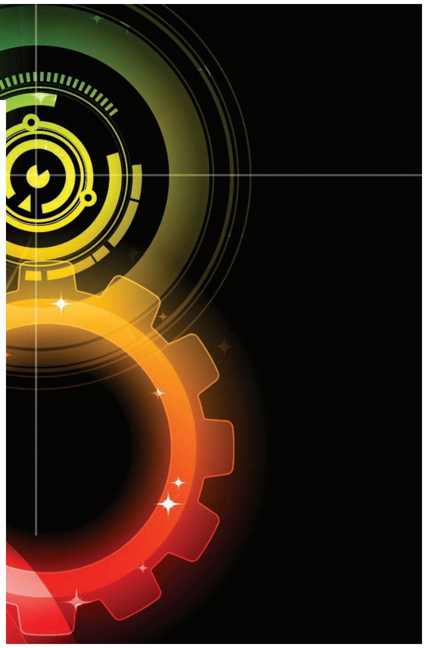

Ethernet: From Office to Data Center to IoT

Geoff Thompson, Past Chair, IEEE 802.3 Working Group

Ethernet started in the 1970s shortly after the beginning of the Arpanet project. The need for computer-to-computer communications prompted companies (such as Datapoint and Xerox) to launch ambitious efforts, resulting in the development of IEEE Standard 802.3.

Before 1970, the mass market need for data communication was primarily long reach (that is, not just within a building) and provided to the public in the United States by AT&T. The company's monopoly position precluded the need for communications standards in the United States because AT&T itself established de facto standards. Short-reach data (that is, within a room or between rooms) was generally provided by Recommended Standard-232 (RS-232), which was originally designed as a connection between customer equipment and the AT&T-supplied modem. Such links were limited to speeds that could be jammed through a single telephone voice channel (300–2,400 bps). There were some other technologies around but there wasn't really much in the way of standards—yet.

Shortly afterward, market opportunities for interconnection began to arrive. These were driven by the arrival of integrated circuits and the products they enabled. An important, but obscure, example of this was the Hewlett-Packard (HP) Instrument Bus. It was originally proprietary and generally oriented for use across pieces of test equipment or within an equipment rack. It was initially approved as IEEE Standard 488 in 1975 and was a groundbreaking success, albeit in a rather narrow field.

Other pertinent activities during the 1970s were the rise of many brands of minicomputers, the early implementation of the Arpanet, and the International Organization for Standardization's (ISO's) efforts to establish an architecture and a set of data communications standards. ISO's theory of development was to write the standards first, finalize them, and then release them for implementation. Against this background, there were several significant events. The first was Datapoint word processors, introduced in 1968, which had a proprietary LAN. Datapoint was constrained by a lack of resources from fully exploiting their early market lead. The second was the simultaneous development of the Alto personal minicomputer, laser printers, and Ethernet (a 3-Mb/s prototype) at Xerox Palo Alto Research Center. Xerox had the resources to deploy and interconnect a large number of these minicomputers internally to a wide

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FROM THE EDITOR

The history of computing is often a winding tale of the alternatives considered, with some accepted and some discarded. Ethernet is no different. In this column, the author recalls the development of IEEE Standard 802.3 from its earliest incarnations as a proprietary standard until becoming one of today's most widely accepted and deployed standards. Various estimates calculate that more than 90% of Internet traffic today is transmitted through an IEEE 802 node. Clearly, without the computer networking standardization of the IEEE 802 community, today's Internet would be much different. *–Don Wright*

variety of users, such as computer scientists, technicians, secretaries, executives, and nontechnical white-collar workers. This proved the utility of the "electronic office" 10–15 years before equivalent systems were common.

In the late 1970s, Xerox moved forward with its electronic office concept (for example, computer, laser printer, and Ethernet) by selling to the general office market. In the meantime, Bob Metcalfe, inventor of Ethernet at Xerox, convinced Xerox that it needed major partners to make Ethernet a market success, but then he left to start 3Com. Intel and Digital Equipment Corporation (DEC) joined the Ethernet effort and the initial "public specification" was published in September 1980. 3Com and a number of start-up companies quickly got into the Ethernet business.

Datapoint was still the leading office network using the Attached Resource Computer Network (ARCnet), but Datapoint did not consider networking a core product and was not interested in having others adopt it. However, Datapoint's silicon supplier, Standard Microsystems Corporation, had the rights to sell the Arcnet chips to others (and did). On the other hand, Ethernet was being actively promoted to other companies by Xerox. Xerox knew Ethernet wouldn't be a big enough product or serve its purposes well enough as only a proprietary implementation. Metcalfe, free of Xerox but heavily oriented toward Ethernet, was busy promoting 3Com, both as a consultancy and as a source of Ethernet hardware.

