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LOW LATENCY 5G/LTE MOBILE FRONTHAUL TRAFFIC IN TDMPON/XGS-PON NETWORKS

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ABSTRACT

Ensuring low latency in a passive optical network (PON) environment for a mobile fronthaul use case is critical and raises a number of challenges. To address those types of challenges, techniques are presented herein that support, among other things, the coordination between a PON scheduler and a Long-Term Evolution (LTE) or Third Generation Partnership Project (3GPP) Fifth Generation (5G) scheduler where the expected traffic in an uplink direction is intimated in advance to the PON scheduler. Such advance knowledge of a bandwidth scheduling requirement in an upstream direction eliminates, for example, the serialization of scheduler latency. Aspects of the techniques presented herein encompass, among other things, the development of a phase relationship between a PON superframe counter (SFC) and a time service, the determination of a bandwidth demand, the exchange of developed information (employing, for example, a variable-sized extension header or a fixed-sized custom header and vendor-specific message types), the creation of a mapping between a transmission container (TCONT) and a flow identifier, etc.

DETAILED DESCRIPTION

A deeply disaggregated virtual optical line terminal (OLT) may comprise, among other things, a PON Media Access Control (MAC) and optics being encompassed in an enhanced small form-factor pluggable (SFP+) form factor. Such an SFP+ is like a micro OLT and may, for example, be plugged into an Ethernet port of a router as a host platform. Similarly, such an SFP+ plug-in may be used as an optical network unit (ONU) on an Ethernet port in a router. Such an approach can, for example, allow a vendor to enter the

PON market without having a previous presence. Going forward, a PON MAC may be instantiated in a field-programmable gate array (FPGA). Aspects of the techniques presented herein, which will be described and illustrated in the narrative below, support both approaches.

From a vendor's business point of view, the importance of PON pluggable optics is key. For example, an architectural shift in network and equipment can be seen and hence a micro OLT design in an SFP+ form factor for 10 gigabit (Gb) symmetrical PON (XGS-PON) is very important.

In a 3GPP 5G dense heterogeneous radio access network (RAN) and centralized RAN or cloud RAN or virtualized RAN (vRAN) scenario, a frequent customer concern involves ensuring a low latency performance in a PON network for a mobile fronthaul use case.

In a centralized RAN and a cloud RAN or vRAN, mobile base stations are split into a centralized baseband unit (BBU) and distributed remote radio heads (RRHs) which are connected by optical fiber. A 5G network will also see a dense RAN network due to bandwidth demands. In such a use case a new functional split point between a BBU and a RRH is identified in the 3GPP technical specification (TS) 38.201 and in the Open Radio Access Network (O-RAN) specification.

As described in 3GPP TS 38.201 and in the O-RAN specification, one of the most important options is Split 7.2, which supports an intra-physical (PHY) layer split as shown in Figure 1, below.

