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IN THIS ISSUE

Evolution of Ethernet Standards in IEEE 802.3 Working Group

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CONTENTS

Letter from the Editor

Ethernet, the Networking Standard: More Mature, More Powerful

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Where the whole world is going with Ethernet

Many people, especially technology historians, often ponder "Where would the world be without Ethernet?" Now, such a rhetorical question typically has no answer because you cannot rewind time, remove Ethernet from being invented, and let time fast forward to the present day. However, we have many active contributors amongst us who have been part of that history as it has evolved over the past 30 years. The Evolution of Ethernet Standards in 802.3 Working Group covers great details on the history of not just Ethernet standards development, but many dot standards that have led to support of wide-ranging applications. For me, just the first sentence captures the past, the present, and the future that I'd like to know more about:

Ethernet is constantly evolving, adapting to the needs of the networking world, addressing the requirements of both operators and end-users, while making sure that the resulting technology is cost-efficient, reliable, and operates in a plug and play manner. One of the fastest growing uses of Ethernet is in automotive applications. As the world moves towards auto-pilot cars, electronic components and smart sensors must be networked to ensure the whole vehicle is a safe, controlled environment. This means many safety devices such as a dozen cameras, GPS system and controllers for the brakes and acceleration, and collision avoidance systems must be networked together. Of course, it is not a simple matter of taking the Ethernet protocol and implementing it into chips to control automotive electronics. Unlike climate controlled environments of office buildings, homes, or most factory floors, vehicles offer some of the harshest environments one has to deal with in terms of temperature range, moisture, and dirt. An Ethernet standard is no exception. Then there is all the communication that takes place between cars, or more broadly, vehicles on the road: vehicle-to-vehicle communication. That means wireless communication and more complex protocols have a wide range of performance, power, and distance requirements. This is where the work of the IEEE 802 Working Group will have a profound impact on us all. Some of the most recently completed work on automotive Ethernet standards will begin to show up in cars by 2020, resulting in vehicles that are significantly automated, safer, and even more entertaining than the 2017 models.

For those who grew up using 10 megabits per second (10Mb/s) Ethernet, you may recall how ecstatic you were when the bandwidths increased to 100 Mb/s and then to 1Gb/s; 100x better. Although those speeds were truly amazing, it is still not even good enough for the members of the 802.3 Working Group. Their work has gone on to enhance the standard over these 30 years to 400Gb/s. That's how these and other standards are changing our lifestyle, making us more productive, and benefiting humanity.

As the years unfold, the world is going to be more connected, whether it is the Internet of Things (IoT) that takes over the world or some other forms that evolve. That is why some of the members of the Ethernet Working Group also focus on a framework for these standards and their interoperability.

So, instead of debating what could have been without Ethernet, let's look at the future trajectory of Ethernet–or more precisely, of networking standards under IEEE 802. This particular eMagazine issue is full of such information to ignite your imagination on the many possible applications of Ethernet and smart technologies.

Happy Reading!
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Evolution of Ethernet Standards in IEEE 802.3 Working Group

by Marek Hajduczenia, Steven B. Carlson, Dan Dove, Mark Laubach, David Law, George A. Zimmerman

Abstract:
Ethernet is constantly evolving, adapting to the needs of the networking world and addressing the requirements of both operators and end-users, while making sure that the resulting technology is cost-efficient, reliable, and operates in a plug and play manner. The IEEE 802.3 Working Group has been working for the last 30+ years, pushing the boundaries on the speed and capacity of wireline Ethernet links, migrating from shared medium CSMA/CD systems to switched point-to-point Ethernet, and then introducing multilane technology and point-to-point emulation over shared media of passive optical networks (PON). In this paper, we look at the latest projects adding new features and capabilities to the family of wired Ethernet standards that enable the exponential growth of the Ethernet ecosystem and are driven by technical maturity, cost-effectiveness, and broad market support.

Index Terms: Ethernet, 802.3 Working Group, 2.5/5G, 25G, 40G, 100G, TimeSync, EPON, EPoC, RTPGE, YANG, backplane.

I. Introduction

The total amount of data created or replicated on the planet in 2010 exceeded 1 zettabyte (1 zettabyte is 1021 bytes)–that is 143 GB for each of the 7 billion people on the planet [1]. This volume of information requires high-speed links between server farms, cloud storage, and end-users to make sure that it can be processed in a timely and reliable fashion. The relentless growth of the number of permanent or nomadic end-stations connected to the network (e.g., computer terminals, mobile devices, automated devices generating machine-to-machine traffic) has led to explosive growth in the volume of information exchanged at all levels of the networking infrastructure. The popularity of Ethernet and its widespread use in access, aggregation, transport, core networks, and data centers, combined with the unprecedented demand for advanced data connectivity services, fuel the development of new Ethernet standards, providing higher-speed links to address market demand.

Ethernet is also venturing into brand-new application areas and adding support for synchronization protocols. Potentially, Ethernet could become the de facto standard for in-vehicle data networks, providing a common transport platform for control and multimedia applications.

This paper examines the evolution of Ethernet standards taking place in the IEEE 802.3 Working Group. There are a number of exciting new projects, pushing the boundaries of Ethernet into new application areas and markets.

II. Evolution of Ethernet Standards

The *802.3-2012-IEEE Standard for Ethernet* was first published in 1985, specifying a half-duplex carrier sense multiple access with collision detection (CSMA/CD) media access control (MAC) protocol operating at 10 Mb/s, and a medium attachment unit (MAU) for operation on a coaxial cable medium supporting a bus topology between the attached end stations.

