Multi-Gigabit Ethernet Controllers for Enterprise Networks and Gaming Systems

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This paper describes the markets and applications for Ethernet speeds beyond 1Gbps in client systems. It discusses NBase-T technology, which forms the basis for the 2.5GBase-T and 5GBase-T standards under 802.3bz. It then describes client implementations, including Aquantia’s new AQtion controller chip. (Note: This paper is sponsored by Aquantia, but all opinions and analysis are those of the author.)

New Workloads Demand Greater Bandwidth

For the last decade, most PC clients have included Gigabit Ethernet for network connectivity. Gigabit Ethernet (GbE) dominates the access layer of enterprise networks, where Category 5e and Category 6 unshielded twisted pair (UTP) cabling enables cost-effective office and cubical connections. Manufacturers (OEMs) integrate single-chip GbE controllers onto PC motherboards along with the ubiquitous RJ45 jack. These LAN-on-motherboard (LOM) designs provide end users with out-of-box GbE support.

In the context of the Internet, 10 years is a very long time. While wired-PC networking has stagnated, everything around it has moved forward at a blistering pace. Mainstream Xeon server processors have moved from 4 cores to 22 cores, server connections have moved from Gigabit to 10G Ethernet, and storage has moved from rotating disks to non-volatile memory (NVM). Enterprise Wi-Fi has also progressed from 54Mbps 802.11g to 802.11ac, which delivers up to 3.5Gbps in its Wave 2 version.

Although many enterprise-client applications don’t require more than 1Gbps of network bandwidth, some specialized workloads benefit from greater LAN bandwidth. One class of workloads, which typically runs on workstations and enterprise PCs, includes video editing, CAD, and 3D graphics processing. Network bandwidth is important when rendering is performed by local servers, meaning the application processing is distributed. Some industrial machine-vision applications use a similar partitioning, with cameras connected to a PC and defect-inspection processing handled by a server.

As enterprises move to private-cloud architectures, client bandwidth can also impact response times more broadly. Particularly for NVM-based storage, client bandwidth can impact response times for cloud-storage access. For example, greater bandwidth can reduce download times for large files or application loads. Another operation that benefits from greater bandwidth is client-PC backups to the private cloud.

In June 2016, the Wi-Fi Alliance updated its certification program to include 802.11ac Wave 2 features, which increase both per-client and aggregate maximum throughputs. Although few installations will use all of these features simultaneously, several real-world implementations now deliver more than 1Gbps of sustained throughput. For enterprise customers, this means new access points (APs) require more than a single GbE link to the unified-access switch.
Outside of enterprise environments, there exists a group of PC enthusiasts that demand maximum performance with cost being a secondary concern. These “gamers” want the best hardware, hoping for any edge over their competition. In situations where multiple players are in the same location, such as Internet cafes (iCafes), LAN bandwidth impacts performance. For Internet-based multi-player games, the broadband connection may limit bandwidth to less than 1Gbps. Still, each network hop, even the PC-to-gateway connection, adds latency. Compared with Wi-Fi, a high-performance Ethernet link will deliver more deterministic latency and is also less susceptible to interference, which can cause sporadic slowdowns.

Because not every application demands a faster Ethernet connection, what’s needed is an evolutionary approach that enables phased upgrades and preserves existing infrastructure wherever possible. For most environments, cabling represents a large investment in installation and testing, creating a barrier to any technology that requires new cables.

**5GBase-T Delivers Easy Upgrade Path**

Although the industry succeeded in developing 10GBase-T to handle 10Gbps speeds over UTP, this standard requires new Category 6a cables to achieve its full 100m reach. As a result, 10GBase-T has been deployed primarily in data centers, where cabling is easily accessed in most cases. Including both servers and switches, we estimate more than 20 million 10GBase-T ports shipped in 2016.

As OEMs began developing 802.11ac Wave 2 access points, they recognized that neither GbE nor 10GbE met the needs of enterprise customers. The former required multiple ports and link aggregation to deliver more than 1Gbps of throughput, and the latter required new Cat6a cabling. What was needed was a multi-gigabit physical layer (PHY) that operated over installed Cat5e and Cat6 cabling.

Working with OEM customers and other partners, Aquantia led the development of the multi-gigabit PHY technology that would become known as NBase-T. Formed at the beginning of 2014, the NBase-T Alliance includes Cisco, Aruba Networks (now HPE), and other switch and AP OEMs, as well as many silicon vendors such as Aquantia and Intel. In March 2015, the IEEE approved the 802.3bz project to standardize 2.5Gbps and 5Gbps Ethernet speeds over 100m of Cat5e/Cat6 UTP. Although the 802.3bz Task Force reviewed competing proposals, it adopted the NBase-T specification with only minor changes. The 802.3bz standard for 2.5GBase-T and 5GBase-T was approved in September 2016.