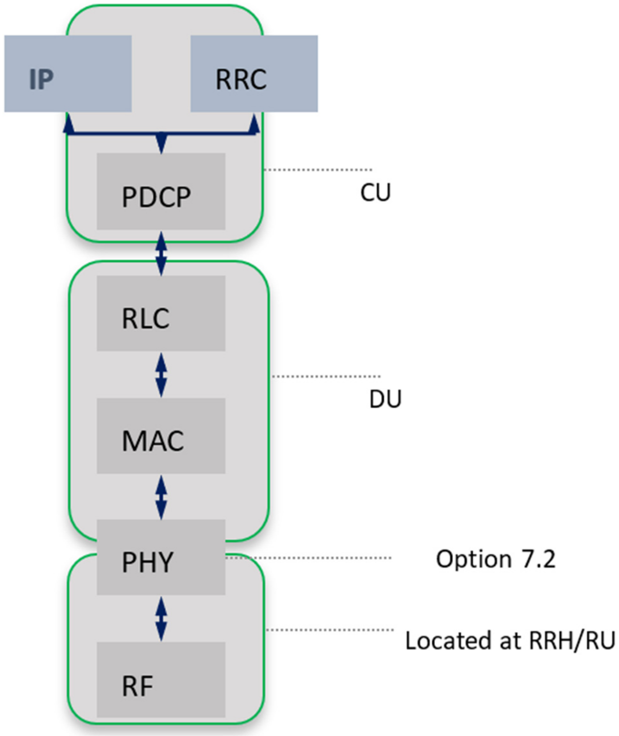

Figure 1: Illustrative Protocol Layers

It is important to note that a stringent 100 microsecond (usec) to 150 usec one-way delay (OWD) in a fronthaul link is applicable in the case where a fronthaul link falls in a hybrid automatic repeat request (HARQ) loop. In Split 7.2, this is applicable. As illustrated in Figure 1, above, HARQ is part of a MAC layer and hence a HARQ loop covers the fronthaul link and consequently a stringent latency demand will exist between a radio unit (RU) and a distributed unit (DU). It is also important to note that a DU and a centralized unit (CU) may be converged on one platform or, alternatively, those functions may also be separate. Such a distinction is not an important point in the context of the techniques that are presented herein.

In Split 7.2, the lower part of the baseband processing happens in the RRH and RU and frequency domain quadrature signals (IQ) and physical random-access channel (PRACH) data is packetized in an enhanced Common Public Radio Interface (eCPRI) Version 2 (V2) or an Institute of Electrical and Electronics Engineers (IEEE) specification 1914.2 Radio over Ethernet (RoE) packet and sent to central DU or CU location through a fronthaul network. It is important to note that unlike a Common Public Radio Interface

(CPRI), this will not send all (i.e., 100 percent) of the duty cycle traffic as time domain IQ samples are converted to frequency domain IQ samples in an uplink direction. Additionally, a BBU sends the frequency domain IQ which is converted to time domain IQ at a RRH or RU. Thus, there is a good impedance match for time-division multiplexing PON (TDMPON) applications such as XGS-PON or next-generation PON 2 (NG-PON2) environments as optical fiber may be shared by multiple RRH in a dense 5G network.

A principal problem with a PON is its higher latency in upstream bandwidth allocation due to centralized dynamic bandwidth allocation (DBA) running at an OLT. In a dense 5G network such a latency challenge needs to be solved for XGS-PON and NG-PON2 networks.

Problems with a TDM-PON in a fronthaul use case may include, among other things, the upstream bandwidth (BW) allocation in TDMPON being performed centrally through a DBA process, which is part of a PON MAC, thus assigning the upstream BW for each ONU. In connection with the techniques presented herein, there are two types of DBA that are relevant:

1. Status reporting DBA (SR-DBA). Bandwidth is dynamically assigned to each ONU based on a report (i.e., a BW demand) from an ONU. This approach has a problem with latency as it needs to arbitrate for upstream allocation when a packet arrives.
2. Non-status reporting DBA (NSR-DBA). A report is not used from an ONU. This is a fixed bandwidth allocation approach and it works well for a CPRI's kind of inelastic traffic. However, Split 7.2 is not all (i.e., 100 percent) duty cycle traffic and hence it needs the dynamic assignment of upstream bandwidth. Also, DBA should ensure the stringent low latency performance as expected in a fronthaul network.

To address the types of challenges that were described above, techniques are presented herein that support, among other things, the co-ordination of a PON scheduler and a Long-Term Evolution (LTE) or 5G scheduler where the expected traffic in an uplink direction is intimated in advance to the PON scheduler. Such advance knowledge of a bandwidth scheduling requirement in an upstream direction eliminates the serialization of scheduler latency.

Aspects of the techniques presented herein support, among other things, coordination between a 5G or LTE scheduler on a DU and a PON DBA on an OLT. In the normal case a bandwidth demand comes from an ONU in a SR-DBA or a fixed bandwidth allocation as configured statically. A fixed bandwidth approach is not good, as discussed above, as fronthaul traffic is not 100 percent duty cycle traffic and it is not known when traffic will arrive. Additionally, a SR-DBA is also not good because it incurs significant of latency in arbitrating for bandwidth in upstream direction. This is essentially a serialized scheduler workflow.

