Illustrates proofreading ability, at levels from English usage to style to content.
Commenting tool: Acrobat pro

Passive Optical Networks for 5G Transport: Technology and Standards

Jun Shan Wey, *Senior Member, IEEE* and Junwen Zhang, *Member, IEEE*

***Abstract*—As the ink is drying on 5G New Radio (NR) standards, the industry is now setting its sight on specifying the transport network layer to support 5G deployments. Several contending transport technologies tailored for 5G are being considered. Which technology will be the most suitable to meet the 5G demands? This paper is intended to address this question with an emphasis on the applicability of passive optical network (PON). Key 5G wireless transport standards are reviewed, followed by an overview of optical access technologies and standards development activities. State of the art PON technologies are highlighted.**

***Index Terms*—5G, Passive optical networks, time-division multiple access, wavelength-division multiple access.**

I. Introduction

~~Transport network~~ plays a central role in successful 5G new radio (NR) deployments. Several contending technologies, for example point-to-point fiber access, passive optical network (PON), and Flexible Ethernet, are being proposed specifically for 5G and discussed in standards bodies. Which of these technologies will be the most suitable to meet the 5G demands? There is really no clear answer to this question because different operators have different business models and deployment plans. They will also need to make ~~the~~ technology selections based on ~~the~~ technology maturity and market timing.

As a start, we need to understand the key 5G requirements and how they would ~~impact~~ the transport network design, before discussing the transport technology choices. Among the contending technologies, PON stands out as a strong candidate because of its point-to-multipoint topology for efficient ~~usage~~ of fiber resources and its wide deployment around the world for fixed access services. Since its introduction in late 1990s, the PON market has expanded rapidly to now ~~serving~~ over 100 million broadband subscribers worldwide. ~~The global~~ PON equipment revenues ~~is~~ projected to be $7.6 billion, with $3.8 billion in China alone~~, by 2022-2023~~. In terms of volume, China will consume over 80% of global shipment of PON ports in the same time frame [1]. As such, it is advantageous for 5G wireless transport to share the fiber infrastructure with fixed access to save operational costs.

In this paper, we review the current 5G wireless transport requirements, followed by an overview of optical access technologies and standards development activities specifically for 5G transport. And finally, state of the art PON technologies are highlighted.

II. Overview of 5G Wireless Transport

Other than faster speed and higher bandwidth ~~from~~ 4G/LTE, 5G networks are designed to take advantage of cloud and virtualized network and to support massive machine type communications. Here, we ~~will~~ discuss the fundamental changes in the 5G wireless transport architecture, bandwidth and latency requirements, typical deployment scenarios, and ~~the~~ recent progress on industry standards.

A. 5G wireless transport architecture

Traditionally in a 4G/LTE radio access network (RAN), the transport network consists of two segments: 1) a backhaul segment between evolved packet core (EPC) and baseband unit (BBU) and 2) a fronthaul segment between BBU and remote radio head (RRH). This conventional fronthaul uses CPRI or OBSAI protocol to transport digitized IQ data at continuous bitrate regardless of whether user traffic is present. This is understandably not a very efficient mechanism. As a result, data rate well over 100 Gb/s can be expected in 5G networks if the same protocols are used. Another important factor is latency, which is limited to 250 μs ~~for~~ maximum end-to-end roundtrip time. This latency requirement is not a concern in 4G as BBU and RRH are connected by direct fiber at the same cell site.

As we move forward to 5G, much focus is on a centralized/cloud transport network to efficiently support a massive scale of connected devices. Ideally, all BBUs would be moved to a common location for centralized processing, leaving only RRHs at the cell sites with minimum power consumption. However, this is not possible in reality because of the high bandwidth and stringent ~~low~~ latency requirements. For example, for a 5G cell site with 64 antenna ports for 200 MHz radio channel bandwidth, the required CPRI bandwidth will be about 640 Gb/s, based on parameters defined in [2]. The latency also has to include propagation time through the transmission media, which limits the allowance for process delay.

As a result, a new design has emerged to mitigate these constraints while allowing for network centralization. The concept behind the new design is to redistribute the radio signal processing functions in EPC and BBU to new functional elements, namely the next generation core (NGC), centralized

This paper was first submitted for review on 12 May 2018.

Jun Shan Wey and Junwen Zhang are with ZTE TX, Inc., Morristown, NJ 07960, USA (e-mail: wey.junshan@ztetx.com).

