Independent market research and competitive analysis of next-generation business and technology solutions for service providers and vendors

Delivering 5G with High-Bandwidth Photonics

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EXECUTIVE SUMMARY

The shift from 4G to 5G is driving a massive increase in demands on wireless infrastructure, including fronthaul and backhaul networks. 5G applications demand both high-bandwidth and low latency connections over the radio link and through to application servers. The architecture of the wireless radio access network (RAN) is evolving, and this can have a big impact on the optical solutions used for fronthaul and backhaul networks.

5G specifications have added significant flexibility to the RAN architecture and transport network options. Carriers need to consider the trade-offs between lower cost baseband processing and fronthaul network bandwidths. Time-Sensitive Networking (TSN) can be used to support low latency fronthaul packet-based links and time synchronization. Some combinations of network bandwidth RAN architecture will require fronthaul links supporting 50 Gbit/s, 100 Gbit/s, and higher bandwidths.

Silicon photonics can provide similar benefits in 5G fronthaul applications as they do in the data center. Centralized RAN (C-RAN) architectures offer some clear benefits but do drive higher fronthaul bandwidths. Millimeter wave (mmWave) deployments will open up a significant spectrum and also drive higher fronthaul bandwidths. There are some clear trends, but not all of the options available make sense in practical 5G network deployments. In this white paper, Heavy Reading highlights the key technologies, identifies some of the important trends, and discusses practical implementations for 5G network deployments.

DATA TRAFFIC GROWTH AND THE MOVE TO 5G

The shift to 4G wireless and LTE has enabled significant growth in mobile data traffic and the deployment of services for other applications, including Internet of Things (IoT). The first steps are now being made in the move to 5G, which will drive further massive growth of mobile data traffic and a more diverse set of applications running over wireless networks. Initial deployments are rolling out in the U.S., South Korea, Switzerland, and elsewhere. According to the Global Mobile Suppliers Association (GSA), 59 countries are rolling out 5G or preparing for 5G.

Figure 1: Growth of 4G Data Traffic and Shift to 5G

Source: Cisco VNI Global Mobile Data Traffic Forecast, February 2019
Figure 1 above, taken from the latest Cisco Visual Networking Index (VNI) Global Mobile Data Traffic Forecast Update released in February 2019, shows a compound annual growth rate (CAGR) of 46% for mobile traffic from 2017 to 2022. During this period, the 4G share is forecast to be steady at 70%; 4G data traffic is projected to grow in line with overall traffic demand. At the same time, the 5G data traffic share is expected to grow from almost nothing in 2019 to 12% in 2022, and the share of 3G and 2G will decline as these services are used less frequently and carriers drop support from their networks.

Leading use cases for 5G and technologies are shown in Figure 2 below. Enterprise and industrial applications include industrial control systems and industrial automation to support smart manufacturing. Business-to-business and business-to-consumer (B2B2C) applications include professional video capture and services for augmented reality and wireless gaming. For consumers, the streaming of high quality video content – which requires high peak speeds and massive capacity – is becoming increasingly important.

For these services and applications, 5G supports three technology service types: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (uRLLC), and Massive Machine-Type Communications (mMTC) for IoT applications. eMBB provides superior peak speeds, greater network capacity, and a high quality link. uRLLC enables low latency connections, down to 1 ms, in contrast to the 50 ms average latency delivered by LTE. These low latency services require application servers to be deployed in new hub locations in the edge cloud.

Figure 2: 5G Use Cases and Their Technologies

Source: Nokia

In addition to new radio technologies, 5G requires a massive increase in network bandwidth. This increase will be enabled through three main vectors: additional spectrum, massive Multiple Input, Multiple Output (MIMO), and more antennas. Additional spectrum is being allocated worldwide for 5G services, both below 6 GHz and mmWave, particularly around 30 GHz. The mmWave bands are much wider and support significantly higher data rates. The sub-6 GHz bands, particularly around 800 MHz, support similar bandwidths to LTE.
Massive MIMO antennas that support beamforming are driving more bandwidth to devices, and the deployment of many more antennas is enabling network densification. More antennas are required to support greater network bandwidth and mmWave connections that do not travel well through walls and over long distances. The shift from 4G to 5G will increase network capacity by up to 1,000x, and this will put extreme pressure on the fronthaul and backhaul connections.