In August 1979, Maris Graube of Tektronix and Bob Stewart submitted a project authorization request to the IEEE for a LAN standard. There were a large number of start-ups as well as a few established companies that had LAN requirements, but there was no clear choice from among the many proprietary implementations. In February of 1980, the new group, christened IEEE 802, first met at the Jack Tar Hotel in San Francisco, concurrent with the spring meeting of IEEE CompCon. According to Bob Stewart, there were 20–25 people at that organizing meeting, including representatives from Xerox, DEC, Intel, IBM, and General Motors. This is important because the initial thrust of the effort was for a single standard. Ethernet was a passive network with no master designed for peer communication. IBM was firmly attached to a model with scheduled delivery and return receipts for "their" network. The company wanted a ring topology. General Motors, joined by Boeing, wanted assured delivery of the IBM protocol but with the topological flexibility of Ethernet's bus topology. The 802 project was deadlocked.

The IEEE 802 participants wanted a layered implementation model aligned with the work undergoing final standardization in ISO (for example, ISO 7498). This commitment to layering put most proprietary LANs out of the running, as many of them had proprietary communications software, which wasn't structured along those lines. Agreeing on only that produced challenges because there were no mechanisms in place for guaranteeing the interoperability of such layers while working under the antitrust rules of the day. Rob Rosenthal of the National Bureau of Standards (NBS) (now NIST) offered to host an "NBS International Workshop for Implementers of OSI" so that work on multivendor interoperability could be debugged in an open environment.

IEEE Standard 802 finally broke its deadlock and split into several working groups (WGs) for the lower layers [that is, physical (PHY) and media access control (MAC) layers], one for IBM (the 802.5 Token Ring WG), another for manufacturing systems (the 802.4 Token Bus WG), and a third for Ethernet [802.3 Carrier Sense Multiple Access with Collision Detection (CSMA/CD) WG], although they were not willing to call it that. In addition, they created WGs for Logical Link Control (802.2 LLC WG), a "higher level interworking" group (802.1 HiLi WG), and the short-lived Media WG. The Media WG's efforts quickly devolved back into 802.3/4/5, and the group dissolved. Don Loughry of HP, who had worked with Graube on IEEE Standard 488, became chair of 802.3.

The advantage was that this was the right moment in history; Metcalfe was beating the drum in the marketplace, gathering future customers and implementers for Ethernet. In the meantime, Ron Crane, 3Com's top engineer, was keeping an eye on competitors' implementations and providing technical assistance to ensure interoperability for Ethernet products entering the market. IBM, on the other hand, wasn't ready to launch its proprietary Token Ring product until 15 October

1985 (still well into the future at this point) and proactively withheld significant portions of the information that other vendors needed for interoperability. Additionally, 3Com and DEC added cabling options (similar to the cabling on Arcnet) of lower-cost RG-58 and broadly available BNC connecting hardware (collectively standardized as IEEE Standard 802.3a-1985), a move rapidly adopted by the industry.

IEEE Standard 802.3a was the first in a series of variations on network cabling to broaden Ethernet's appeal and find the market's sweet spot. The next was 10BASE-T. In 1982, AT&T agreed to be broken up; this resulted in the company relinquishing ownership of its significant investment and ownership of in-building telephone wiring. The 10BASE-T standards project, started in August of 1987, resulted in the ability to run Ethernet on surplus pairs of telephone wire in a star-wired topology connecting through a multiport repeater often housed in what had been a closet for private branch exchange telephone equipment. This reuse of existing cabling significantly lowered the installation cost of a LAN and gave Ethernet a big boost over Token Ring.

For the next five-plus years, it looked as if Ethernet had fulfilled its mandate. The big standards effort for "the next generation" LAN was Fiber Distributed Data Interface (FDDI). That effort was done in ANSI X3/T9, rather than in the IEEE. FDDI was a true multivendor effort to run at 100 Mb/s on fiber or on improved performance [the Electronic Industries Alliance/Telecommunications Industry Association (TIA) Category (CAT) 5] twisted-pair cabling. This was important because an industry specification for the cabling had been done in the TIA and was in production. The incremental cost for Cat 5 over telephone grade (Cat 3) was small enough that nearly all new commercial cabling installations put Cat 5 in for future proofing. Unfortunately (but not for IEEE Standard 802.3), FDDI never shipped in volume. The hardware specifications were mostly finished, but the required station management never quite made it.