Summary of Comments on PON for 5G transport

Page: 1

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 1:45:48 PM
we review is a different voice from *are highlighted*. Be consistent; active voice is preferred.

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 1:46:22 PM
wording sounds as if the transport is wireless

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:46:36 PM
than

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:50:43 PM
concepts

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 1:50:59 PM

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 1:51:11 PM

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:40:14 PM
The transport network ...

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 1:52:31 PM
[insert refs]

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:51:26 PM
the

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:52:44 PM
a

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:53:16 PM
s

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:53:31 PM
fronthaul

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 1:54:58 PM

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 1:55:46 PM
This is not helpful because we have no knowledge where the ends are. At best, we would speculate (incorrectly) that one end was the UE.

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 1:38:18 PM

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:53:54 PM
, in 5G,

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:03:32 PM
This conflicts with the assertion that fronthaul from BBU to RRH is already part of the traditional architecture.

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 1:38:35 PM

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:41:01 PM
"impact" is a buzzword. Suggest "affect" instead.

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:41:21 PM
use

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 3:03:40 PM

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:41:37 PM
serve

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:42:09 PM

Comments from page 1 continued on next page

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Global ...

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:04:02 PM
We would expect this to match some row of Table 1, but it doesn't.

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:43:11 PM
by 2022-2023

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 1:42:22 PM
are

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 1:43:19 PM

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 1:44:05 PM
If China consumes 80% of PON ports, why is it only ~50% of revenues? If you don't want to explore that topic, maybe omit some of this material?

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 3:04:59 PM
[insert ref]

unit (CU), distributed unit (DU), and radio unit (RU). The top part of Fig. 1 shows the functions in the radio signal processing chain and the eight potential split options. Also shown in Fig. 1 (bottom part) is the functional composition in BBU and RRH for 4G LTE, as well as an example implementation for 5G.

There are indeed many more ways to implement the functional splits, each with its own merits and drawbacks. The specific split options will of course depend on deployment choices.

Two important interfaces are noted in Fig.1: a high layer split point called Fronthaul-II/Midhaul/F1 and a low layer split point called Fronthaul-I/Fx [2][3].

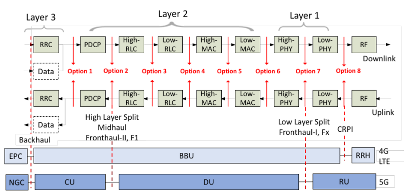

Fig. 1. Evolving from 4G to 5G. Top: signal processing function chain. Bottom: functional composition of network elements for 4G LTE and an example 5G implementation.

B. Bandwidth and latency requirements

A key characteristic of the 5G architecture is that the amount of data transported scales with the user traffic. By contrast, traditional CPRI/OBSAI protocols requires continuous bitrate transport independent of user traffic. This means that 5G transport can adapt to traffic conditions dynamically and aggregate traffic from different cell sites making use of statistical multiplexing.

Table 1, an excerpt of Table A-1 in [2], shows the transport bandwidth requirements for selected split options. These values are calculated for the case of 100 MHz radio frequency bandwidth, 256-QAM modulation, 8 MIMO layers, and 32 antenna ports. Option 2 split has been specified by 3GPP as the F1 interface, while Fx is still open and could be either Options 7a, 7b, or 7c.

A general guidance from operators for throughput bandwidth in both backhaul and F1 is 10 Gb/s during 5G Phase 1 rollout (radio bandwidth up to 3.5 GHz) and increasing to 25/50 Gb/s in Phase 2 (radio bandwidth > 6 GHz) [4].

TABLE 1
5G WIRELESS TRANSPORT BANDWIDTH AND LATENCY REQUIREMENTS

Split Option	Uplink Bandwidth	Downlink Bandwidth	One-way Latency
2 (F1)	4016 Mb/s	3024 Mb/s	1-10 msec
3	Lower than Option 2		100 to a few 100 µsec
4	4000 Mb/s	3000 Mb/s	
7a	10.1-22.2 Gb/s	16.6-21.6 Gb/s	
7b	37.8-86.1 Gb/s	53.8-86.1 Gb/s	
7c	10.1-22.2 Gb/s	53.8-86.1 Gb/s	
8 (CPRI)	157.3 Gb/s	157.3 Gb/s	

For 100 MHz radio bandwidth, 256-QAM modulation, 8 MIMO layers, 32 antenna ports.