Amendments to IEEE 802.3 then added specifications for, among other items, a repeater to extend the topologies supported, MAUs for operation over fiber optic cabling, a MAU for operation over twisted pair cabling, 10BASE-T, and layer management. In 1995, *Amendment IEEE 802.3* was published adding operation at 100 Mb/s (fast Ethernet). This included a number of physical layer entity (PHY) specifications for operation over fiber optic and twisted pair cabling (100BASE-TX).

Amendment IEEE 802.3x, published in 1997, added full-duplex operation to the MAC. A flow control protocol was also added to take advantage of full-duplex-capable media such as twisted pair and fiber, for which PHYs had already specified for in IEEE 802.3, as well as support switching, which was becoming more cost-effective due to increased device integration.

In 1998, *Amendment IEEE 802.3z* was published to add operation at 1,000 Mb/s (Gigabit Ethernet). In 1999, Amendment IEEE 802.3ab was published to add 1000BASE-T PHY specifications to support 1,000 Mb/s operation over twisted pair cabling.

Amendment IEEE 802.3ad (link aggregation) was published in 2000, adding the ability to aggregate multiple full-duplex point-to-point links into a single logical link from the perspective of the MAC client. Since link aggregation has applications beyond Ethernet, as well as architectural positioning, it was subsequently moved to the IEEE 802.1 Working Group in 2008 and is now titled *IEEE 802.1AX Link Aggregation.*

In 2002, *Amendment IEEE 802.3ae* was published to add operation at 10 Gb/s (10 Gigabit Ethernet). In 2006, *Amendment IEEE 802.3an* was published adding 10GBASE-T PHY specifications to support 10 Gb/s operation over twisted pair cabling. It was followed in 2010 by Amendment IEEE 802.3ba, which added operation at 40 Gb/s and 100 Gb/s (40 Gigabit Ethernet and 100 Gigabit Ethernet). The development of 40 Gb/s and 100 Gb/s Ethernet was done in close cooperation with ITU-T Study Group 15-Networks, Technologies and Infrastructures for Transport, Access, and Home to ensure transparent connectivity into the optical transport network (OTN); operation at 10 Gb/s, 40 Gb/s, and 100 Gb/s only supports full-duplex operation.

Amendment IEEE 802.3ah was published in 2004 to add support for subscriber access network Ethernet (Ethernet in the first mile, or EFM for short). This amendment added a number of fiber optic and voice grade copper PHYs and specified a fiber optic point-to-multipoint network topology using passive optical splitters, which is known as Ethernet passive optical network (EPON).

In 2007, *Amendment IEEE 802.3ap* was the first to add support for backplane Ethernet.

A summary of the speed and distance for various MAUs and PHYs supported by the approved IEEE 802.3 standard (at the time this paper was written) and amendments is shown in Fig. 1.

Other additions include *IEEE 802.3af DTE Power via MDI*, which was published in 2003, and is also known as power over Ethernet, which enables power to be supplied on the same cabling as the data transmission. *IEEE 802.3at* was published in 2009 and enhanced the maximum power available and the classification mechanism.

In addition, the 2010 amendment *IEEE 802.3az* added support for energy-efficient Ethernet (EEE) to the 100BASE-T, 1000BASE-T, and 10GBASE-T PHYs, among others. This not only reduces the power consumption of the PHYs, but also specifies signaling that can enable the reduction of the power consumption of the attached device.