Aspects of the techniques presented herein account for, among other things:

1. The time scale of a wireless scheduler being much higher than a PON DBA operation.
2. Since a wireless scheduler allocates the upstream bandwidth it also knows when the upstream bandwidth will arrive.
3. A wireless scheduler conveys this information to a PON OLT in advance so that a grant may be issued and when a fronthaul packet arrives it does not have to wait for a longer period of time in the ONU queue.
4. Based on a RRH's configuration (e.g., the number of antennae, the number of bands, the number of sectors or multiple-input and multiple-output (MIMO) layers, etc.) a BW demand may be calculated at the BBU or DU and this information may be sent to an OLT when it will be required. Alternatively, this RRH information may be configured with an OLT DBA and a DU or BBU by just identifying when uplink traffic is expected (as described previously) and a DBA allocates the BW based on the configured information.

Elements of points number 1, 2, and 3 in the above narrative are depicted in Figure 2, below.

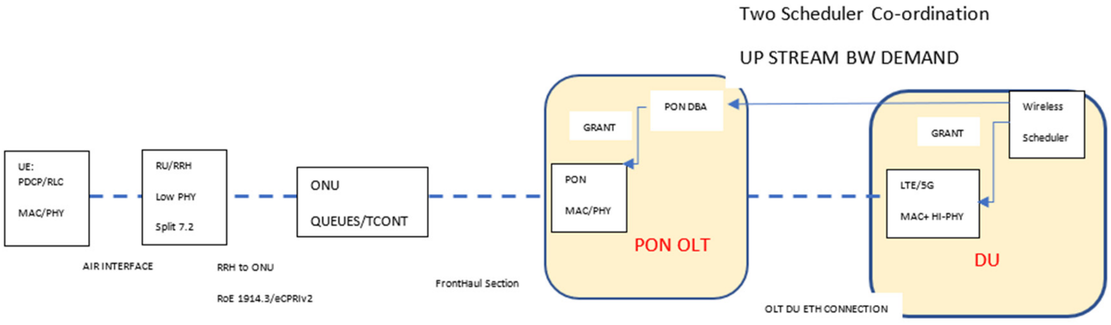

Figure 2: Exemplary Scheduler Coordination

From the discussion above what is achieved is the latency of PON media arbitration being covered under wireless scheduling and thus there is no extra penalty from PON arbitration.

For purposes of exposition, aspects of the techniques presented herein may be captured in the following multi-step workflow. The whole workflow may be modeled as a BBU or DU as a physical network function (PNF) or a virtual network function (VNF) at a service layer that has a hardware slice in a piece of PON OLT equipment for transport.

A first step of the multi-step workflow considers the phase relationship between a PON SFC and the Precision Time Protocol (PTP) as specified by IEEE specification 1588 Version 2 for Time of Day (ToD). A PON DBA cycle is run in coherence between a SFC (i.e., a 64-bit counter in a PON transmission convergence (TC) layer). This also works like a PON ToD. The phase relationship between a SFC is established with an IEEE 1588 ToD. For this PON SFP and PON OLT the system will initiate a PTP type of packet with an SFC counter and this is the time that is stamped by a PTP interface. This can also be accomplished the other direction when a PTP system initiates the PTP packet with its own time stamp and, once received by a PON, it is time stamped by the PON SFC counter with the value of the PON ToD. It is important to note that the phase relationship is not required to be as precise as, for example, a Class B, Class C, or Class D clock (e.g., on the order of a few nanoseconds (ns)).

A second step of the multi-step workflow externalizes the phase information to a DU or BBU. The DU will then use the information to create a BW demand to a PON

DBA in an upstream direction. The DU will align the BW demand with an SFC. It is also possible for the DU to align the BW demand with a ToD and a ToD to SFC phase relationship is configured in a DBA and hence the DBA can calculate when to pre-allocate the upstream BW.

