][TS36211] [TS36133].

The fronthaul time synchronization requirements for the current 3GPP LTE-based networks are listed below:

Transport link contribution to radio frequency error:

> +-2 PPB. The given value is considered to be "available" for the fronthaul link out of the total 50 PPB budget reserved for the radio interface.

Delay accuracy:

> +-8.138 ns i.e. +-1/32 Tc (UMTS Chip time, Tc, 1/3.84 MHz) to downlink direction and excluding the (optical) cable length in one

direction. Round trip accuracy is then +-16.276 ns. The value is this low to meet the 3GPP timing alignment error (TAE) measurement requirements.

Packet delay variation (PDV):

* For multiple input multiple output (MIMO) or TX diversity transmissions, at each carrier frequency, TAE shall not exceed 65 ns (i.e. 1/4 Tc).

* For intra-band contiguous carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 130 ns (i.e. 1/2 Tc).

* For intra-band non-contiguous carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 260 ns (i.e. one Tc).

* For inter-band carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 260 ns.

The above listed time synchronization requirements are hard to meet even with point to point connected networks, not to mention cases where the underlying transport network actually constitutes of multiple hops. It is expected that network deployments have to deal with the jitter requirements buffering at the very ends of the connections, since trying to meet the jitter requirements in every intermediate node is likely to be too costly. However, every measure to reduce jitter and delay on the path are valuable to make it easier to meet the end to end requirements.

In order to meet the timing requirements both senders and receivers must is perfect sync. This asks for a very accurate clock distribution solution. Basically all means and hardware support for guaranteeing accurate time synchronization in the network is needed. As an example support for 1588 transparent clocks (TC) in every intermediate node would be helpful.

4. Time-sensitive stream requirements

In addition to the time synchronization requirements listed in Section Section 3 the fronthaul networks assume practically error free transport. The maximum bit error rate (BER) has been defined to be 10^-12. When packetized that would equal roughly to packet error rate (PER) of 2.4*10^-9 (assuming ~300 bytes packets). Retransmitting lost packets and/or using forward error coding (FEC) to circumvent bit errors are practically impossible due additional incurred delay. Using redundant streams for better guarantees for delivery is also practically impossible due to high bandwidth requirements fronthaul networks have. For instance, current uncompressed CPRI bandwidth expansion ratio is roughly 20:1 compared to the IP layer user payload it carries in a "radio sample form".

The other fundamental assumption is that fronthaul links are symmetric. Last, all fronthaul streams (carrying radio data) have equal priority and cannot delay or pre-empt each other. This implies the network has always be sufficiently under subscribed to guarantee each time-sensitive flow meets their schedule.

Mapping the fronthaul requirements to [I-D.finn-detnet-architecture] Section 3 "Providing the DetNet Quality of Service" what is seemed usable are:

(a) Zero congestion loss.

(b) Pinned-down paths.

The current time-sensitive networking features may still not be sufficient for fronthaul traffic. Therefore, having specific profiles that take the requirements of fronthaul into account are deemed to be useful [IEEE8021CM].

The actual transport protocols and/or solutions to establish required transport "circuits" (pinned-down paths) for fronthaul traffic are still undefined. Those are likely to include but not limited to solutions directly over Ethernet, over IP, and MPLS/PseudoWire transport.

5. Security considerations

Establishing time-sensitive streams in the network entails reserving networking resources sometimes for a considerable long time. It is important that these reservation requests must be authenticated to prevent malicious reservation attempts from hostile nodes or even accidental misconfiguration. This is specifically important in a case where the reservation requests span administrative domains. Furthermore, the reservation information itself should be digitally signed to reduce the risk where a legitimate node pushed a stale or hostile configuration into the networking node.

6. IANA Considerations

This document has no IANA considerations.

7. Acknowledgements

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