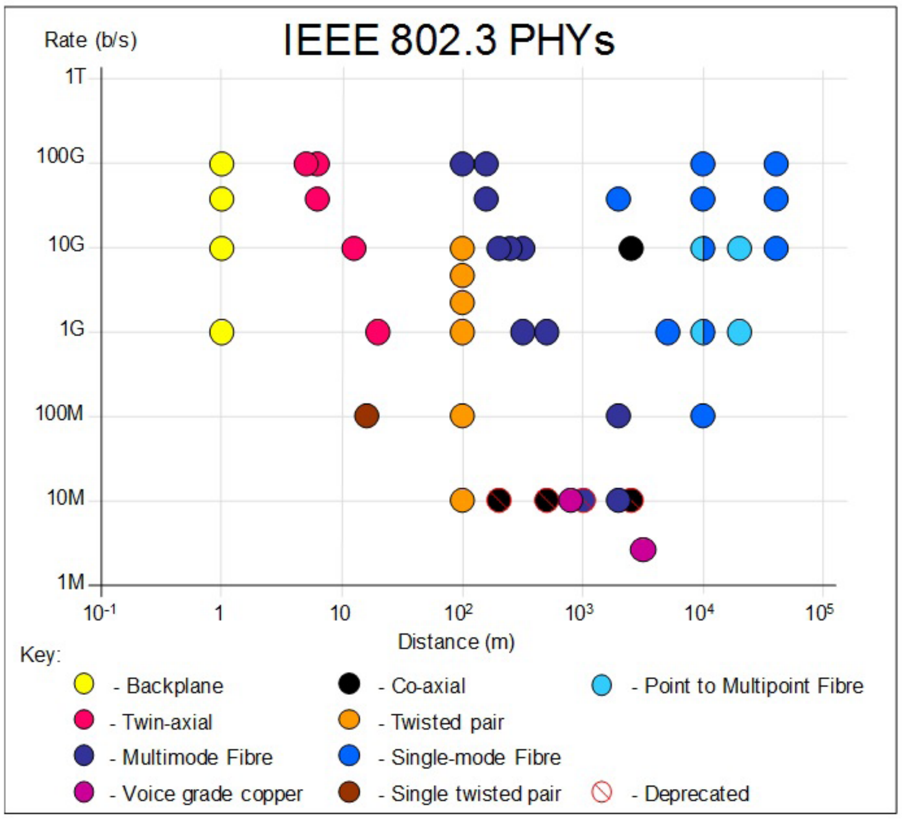

Figure 1: Speed and reach for various IEEE Std 802.3 MAUs and PHYs

A. High-speed Copper P2P Links and Backplane Technologies

In 2007, the family of PHYs for Ethernet operation over electrical backplanes for Gigabit Ethernet and 10 Gigabit Ethernet was first introduced. Two PHYs were introduced for 10 Gigabit Ethernet: 10GBASE-KX4 and 10GBASE-KR. The 10GBASE-KX4 PHY is a full-duplex solution employing four data lanes in each direction, where each lane operates at 3.125 Gb/s and employs 8B/10B line encoding to support the effective data rate of 10 Gb/s. The 10GBASE-KR PHY is a serial lane solution operating at 10.3125 Gb/s and employing 64B/66B encoding to support the effective data rate of 10 Gb/s.

These two PHYs laid the groundwork for the 40 Gigabit Ethernet backplane PHY, which was developed during the IEEE P802.3ba project. Using the four lane approach of 10GBASE-KX4 and the serial 10 Gb/s electrical signaling developed for 10GBASE-KR, the 40GBASE-KR4 PHY supports 40 Gigabit Ethernet operation across an electrical backplane. At the time of the IEEE P802.3ba project no 25 Gb/s per lane electrical signaling solution was available, therefore no 100 Gigabit Ethernet backplane PHY was developed.

The call-for-interest (CFI) to develop the operation of Ethernet at 100 Gb/s across an electrical backplane, as well as across twin-axial cables, took place in November 2010. Fueled by the SFP+ form factor supporting 10 Gigabit Ethernet, QSFP supporting 40 Gigabit Ethernet, or the CXP or CFP supporting 100 Gigabit Ethernet, potential front-panel capacities ranging anywhere from 480 Gb/s to 3.2 Tb/s were observed. These front-panel capacities could create backplane requirements ranging anywhere from 3.2 Tb/s to 44.8 Tb/s depending on the specific system configuration. A comparison was made between the then-existing 10 Gb/s signaling technologies against a potential 25 Gb/s signaling to understand the impact on the total number of copper of differential pairs needed to support various backplane capacities. Fig. 2 illustrates the impact of 10 Gb/s versus 25 Gb/s on the total number of differential pairs needed when supporting various backplane capacities for various switch fabric configurations. Note that as the capacity requirement of the backplane increases, the ability to support an actual total capacity of the backplane with 10 Gb/s per lane signaling becomes questionable [9].

The challenge with electrical backplanes as compared to copper cabling is that they are essentially custom-designed. There are a multitude of factors that influence the electrical performance of the backplane channel: FR4 board materials, trace geometries, surface roughness of the copper traces, and the actual system configuration among other characteristics. This is further complicated by the cost sensitivity of channels, where material costs alone could increase the cost of a backplane by 500% depending on the materials compared [10].

The large variation in electrical performance and sensitivity to cost resulted in the development of 100 Gigabit Ethernet backplane objectives targeting different performance/cost targets:

- Define a four lane PHY for operation over a printed circuit board backplane with a total channel insertion loss of <= 35 dB at 12.9 GHz.
- Define a four lane PHY for operation over a printed circuit board backplane with a total channel insertion loss of <= 33 dB at 7.0 GHz.
-

IEEE Standard for Ethernet 802.3bj-2014 specifies an NRZ (nonreturn to zero)-based solution for the 35 dB @ 12.9 GHz objective, and a PAM-4 based solution for the 33 dB at 7.0 GHz objective. In addition, the same amendment added a 100 Gigabit Ethernet x4 twin-ax cable solution, defining a four-lane 100 Gb/s PHY for operation over links consistent with copper twin-axial cables with lengths up to at least 5 m. An NRZ-based solution was selected to address this objective. These new PHYs included support for an optional energy-efficient Ethernet mode.

The four lane 100 Gb/s connections defined in IEEE 802.3bj-2014 laid the groundwork for 25 Gb/s signaling over a single lane. High-performance server interconnects rapidly seized on the technology, and in July 2014 a study group was formed to standardize a 25 Gb/s single-lane Ethernet. IEEE Standard for Ethernet 802.3by-2016 was built on the basis of 802.3bj-2014 and specified 25 Gb/s solutions for use on copper backplanes, copper twin-axial cables with lengths of 3m and 5m, and multimode fiber solutions for 100m. Building on existing technology, IEEE 802.3by-2016 went from CFI to ratification in 23 months.