Under a third step of the multi-step workflow, in RoE, as defined in the IEEE specification 1914.3, there are multiple options possible for passing the BW demand (BW-DEMAND) that is aligned with a future SFC or PTP ToD to PON DBA as described and illustrated below. In brief, a BW-DEMAND instruction may be encoded (as discussed below) and it may carry the required BW aligned with a SFC or ToD (as described above in the discussion of the second step of the multi-step workflow).

Under a first option, as depicted in Figure 3, below, a variable-sized extension header may be used in the RoE frame to carry the BW-DEMAND information.

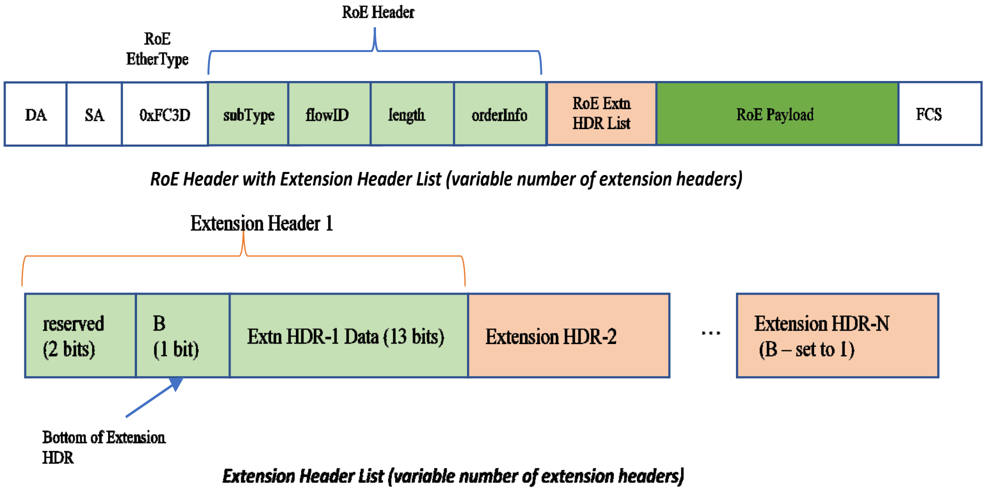

Figure 3: Variable-Sized Extension Header in the RoE Frame to Carry BW-Demand Information

Alternatively, under a second option, as illustrated in Figure 4, below, a fixed-sized custom header in the RoE frame may be employed to carry the BW-DEMAND information.

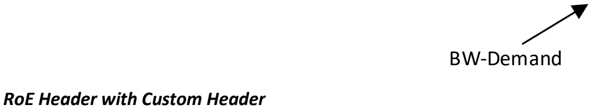

Figure 4: Fixed-Sized Custom Header to Carry BW-Demand Information

Under a fourth step of the multi-step workflow, in the case of eCPRI V2 use can be made of one of eCPRI's message types 64 to 255 which are reserved for vendor specific use (as described in the eCPRI V2 specification that was released in May 2019) to carry a BW requirement from a DU to an OLT.