In the meantime, after more than a decade, Ethernet was actually running out of bandwidth in some installations, and new chip designs, due to Moore's law, could easily perform at 100 Mb/s. Those two factors, that is, FDDI's nonarrival and a 100-Mb/s Ethernet implementation from a start-up, made it easy to start a standards project for 100-Mb/s Ethernet. It was made all the easier because, although FDDI had not yet arrived, the PHY layer chips for Cat 5 cabling and fiber were available in volume and subsequently deployed. The fly in the ointment was an alternate proposal from HP employees for a non-Ethernet access method but using telephone grade (Cat 3) cabling instead of Cat 5. Since HP employees held both the chair of 802 and 802.3, they leveraged their positions to override a vote of the membership of 802.3. Things got very ugly for a while and resulted in a new chair for 802.3 and the HP proposal being assigned to a new WG (802.12, Demand Priority Access Method).

At the same time, the 802.3 WG wrote the small specification needed to glue FDDI PHY layer chips to an unchanged but sped-up Ethernet. The WG also added a very important feature: auto-negotiation. This feature allows multispeed capable equipment on each end of a wire to automatically select the highest speed they have in common. This turned out to be very important as most 100BASE-Tx interface cards also supported 10BASE-T. 10/100 network interface cards (NICs) with auto-negotiation became a big market winner selling for under US$100 in a market where IT managers had budgeted US$200 for Token Ring NICs. That swung the market momentum to Ethernet and turned Token Ring into a niche technology. IEEE Standard 802.4 never gained significant market momentum, and the WG went into hibernation after its last amendment in 1997 and was officially disbanded in September 2004. The Token Ring WG hung on a little while longer but was officially disbanded, and its standards withdrawn by the IEEE at the end of 2008.

Although 100BASE-Tx was standardized late, relative to technology development and Moore's law, Gigabit was a little early. The project started in June of 1996. The MAC and optical PHY portions progressed smoothly and reasonably quickly, but the twisted-pair version did not. 1000BASE-T (802.3ab) was a significantly more complex implementation than previous PHYs and pushed the silicon state of the art. The 1000BASE-T project was split off from the rest of Gigabit to allow for more development time. When that amendment was approved and published, it was still too early for both production technology and market demand. That was a new situation for a 802.3 twisted-pair standard. It wasn't until Apple included support in its default Ethernet port (that is, 10/100/1,000) several years later that 1000BASE-T started to take off in the market.

At this point, Ethernet had become the only game in town. A few things happened in the market, and Ethernet, as both a technology and a standards body, was flexible enough to incorporate them. The first was full duplex, which became the dominant hub technology replacing repeaters because of the following reasons.

- Moore's law (again) allowed a significantly more complex box to replace an older generation one.
- The switchover from repeaters as hubs to multiport bridges as hubs allowed full duplex, whereas repeaters were half duplex, single-speed devices.
- It allowed the independent selection of port speed.

The second was power over Ethernet (PoE). The original PoE project was started to support Internet Protocol telephones. That market was not as big as expected, but support for wireless access points (such as IEEE Standard 802.11 or Wi-Fi) was a major success. It made their installation significantly less expensive because their preferred location was seldom near a power outlet.

One would think that all of these standards would fill out the market, and they did, from a limited point of view. The enterprise LAN needs, from a 1980–1990s perspective, were certainly fulfilled, but the emergence of the Internet of Things (IoT) significantly expanded the need for Ethernet in terms of speed, capacity, and in the number of places it would be used. As the Internet became more broadly used and large data centers were the norm, there was a market requirement for ever-increasing speeds, both short reach in the data center and long reach to support the data-transmission needs of the Internet. What once was a network for email, documents, still images, and static web pages has become the conveyance for a much broader range of data to a much larger market. Movies, TV, and gaming are good examples, and they reach the broad consumer market, where Ethernet was originally a technology for the business office.

Where will Ethernet go from here? It has a rich future as the wired backbone for the wireless services in the present (Wi-Fi and cellular) and in the future (Wi-Fi, 5G, and the IoT), but higher bandwidth over twisted pair will be needed in the future. The IEEE 802.3 team is working on that now. Ethernet has also been picked by automotive companies to reduce the weight and complexity of vehicle wiring harnesses and service the sensors needed for automated driving. The WG has redone the speeds of the past (10/100/1,000) for a single twisted pair with a shorter reach. In many ways, the WG is starting all over again.

For more information about materials collected for the IEEE Computer Society History Committee's unfinished project about the IEEE 802 standard, please visit https://history.computer.org/pubs/802/802.html C

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