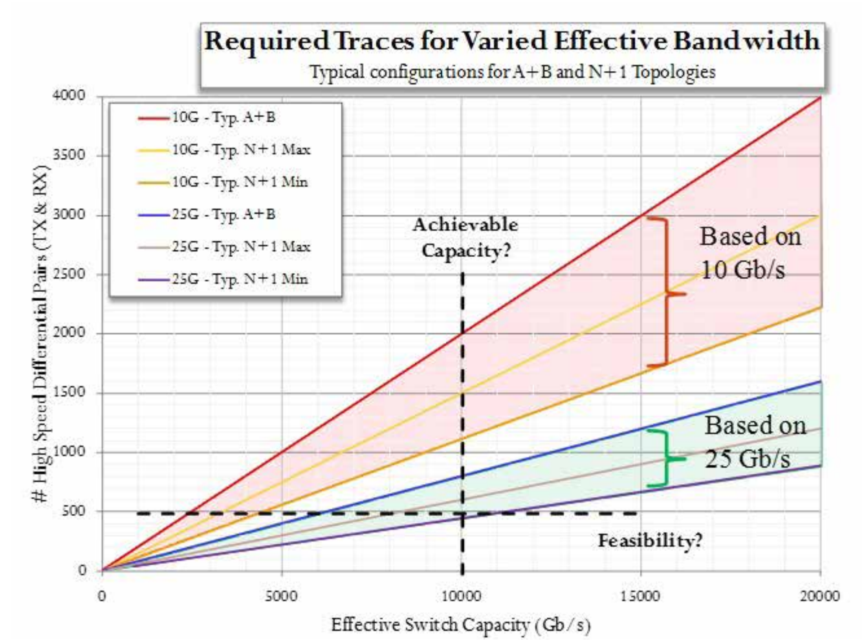

Fig. 2. Impact of signaling speed on switch capacities.

B. Optical P2MP Links and Evolution of EPON

EPON is a relatively new addition to the family of Ethernet standards, with the first standard for this technology (1G-EPON, operating at the symmetric data rate of 1 Gb/s) published in 2004. In 2009, a higher-speed version of EPON was standardized, supporting the symmetric data rate of 10 Gb/s as well as an asymmetric data rate of 10 Gbit downstream (towards the customer) and 1 Gb/s upstream (from the customer). Supporting the nominal distances of 20 km (or more) and the nominal split of 1:32 (or more) with three available power budget classes, EPON is used in a variety of deployment scenarios, some of which are shown in Fig. 3. More details about EPON technology can be found in [2] and [3], including a definition of the individual power budget classes.

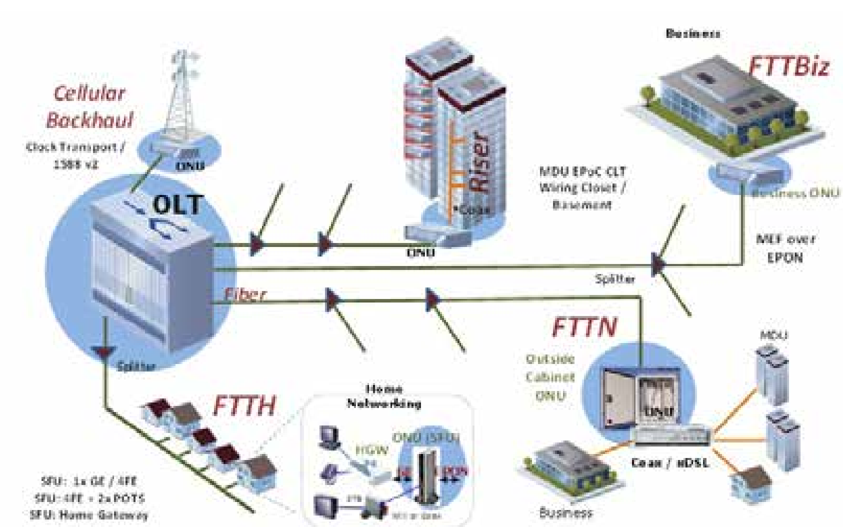

Fig. 3. Examples of various EPON deployment scenarios.

The observed ~50% annual growth in volume of Internet traffic in residential applications is driving the migration from legacy to fiber-based access technologies. For the residential subscribers served by EPON, the speed of residential wired or wireless local area networks (LANs) becomes the primary gating factor for the bandwidth demand. While being predominantly in the range between 100 Mb/s and 1 Gb/s today, the interface speeds of customer equipment (PCs, laptops, set-top boxes, TVs, security cameras, personal storage farms, etc.) are expected to increase by 2.5–5.0 Gb/s with the advent of IEEE 802.3bz 2.5/5-GBASE-T interfaces.

While unified in the common trend to support more subscribers with higher data rates, the residential access, business access, and mobile backhaul markets have different bandwidth targets and technical performance requirements. Not only are the technical requirements different in all of these markets, but the cost-to-performance objectives are also different. The IEEE P802.3ca Next Generation EPON Task Force was created to address these diverse requirements:

- A multiwavelength (per-direction) EPON PHY (i.e., hybrid PON) with an aggregate downstream capacity of at least 40 Gb/s (40G-EPON), with an evolutionary path to 100 Gb/s (100G-EPON).
- A single wavelength (per direction) EPON PHY (i.e., TDM-PON) that supports symmetric downstream and upstream line rates of at least 25 Gb/s (25G-EPON) or 25 Gb/s downstream and 10 Gb/s upstream (25/10G-EPON).