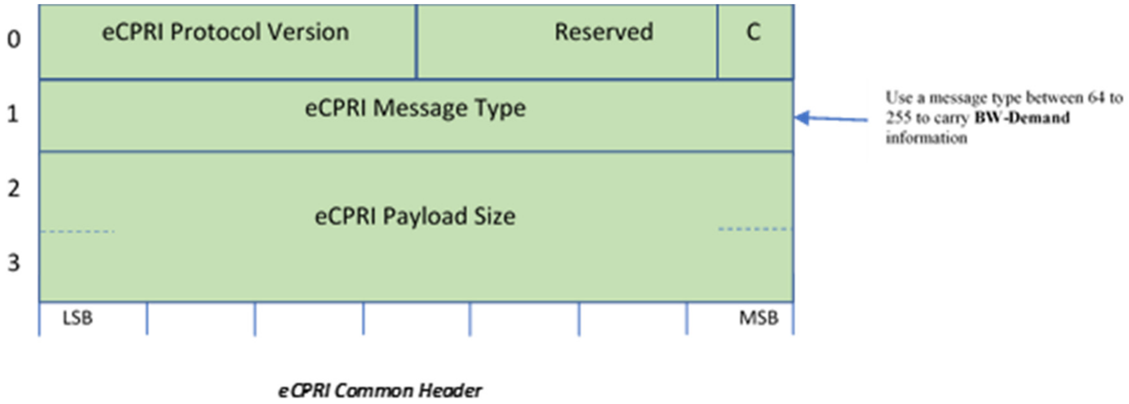

Figure 5: Experimental RoE subType in RoE Header to Carry BW-DEMAND Information

Under a fifth step of the multi-step workflow, a RoE or eCPRI flow which carries information as described above may also identify the ONU and the TCONT for which BW demand is being raised. This information may be retrieved from a frame-like flow identifier in a RoE or a physical cell identifier (PCID) in eCPRI V2 to select the correct TCONT which is the traffic bearing entity in the PON. Importantly, a mapping may be created between a TCONT and a flow identifier or a PCID in conjunction with a BBU or DU.

Figure 6, below, illustrates aspects of the workflow that was presented in the above narrative.

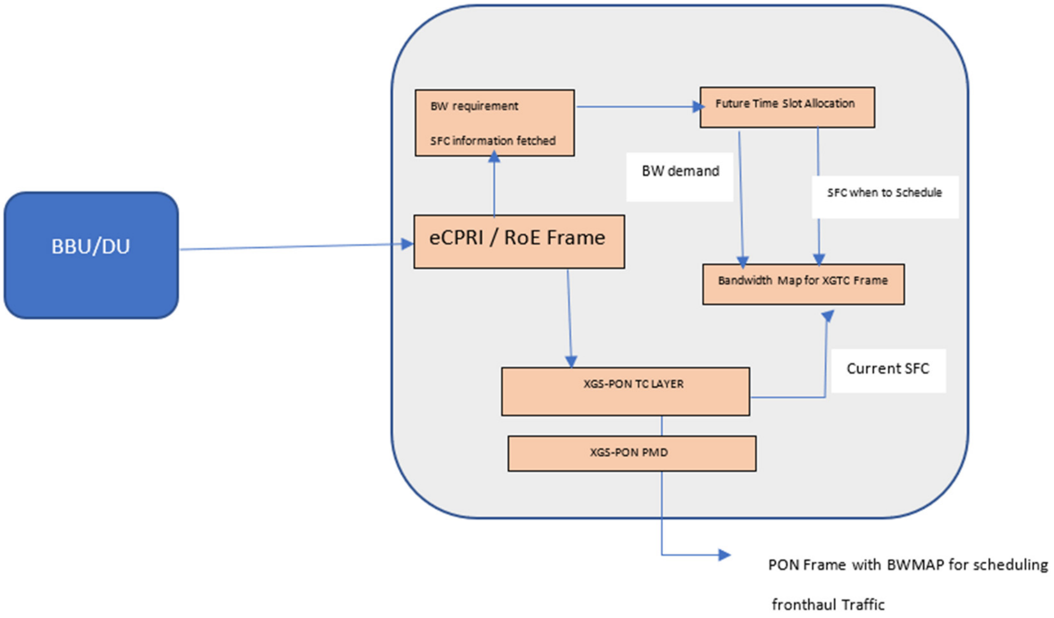

Figure 6: Exemplary Workflow

In summary, techniques have been presented that support, among other things, the coordination between a PON scheduler and an LTE or 3GPP 5G scheduler where the expected traffic in an uplink direction is intimated in advance to the PON scheduler. Such advance knowledge of a bandwidth scheduling requirement in an upstream direction eliminates, for example, the serialization of scheduler latency. Aspects of the techniques presented herein encompass, among other things, the development of a phase relationship between a PON SFC and a time service, the determination of a bandwidth demand, the exchange of developed information (employing, for example, a variable-sized extension header or a fixed-sized custom header and vendor-specific message types), the creation of a mapping between a transmission container TCONT and a flow identifier, etc.