The 802.3bz Task Force went to great lengths to validate the reach of 2.5GBase-T and 5GBase-T over real-world cable configurations. In office buildings, so-called horizontal cabling runs from a wiring closet to a set of offices, cubicles, or Wi-Fi APs. Although the maximum length of these runs is 100m, they comprise patch cables plus longer cables, with the latter often run in bundles. Bundling results in crosstalk noise introduced by adjacent cables, reducing the signal-to-noise ratio relative to an unbundled cable.
Tests showed that 2.5GBase-T operated over both Cat5e and Cat6 even when the entire 100m run was bundled. By contrast, the tests showed that some unbundling was required for 5GBase-T to operate reliably. Using autonegotiation, PHY implementations can select the fastest speed each link supports. In the unlikely event a given cable run cannot handle 5GBase-T, the link will automatically fall back to 2.5GBase-T.

OEMs that have been shipping products supporting NBase-T are now able to update their systems via software for 802.3bz compliance. Cisco and HPE both shipped enterprise-access switches during 2015 that support 2.5Gbps and 5Gbps speeds. In its Catalyst line, Cisco dubs this capability as “Multigigabit.” During the first half of 2016, Aruba (HPE) and Cisco also began shipping Wi-Fi APs that offer 2.5Gbps Ethernet ports. All shipping designs use Aquantia PHYs, which comply with the 802.3bz standard in addition to the NBase-T specification.

All available NBase-T designs also support operation at 1Gbps (1000Base-T) and even 100Mbps (100Base-TX). This backward compatibility enables phased upgrades, where switches, access points, and PCs may be replaced independently. Once both ends of a given link support 5GBase-T, autonegotiation ensures that the link will operate at the maximum speed possible. Enterprises that have already deployed multi-gigabit access switches to support their Wi-Fi network can install new PCs that support 5GBase-T and connect them to multi-gigabit switch ports.

**Diverse Markets for Multi-Gigabit Controllers**

There exist many potential applications for multi-gigabit Ethernet controller chips and associated adapters (NICs), creating a total available market measured in hundreds of millions of units. Some segments are relatively small but have an immediate need for faster connectivity, whereas others are large but more cost sensitive.

Workstations represent one of the smaller segments, but also one that could rapidly adopt 5GBase-T NIC options for existing designs and LOM in next-generation systems. These high-performance platforms use an architecture more closely related to servers than to desktop PCs. Their high prices also enable OEMs to include advanced features that would be too costly for mainstream PCs. We estimate about 4.5 million workstations shipped in 2016 and expect that number to break 5.0 million by 2020.
Three OEMs—Dell, HP, and Lenovo—dominate the workstation market, and these same OEMs control much of the enterprise-PC market. Although the PC market has been in decline in recent years, annual shipments still exceed 250 million units. Most new desktop and laptop systems include GbE LOM connections; we estimate 217 million such ports shipped in 2016. Due to cost constraints, however, 5GBase-T controllers are likely to penetrate only high-end enterprise PCs, which sell for more than $1,000. In addition, some laptop form factors (such as ultrabooks and convertibles) omit Ethernet jacks due to space constraints. We estimate the serviceable market for 5GBase-T in PCs at about 50 million units per year.

Although many people view consumer PCs as low-cost commodity products, the thriving enthusiast segment represents about 10% of worldwide PC sales. These systems are well suited to 5GBase-T LOM as they are largely unconstrained by cost, power, and space. End users could also build or upgrade desktop systems using 5GBase-T NICs. Game consoles carry lower prices, making their designs more cost sensitive. Rather than integrating 5GBase-T support, console manufacturers are likely to rely on external adapters (dongles) for faster wired-networking options.

Dongles and docking stations represent a growing approach to I/O expansion in space-constrained designs. Apple led this approach with ThunderBolt, now in its third generation and capable of speeds up to 40Gbps. The broader PC, tablet, and smartphone industry has embraced the USB Type-C (USB-C) connector, which provides 10Gbps speeds using the USB 3.1 protocol. A USB-C-to-5GBase-T dongle could serve as an option for many systems, providing an easy upgrade path for end users.

A vertical segment within the PC market, industrial PCs represent another target for 5GBase-T controllers and NICs. Although small, the industrial networking market is shifting from older technologies such as Profinet, Fieldbus, and EtherCat to standard Ethernet over UTP. Rather than using low-cost PC components, this segment requires special features such as support for IEEE 1588v2 timing and time-sensitive networking.

Across these varied market segments, 5GBase-T adoption can begin with adapter and dongle options. The most demanding applications can then adopt 5GBase-T LOM in next-generation system designs. These early LOM designs can quickly drive port shipments into the millions, in turn driving down controller prices. Lower prices should enable broader 5GBase-T LOM adoption across the segments that value higher performance.