Coexistence with 10G-EPON on the same ODN, support for multiple generations of equipment, as well as a flexible and extensible standard definitions are examples of other critical requirements for this new technology. The task force is still in the early stages of technical development, focusing on a power split multirate P2MP architecture, as shown in Fig. 4, where a single optical line terminal (OLT) capable of multirate operation supports optical network units (ONUs) with different data-rate capabilities depending on the number of supported wavelength channels.

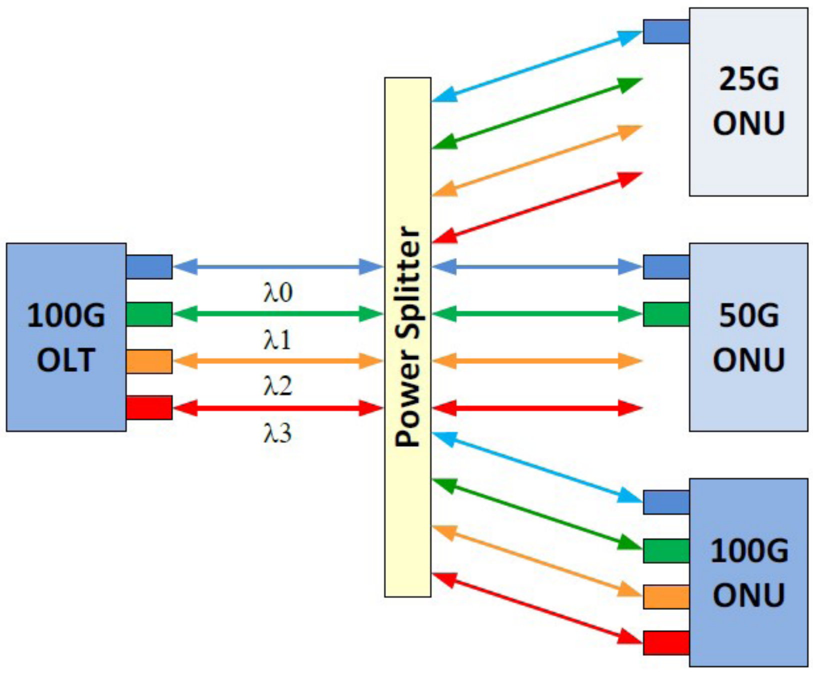

Fig. 4. NG-EPON OLT supporting multiple NG-EPON ONUs.

Given the interest in the development of a single extensible standard to support multiple data rates and generations of NG-EPON devices, it is likely that the multipoint control protocol (MPCP), used extensively in 1G-EPON and 10G-EPON for the purpose of station discovery and bandwidth allocation, will be extended in NG-EPON and will also perform device capability discovery and wavelength channel negotiation.

More details about the progress of the IEEE P802.3bc Task Force can be found at: http://www.ieee802.org/3/ca/index.html.

C. EPON Protocol over Coax: Bringing the Copper and Optical Worlds Together

Deployment of gigabit-capable EPON (based on 1G-EPON and 10G-EPON) services by cable operators in both China and the United States has been increasing over the past several years. The market drivers in both markets are slightly different. Hybrid fiber-coaxial (HFC) deployments as well as DOCSIS [4] are not as widely deployed in China as in other parts of the world. Chinese cable operators are looking at the opportunity of transparently extending EPON services over legacy coaxial cabling in multi-tenant/dwelling units (MxU) and businesses. In North America, high-speed data (HSD) residential services are currently provided using DOCSIS technology. However, for competitive multigigabit business class services, cable operators are increasingly deploying EPON to capture market share leveraging metro Ethernet forum (MEF) [5] service performance and competitive service level agreements (SLAs), all managed by DOCSIS provisioning of EPON (DPoE™ [4]) technology, which was developed jointly by operators, vendors, and the company CableLabs.

Another trend in the worldwide cable network industry is the step-wise migration from backend legacy MPEG-2 transport to MPEG-4 video distribution via IP over Ethernet. In the future, a large Ethernet-based gigabit pipe to the home and business will be fundamental for cost-effective growth and evolution. Fig. 4 shows examples of some of the target applications of the mix of EPON and EPoC technologies, leveraging the fiber-deep access architecture of current networks and also reusing existing coaxial distribution infrastructure to the greatest extent possible.

Both Chinese and North American operators share the desire for the simplicity of Ethernet at gigabit speeds, and collectively asked the IEEE 802.3 Ethernet Working Group [6] to create a standards effort for extending the operation of EPON protocols over coaxial distribution networks, a project that was called EPON Protocol over Coax, or EPoC for short. There are many opportunities where EPON has been deployed adjacent to or alongside existing coaxial networks, and some customers are more opportunistically reached by simply extending EPON over coax. The key to this transparent extension is unified management, service, and quality of service (QoS).

Fig. 5. EPoC applications for extending EPON services over coax.

For EPON, IEEE 802.3 standards define the MAC and PHY sublayers for a service provider OLT and a subscriber ONU. The fiber optical interconnecting media uses two wavelengths for full-duplex operation, one for continuous downstream channel operation and another for upstream burst mode operation. The OLT MAC controls time-division sharing of the upstream channel for all ONUs.

Similarly, the EPoC architecture consists of a service provider coax line terminal (CLT) and a subscriber coax network unit (CNU). The EPoC CLT and CNU MAC sublayers will be substantially similar (if not the same) to the layers found in the OLT and ONU, respectively. A new PHY will be specified for operation over the coaxial distribution network (CxDN) media. Downstream and upstream communication channels will use the radio frequency (RF) spectrum as assigned by a cable operator for their coax network.