The narrowband sub-6 GHz 5G spectrum provides tens of megahertz, similar to LTE. Like LTE Advanced (LTE-A), 5G requires technologies such as coordinated multipoint (CoMP) and carrier aggregation to support higher bandwidth services. To employ these technologies, the baseband processing must be centralized. On the other hand, ultra-wideband mmWave 5G spectrum provides hundreds of megahertz and does not require support for CoMP and carrier aggregation. In this case, the baseband processing can be distributed and multiple midhaul solutions used.

RAN ARCHITECTURES AND THE NEED FOR TIME SYNCHRONIZATION

The classical 4G/LTE RAN has a distributed architecture in which the antenna, radio unit (RU), and baseband unit (BBU) are located at the cell site and connected through a backhaul link to the mobile core. This backhaul connection can be a standard IP/Ethernet link with no specific timing or synchronization requirements. This approach is shown at the bottom of Figure 3 and can also be used for 5G where the base station at the radio site is upgraded to support 5G.

Figure 3: RAN Architectures

Many of the latest 4G network installations have used a C-RAN architecture in which a remote radio head (RRH) at the radio site just contains the antenna and RU and the BBU is moved to the central office (CO) or data center. This approach is shown at the top of Figure 3 above. The key advantage of the C-RAN approach is that the BBU can be shared across multiple radio sites. This is particularly important in radio networks that have many radio sites in a relatively small area. The BBU can be implemented as a physical system or a virtual function that is hosted on edge cloud servers. These edge servers can also be used to host low latency 5G services.
The 5G specifications allow the BBU function to be split into distributed units (DUs) and a central unit (CU). This introduces two further RAN architecture options for 5G, with the DU and CU split between the edge cloud and regional cloud (centralized cloud RAN) or radio site and regional cloud (distributed cloud RAN). The DU and CU are connected through a midhaul Ethernet link. In centralized architectures, the DU and RU must be connected through a low latency fronthaul link that can handle the radio information. This fronthaul link can be Common Public Radio Interface (CPRI) for 4G but needs to be eCPRI or Radio over Ethernet (RoE) to handle the higher speeds required for 5G.

For these multiple RAN architectures, flexible transport networks are required to implement deterministic fronthaul connections between the DU and RU and support high accuracy time synchronization across the RAN. TSN networks will handle eCPRI and CPRI inputs with support for RoE. As shown in Figure 4, the TSN switch supports IEEE 802.1 CM TSN, strict priority scheduling, and frame preemption to guarantee low latency connections.

**Figure 4: Time-Sensitive Networking (TSN)**

Source: Nokia

One side effect of moving from CPRI to a full packet-based solution for fronthaul is the loss of the time synchronization provided by the CPRI connection. The TSN switch network therefore needs to support Precision Time Protocol (PTP) paths for time synchronization from the hub to the radio sites. International Telecommunication Union (ITU) G.8273.2 Class C ultra-high accuracy PTP is required for the 5G fronthaul and ITU G.8273.2 Class B high accuracy PTP for the midhaul and backhaul networks. This removes the need for a GPS at every cell site, saving on costs and avoiding limitations from poor satellite receptions.

**SILICON PHOTONICS FOR 5G AND XHAUL OPTIONS**

The connections in these fronthaul, midhaul, and backhaul networks are point-to-point fiber optic links. For 4G LTE fronthaul links using CPRI, 1-10 Gbit/s links with 1,300 nm optics in the 2-10 km range have been used. These are similar to links used in data centers except for a wider temperature range requirement of -40°C to +85°C and support for CPRI. 5G networks require links supporting higher data rates of 25 Gbit/s, 100 Gbit/s, and more. Due to the shift to eCPRI and RoE, these 5G fronthaul links can use silicon photonics-based optical modules developed for data center applications that support the wider operating temperature range needed for wireless fronthaul networks.
5G specifications allow multiple RRH and BBU split options. Two key split options include the following:

- Option 2: Layer 1 and Layer 2 functionality is implemented in the RRH, allowing for data aggregation and statistical multiplexing.
- Option 7: The RRH just implements Layer 1 functionality.

Option 2 requires a more expensive RRH but limited data rates over the fronthaul connection. Option 7 keeps the cost of the RRH low and minimizes the impact of future network changes but requires higher fronthaul bandwidths.