### The Unique AQtion Controller

The pioneer in NBase-T PHYs, Aquantia has now developed a single-chip controller that integrates MAC and PHY functions. Branded AQtion, the controller delivers the features, small size, and low power required by client-NIC and -LOM designs. Aquantia offers two versions of the chip optimized for different applications. The superset AQC107 includes 10GBase-T support for applications that demand the greatest performance, such as workstations. The mainstream AQC108 handles speeds up to 5Gbps while dissipating only 3.0W at that rate.
On the network side, the controllers naturally include Aquantia’s proven 802.3bz PHY, which also handles 1000Base-T and 100Base-TX for backward compatibility with legacy switches. As Figure 1 shows, the AQtion design includes a four-lane (x4) PCI Express Gen3 host interface for broad compatibility. In a system that supports only Gen2 operation, the x4 interface provides 16Gbps of bandwidth, more than enough to handle 10G Ethernet. For 5GBase-T mode in a Gen3-capable system, a single 8Gbps lane provides the optimal bandwidth/power tradeoff.

![AQtion AQC107 block diagram.](image)

The remainder of the chip design implements the blocks necessary to deliver high performance, power management, and remote system management features. The Ethernet MAC, packet buffer, and DMA engines handle data movement from the Phy block to the PCI Express block. On the transmit side, the TX-offload block implements large-send offload (LSO) under Windows and giant-send offload (GSO) under Linux. The receive (RX) side handles large-receive offload (LRO), receive-side scaling (RSS), and IP/TCP/UDP header-checksum calculations in hardware. The scheduler implements quality-of-service (QoS) features for 32 queues in each direction, including transmit-rate shaping and Audio Video Bridging (AVB) support.

For LOM designs, the controller includes two SMBus interfaces for out-of-band management. An on-chip CPU implements the DMTF’s DASH standard for remote management.
system management. The chip also supports wake-on-LAN, which enables a remote management agent to wake up a system that is in a standby state. Also important for LOM designs is the chip’s compact 12mm by 14mm BGA package, which the two controller variants share. As Figure 2 shows, the controller requires few external components aside from a serial-flash device, crystal, and RJ45 jack.

Figure 2. AQtion 10GBase-T adapter reference design.

In total, the AQtion chip includes the expected features of a client controller, whereas it omits capabilities found in more costly server-oriented designs. In fact, the only other company that offers a single-chip controller for 10GBase-T and NBase-T is Intel, which primarily targets servers. Intel’s X550 (Sageville) controller includes dual 10GBase-T ports and a PCI Express Gen3 x8 host interface, and it implements network- and server-virtualization features that are not required in client designs. Although Intel offers a single-port variant of Sageville (X550-AT), this chip dissipates 8W (TDP), comes in a 17mm by 17mm package, and carries a list price of $60.
Whereas LOM designs require a single-chip solution, NICs can use a two-chip (MAC+PHY) design. Aside from Aquantia, Marvell is the only vendor that offers a single-port NBase-T PHY. Sampled in 2Q16, the 88E2010 comes in a 10mm by 12mm BGA and handles all speeds from 10Mbps (10Base-T) to 5Gbps (5GBase-T). The only available PHY-less controller for 5G Ethernet comes from a tiny Israeli company, Tehuti Networks. The TN4010 implements a single Ethernet port and a PCI Express Gen2 x4 host interface, dissipates only 0.9W, and comes in a 11mm by 11mm PBGA. Tehuti offers NIC reference designs with either Aquantia or Marvell NBase-T PHYs.

Overall, we doubt either Intel’s X550-AT or the two-chip Tehuti plus Marvell design can compete with Aquantia on price. These competitors do, however, offer proven NIC drivers, whereas Aquantia must get its drivers certified and included in commercial OS distributions. The initial AQtion software includes drivers for Windows (10, 8.x, and 7), Mac OS X, and Linux. Aquantia also provides UEFI and PXE boot code.

**Aquantia Enables Client Evolution**

In developing NBase-T technology, Aquantia recognized an unserved market need and drove a new industry standard in 802.3bz. Facing no competitors, it secured every first-generation NBase-T design in switches and access points. Marvell should reach production with competing PHYs in 2017, and competition should drive further adoption and declining prices for 5GBase-T technology.

Now, Aquantia has turned its attention to the client market, where speeds have been stuck at 1Gbps for a decade. With AQtion, it has developed the industry’s first 5GBase-T single-chip controller optimized for a range of client designs. We expect AQtion will capture early design wins in workstations and enthusiast systems, and that NICs will enable end-user upgrades for other platforms. We see pricing and software maturity as the only barriers to broader adoption, and these factors should diminish by 2018.

By delivering a unique product, Aquantia is enabling the client market for 5GBase-T. Were it not for the success of NBase-T in network infrastructure, we would be skeptical about AQtion’s rate of adoption in clients. Network-equipment OEMs, however, embraced the evolutionary approach enabled by NBase-T. We expect PC and workstation OEMs will follow suit in 2017.

*Bob Wheeler is a principal analyst at The Linley Group and networking editor of Microprocessor Report. The Linley Group is the leading vendor of technology analysis on networking, communications, mobile, and computing semiconductors, providing a unique combination of technical expertise and market knowledge. Our in-depth reports cover topics including Ethernet chips, base-station processors, server processors, embedded processors, and CPU IP. For more information, see our web site at www.linleygroup.com.*