Two system models are supported by EPoC, as shown in Fig. 5. The first is a CLT with one more CNU interconnected by a coaxial distribution network. The second is enabled by the future EPoC standard, but is outside the scope of the IEEE 802.3 Working Group. That is a traditional EPON with an OLT and multiple ONU devices together with one or more optical-to-coax media converter devices that attach between the PON and a CxDN using EPoC, permitting CNUs to appear as ONUs to the OLT. The industry will likely create new products using the second model.

For more information about the task force, please see http://www.ieee802.org/3/bn/index.html.

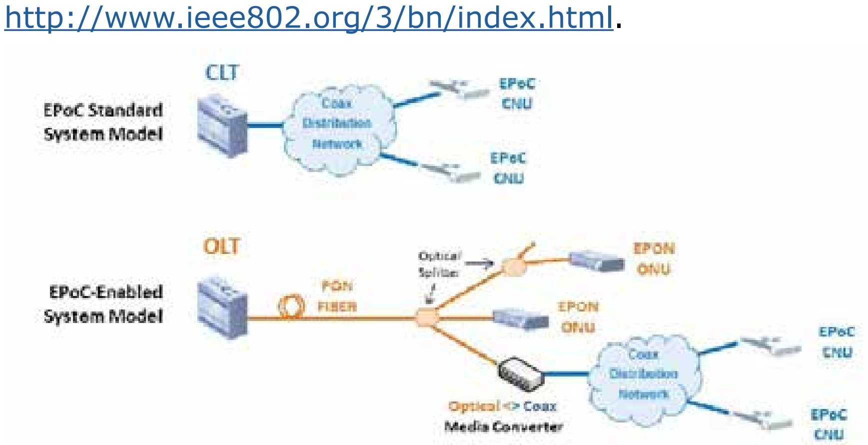

Fig. 6. EPoC standard and EPoC-enabled system models.

D. Timing and Synchronization in Ethernet (TimeSync)

Support for synchronization in Ethernet rapidly becomes a critical feature, especially due to requirements of digital content distribution, video and audio systems with remote streaming, or even mobile backhauling. All of these application areas require not only delay-guaranteed, engineered, and strictly controlled links (in terms of QoS, bandwidth, and jitter), but also the ability to synchronize with a common reference clock to assure proper operation of specific features of the given application. To address these requirements, the IEEE P802.3bf Task Force was created in 2009 to develop a method for "an accurate indication of the transmission and reception initiation times of certain packets, as required to support IEEE P802.1AS" [7].

The resulting architecture is presented in Fig. 6. This project added the following new features to the IEEE 802.3 architecture:

- Rx SFD detect and Tx SFD detect functions, responsible for detecting the reception and transmission of an Ethernet frame, respectively, and relaying this information to upper layers (TimeSync client) via the TSSI (TimeSync service interface).
- Set of managed objects and registers, providing the TimeSync client with the ability to read ingress and egress latency information characteristic of the given PHY. This provides the TimeSync client with the ability to perform necessary synchronization calculations relative to the reference plane located at the bottom of the 802.3 stack at the media dependent interface (MDI).

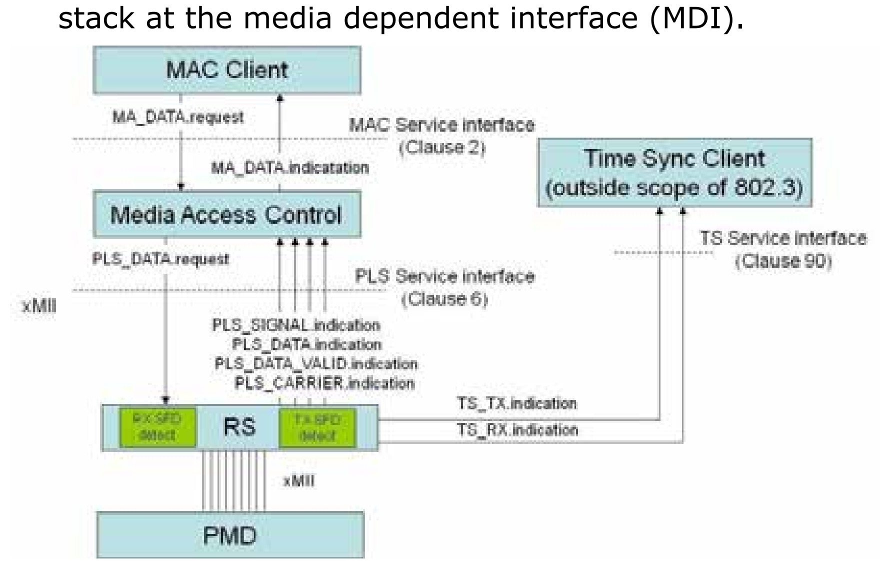

Fig. 7. Relationship between IEEE 802.3bf functions, TSSI, and remaining IEEE 802.3 layers. All clause numbers are relative to IEEE 802.3.

The *802.3bf-2011-IEEE Standard for Information Technology* architecture was designed to provide direct support for the *802.1AS-Timing and Synchronization* TimeSync client operating on top of IEEE 802.3 PHYs. However, it was quickly discovered that potential applications of the newly-specified TSSI could also cover other synchronization protocols, e.g. IEEE 588v2 and other proprietary use cases, which can benefit from information about transmit and receive path latencies as well as identification of the frame transition event through the RS sublayer.