**Figure 5** shows distributed RAN (DRAN) and partially centralized RAN examples for sub-6 GHz using Option 2 and Option 7 splits. The Option 2 and Option 7 fronthaul rate estimates for a 3-sector, 1 carrier macro cell with 4x4 or 8x8 MIMO are given below. This shows the trade-off between Option 2, which requires a more complex RRH and sub-10 Gbit/s bandwidths, and Option 7, which requires 50 Gbit/s or 100 Gbit/s fronthaul links.

**Figure 5: DRAN and Partially Centralized RAN**

The bandwidths required for a fully centralized virtualized RAN using Option 7 increase significantly when multiple sites are connected through a multiplexer or switch (see **Figure 6** below). For 5G 3-sector macrocells with 8x8 MIMO and four antenna sites, the fronthaul connection from the switch back to the CU would require up to 267 Gbit/s.
5G networks are likely to require many small cells when supporting sub-6 GHz connections in dense areas and mmWave connections. Figure 7 shows single sector small cell examples with eight antenna sites, using Option 7 with 4x4 MIMO or 16x16 MIMO. For the 16x16 MIMO example, the fronthaul rate could be up to 355 Gbit/s.

mmWave deployments require significantly higher fronthaul connections. The final example in Figure 8 below shows a 5G single sector small cell deployment with eight antenna sites and 128x128 array panels. In this case, the Option 2 fronthaul rate is estimated to be 618 Gbit/s, which would require multiple 100 Gbit/s fiber links.
Figure 8: Small Cell Example, Option 2

Table 1: 5G Deployment for 8-Antenna Sites (mmWave configurations) and Bandwidth (BW) and Numerology

<table>
<thead>
<tr>
<th>Deployment Type</th>
<th>BW</th>
<th>Numerology</th>
<th>3GPP Split Option 2 Fronthaul Rate Estimates (CU to Switch or Router)</th>
<th>3GPP Split Option 2 Fronthaul Rate Estimate per Small-Cell Site (Switch or Router to Small Cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5G: small-cell; 64x64 array panel</td>
<td>BW = 100 MHz</td>
<td>SCS = 120 kHz (u=3)</td>
<td>~309 Gbps</td>
<td>~39 Gbps</td>
</tr>
<tr>
<td>1-sector, 1 carrier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5G: small-cell; 128x128 array panel</td>
<td>BW = 100 MHz</td>
<td>SCS = 120 kHz (u=3)</td>
<td>~618 Gbps</td>
<td>~78 Gbps</td>
</tr>
<tr>
<td>1-sector, 1 carrier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5G: sub-carrier spacing, CU – centralized unit</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Source: Intel

5G IMPLEMENTATIONS

Figure 9 shows some practical 5G fronthaul implementations that avoid the use of too many fiber links. In the first example, 5G mmWave cell sites are implemented with integrated DUs. This has the advantage of limiting the latency required to microseconds rather than milliseconds and allowing a single fiber implementation, passive optical network (PON) or dark fiber, for each radio. These radio sites can also be daisy-chained to limit the number of connections required. Alternatively, integrated access backhaul can be used with the radio sites connected over separate radio links. If the fibers are available, then the links can be multiplexed using electrical multiplexing or optical wavelength-division multiplexing (WDM) equipment at both ends. For sub-6 GHz narrowband deployments, the Option 7 split is used with high-bandwidth eCPRI links to a centralized DU.

CONCLUSIONS

5G is here now, building on the infrastructure developed for 4G and using high speed optical connections to radio sites. There are various network architectures with some significantly increasing bandwidth demands on fronthaul networks. The 1-10 Gbit/s required for 4G LTE
are growing to 25 Gbit/s, 100 Gbit/s, and above for 5G. These deployments will require high volume scalable solutions – and one design will not fit all the different applications. Moreover, low latency and TSN are essential and network synchronization is a critical parameter for deployments. Balancing the complexity of the RRHs, DUs, and CUs and providing the right connectivity in the RAN and Xhaul networks are key to delivering on the promise of 5G.

Finally, Heavy Reading would like to thank Giacomo Mirelli from Nokia, Robert Blum from Intel, and Glenn Wellbrock from Verizon for their contributions to a recent Light Reading webinar and this white paper. For additional background, please view the Light Reading webinar, *Delivering 5G with High-Bandwidth Photonics*. 