C. Deployment scenarios

Depending on different operators' requirements, there are four potential deployment scenarios, as illustrated in Fig. 2.

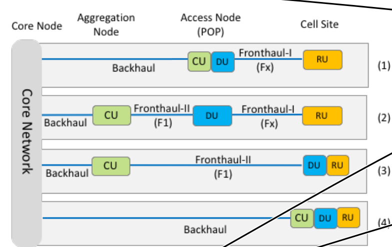

Fig. 2. Typical deployment scenarios.

1) Scenario 1: C-RAN

This scenario is an extension of 4G LTE and mostly applicable to ultra-reliable low latency communication (URLLC). CU and DU are collocated in the access node enabling centralized radio access network (C-RAN).

2) Scenario 2: C-RAN

This scenario is typically for enhanced mobile broadband (eMBB). It allows for simultaneous support of fixed wireless access over F1 interface and massive machine type communication (mMTC) over Fx in dense urban areas and greenfield. CUs are located at the aggregation node as part of the Mobile Edge Cloud.

3) Scenario 3: D-RAN

This scenario is relevant for eMBB in a latency tolerant, distributed radio access network (D-RAN). The fronthaul segment between DU-RU, co-located at the cell site, can employ direct and short fiber (<100s meters). In many cases, legacy fiber connections between RRU and BBU can be reused. The CU-DU connection can employ existing optical access infrastructure with wavelength overlay.

4) Scenario 4: small cell, hotspot

This scenario is most applicable for small cell and integrated macro-cell for high-speed hotspot (5G HF cell) and general coverage. This is a traditional backhaul link where existing transport resources can be used to save cost. Wavelength overlay is another method to cover small cell dead zone.

D. Progress in 5G transport standards development

Led by 3GPP, many standards bodies are contributing to the development of 5G specifications. 3GPP approved its first non-standalone 5G NR specification (4G control plane and 5G data plane) in December 2017 [5], with the standalone version (5G in both control plane and data plane) anticipated by June 2018.

With respect to the functional split options, several SDOs have published ~~complimentary~~ specifications. 3GPP has prioritized Option-2 and Option-3 work as the immediate step, with Option-4 and Option-7 to follow shortly after [6].

Page: 2

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:08:33 PM
add ref? or is this an original observation unsupported by refs?

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:05:19 PM
IEEE has always allowed, if not actively encouraged, graphics, and especially text, so small as to be illegible except on high-quality glossy magazine paper. Consider what you can do about it. Simpler pictures, as in Fig 2? Double-column graphics would improve Fig 1.

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:08:57 PM
It would be good to put these labels on the figure, to avoid the need for the reader to switch back and forth.

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:09:18 PM
Explain why this is more reliable or lower latency than the other scenarios. It sounds as if co-location is a defining characteristic of C-RAN. This conflicts with scenario 2, and should be explained.

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:05:47 PM
Confusing: if the lower part is just an example, well-defined reference points would not be expected. This requires explanation.

Author: Dave Hood Subject: Cross-Out Date: 2/19/2019 3:06:08 PM

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:09:36 PM
Is embb a defined term in the art? If so, add a reference. Why is mmtc better supported by scenario 2 than 1?

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:06:27 PM
This is only true over shared media, eg PON. For PtP DU-RU, it wouldn't matter.

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:10:09 PM
we said earlier that 5G would not tolerate latency. Please resolve. If DU/RU are co-located, explain why we would not just continue to use cpri/obsai?

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:06:51 PM
So why does the table include options 3 and 4?] ["a few hundred usec" one-way is incompatible with the earlier requirement for 250 us round trip. Please resolve.] [Does Table 1 refer to fronthaul, backhaul, or both? (In section D, it appears that we are talking fronthaul.)

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:10:45 PM
acronym HF?

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:07:37 PM
10G per what?

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:08:03 PM
3.5 and 6G are spectral bands, but the entire 0-X spectrum is not available for use. (10Gb/s per 3.5GHz spectrum implies 3.5 bits/Hz efficiency.)

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:11:02 PM
Sounds as if wavelength overlay is related to small cell dead zone, but we're talking about transport here, not radio.

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:11:27 PM
acronym?

Author: Dave Hood Subject: Inserted Text Date: 2/19/2019 3:11:43 PM
complementary

Author: Dave Hood Subject: Sticky Note Date: 2/19/2019 3:12:01 PM
In the description of table 1, there appears to be no reason to care about options 3, 4.