The potential use of IEEE 802.3bf to support IEEE 1588v2 (*IEEE 1588 Standard for A Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*) resolves one of the long-standing problems of this specific synchronization protocol, namely the lack of a standardized way to retrieve correlated information between the frame transmission time and synchronized time. Various proprietary mechanisms have been developed over the course of the last few years, some of them quite similar to the solution proposed in IEEE 802.3bf. It is expected that the TSSI will become a de facto standard for future implementations of the IEEE1588v2 protocol operating on top of Ethernet PHYs.
IEEE 802.3bf is now part of 802.3-2015 – *IEEE Standard for Ethernet (see Clause 90).*

E. Ethernet on Twisted Pairs: BASE-T Differentiates

Following the standardization of IEEE 802.3an-2006 defining 10GBASE-T, and IEEE 802.3ba-2010 defining 40 Gb/s and 100 Gb/s Ethernet, work began in the industry to standardize the next higher speeds of twisted-pair Ethernet. Following a successful CFI in July 2012 and subsequent study group, the IEEE P802.3bq Task Force began work on 40GBASE-T. With the advent of 25 Gb/s Ethernet, this work expanded to include 25GBASE-T. Focusing on data center middle-of-row and end-of-row architectures (see Fig. 6), *802.3bq-2016-IEEE Approved Draft Standard for Ethernet* maintains the backwards compatibility of the standard Ethernet RJ-45 connector and the support for the auto-negotiation function, which has made BASE-T Ethernet successful. This standard adds two new BASE-T PHYs, one for 25 Gb/s and another for 40 Gb/s operation over Category 8 (ISO/IEC Class 1 or Class 2 channels) cabling at a distance of up to 30 meters. The technology base of 10GBASE-T proved useful to this project, and in addition to the increased bandwidth of the cabling, the standard made minor improvements to the error correction coding and startup parameter exchanges in 10GBASE-T. 10GBASE-T, 25GBASE-T, and 40GBASE-T; both support *Clause 28-Auto-Negotiation and Energy Efficient Ethernet*.

Fig. 8. ToR, MoR, and EoR interconnection options.

The demand for higher-speed backhaul for IEEE 802.11 wireless LAN access points and the need to use in-line power drove the IEEE 802.3 WG to standardize two new lower speeds for BASE-T at 2.5 Gb/s and 5 Gb/s. Two of the primary requirements included operation on the large installed base of Category 5e and Category 6 cabling as well as operation above 1 Gb/s and below 10 Gb/s. The work of the IEEE P802.3bz Task Force showed a lot of synergies with the IEEE 802.3bq-2016 standard, and its resulting technical solution is largely based on 10GBASE-T technology with some differences in the modulation and coding structure. The (at the time of this writing) new IEEE P802.3bz amendment draft defines MAC parameters for two new speeds (2.5 Gb/s and 5 Gb/s), both using an extension of the 10 Gb/s MAC interface (XGMII). The draft also specifies two PHYs, operating at speeds of 2.5 Gb/s and 5 Gb/s over Category 5e, Category 6, or better cabling at distances of up to 100 meters. The new 2.5GBASE-T and 5GBASE-T PHYs offer a bridge to higher speeds for existing 100-meter BASE-T networks and intermediate speed operation on newer networks. At the time of this writing, IEEE P802.3bz 2.5G/5GBASE-T Draft 3.1 (see http://www.ieee802.org/3/bz for more details) is in the final stages of sponsor ballot recirculation, and is expected to be approved in September 2016.

F. Ethernet in New Markets: Applications in the Automotive Industry

The IEEE 802.3 family of standards provides a wide variety of solutions for data networks with many different operating speeds over copper wire, electrical backplanes, and various optical media. Recently, the global automotive industry has decided to deploy Gigabit Ethernet as a network backbone in automobiles and light trucks by the year 2020 [8]. 1000BASE-T as defined in IEEE 802.3 uses four twisted copper wires pairs. While this is not an issue for structured wiring plants, it results in a cable that is too heavy, costly, and cumbersome for vehicular use. (See slide 15 in [8] for an example of a typical passenger vehicle harness.)

The IEEE P802.3bp 1000BASE-T1 Task Force has completed the development of a robust 1 Gb/s copper PHY for this new market area. Estimates place the number of Ethernet ports in cars at around 300 million ports per year by 2019. The 1,000BASE-T1 PHY will allow for smaller and lighter cabling and the use of a network backbone architecture that will make the in-car wiring harness easier to manufacture and lower in cost. In fact, the wiring harness in a car is the third most expensive component in the car behind the engine and chassis, and is also the third heaviest.

In 2012, modern cars had between 40 and 60 microcontrollers, while high-end cars had over 120. Future sophisticated camera and control systems, vehicle safety devices (automatic braking, collision avoidance, etc.), infotainment, and GPS systems will create large traffic volume for the in-car network that the previous automotive networks could not handle.

The number of microcontrollers or electronic control units (ECUs) in cars is expected to rise dramatically over the next decade as these functions become standard features in new cars. Automotive networks will also leverage other IEEE 802.3 technologies such as IEEE 802.3az and IEEE 802.3bf (discussed in the previous section) to provide an optimized network solution.

802.3bp-2016-IEEE Approved Draft Standard for Ethernet was approved in June 2016 and is being designed into the cars that will appear in the early 2020s.

But there is much more to the story. The IEEE P802.3bp project generated so much interest in the Ethernet community that the IEEE P802.3bu 1-Pair Power over Data Lines (PoDL) project was initiated to provide DC power over the same single twisted wire pair used for IEEE 802.3bp-2016. IEEE P802.3bu is expected to finish in early 2017. A proprietary 100 Mb/s Ethernet solution, the OPEN Alliance BroadR-Reach compliant Ethernet PHY, was brought into the IEEE 802.3 Ethernet Working Group and standardized as 802.3bw-2015-IEEE Standard for Ethernet Amendment 1. In addition, work on a 1 Gb/s solution on plastic optical fiber (POF) is being done in the IEEE P802.3bv Gigabit Ethernet Over Plastic Optical Fiber Task Force, with an expected completion date in 2017.

G. Management for Ethernet Networks

Ethernet as defined by the IEEE 802.3 Working Group continues to evolve by adding support for higher data rates, new media types, and new features. Ethernet will expand into new markets and address new application areas, as discussed in the previous sections. However, this evolution may require changes in the managed objects stored in the management information base (MIB), allowing management systems to take full advantage of the newly-added Ethernet features

In order to provide a consistent, up-to-date version of MIB definitions and eliminate dependence on external MIB definitions produced outside of the IEEE 802.3 Working Group, a project was started at the end of 2008 (IEEE P802.3be) targeting organization, updates, and the consolidation of managed object definitions provided in IEEE 802.3-2008, including the logical link discovery protocol Ethernet extensions provided in IEEE 802.1AB-2009, Annex F. In addition, the initial version of this standard incorporated and updated the MIB module definitions formerly defined in a series of RFC documents, namely RFC 2108, RFC 3621, RFC 3635, RFC 3637, RFC 4836, RFC 4837, RFC 4878, and RFC 5066. The final version of IEEE 802.3.1 was published in July 2011, containing both the definitions of individual MIBs and associated descriptions as well as the machine-readable MIB files, which are available from the website of the IEEE P802.3be project. The published standard was then amended to account for amendments to IEEE 802.3-2008, including IEEE 802.3at, IEEE 802.3av, IEEE 802.3az, IEEE 802.3ba, IEEE 802.3bc, IEEE 802.3bd, IEEE 802.3bf, and IEEE 802.3bg. The resulting *802.3.1-2011-IEEE Standard for Management Information Base (MIB) Definitions for Ethernet* was published in June 2013, comprising the latest version of Ethernet MIB.

Apart from maintaining MIB for legacy SNMP-based management systems, the IEEE 802.3 Working Group is also actively pursuing more modern management schemes for Ethernet devices. YANG (yet another next generation data model, see RFC 6020) is quickly becoming the de facto data modeling language for next generation network management systems, replacing the legacy management (MIB)/simple network management protocol (SNMP)-based tools. YANG is a data modeling language, which replaces the rigid structure of MIB with a very flexible and extensible way to describe different data types, aggregating them into different object types. It is used to express, for example, interfaces, devices, network topology, or even protocol models, and builds on existing models to create more complex data structures. YANG data models describe configuration, monitoring, administration, and notification capabilities in a device-independent but end-to-end network service-oriented manner, providing network management in a simple, human-readable language syntax.

When combined with a reliable transport protocol (e.g., NETCONF), YANG provides substantial advantages to operators, simplifying end-to-end network deployment, and providing vendor-independent service modeling across different hardware platforms.

The development of YANG data models has seen incredible growth in many industry organizations such as the IETF, Metro Ethernet Forum, and the IEEE 802.1 Working Group. Within the IEE 802.3 Working Group, the work on YANG models for Ethernet will be undertaken by the recently-formed YANG Data Model(s) Study Group. (See http://www.ieee802.org/3/ce/index.html for details.)

III. Summary

The work within the IEEE 802.3 Working Group is far from done, with the next generation of high-speed 40/100/200/400G links aiming for broader market adoption through increasing the cost-effectiveness of solutions while decreasing the power consumption and complexity of compatible products. This work also focuses on lower speeds. The 10 Mb/s Extended Reach Single Twisted Pair Ethernet PHY (http://www.ieee802.org/3/cfi/request_0716_1.html) project, aims to address existing market demand for a unified lower speed and a longer-reach PHY for automation purposes. The IEEE 802.3 Working Group is thus looking for ways to expand Ethernet market coverage and to support higher data rates while also providing coverage for emerging markets such as the automotive industry.

It can be expected that innovation in the area of wired Ethernet will continue in the years to come, bringing the same highly reliable and well-understood networking philosophy to new markets, enabling new applications, and making networking in general more ubiquitous.

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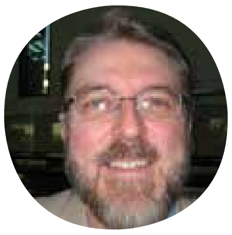

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Standardization of Device-to-Device Communications in IEEE 802.15.8

by Marco A. Hernandez

The next generation of wireless communications must support a wide range of applications and services. Recent advances in wireless applications and services have shown a fast growth in mobile traffic with prospects to increase in coming years. So-called 5G applications, Internet of things (IoT), and machine-to-machine (M2M) applications require massive connectivity of users and/or autonomous devices to meet the demand of diverse services in terms of low cost, low latency, reliability, and throughput.

New technologies are being developed to respond to the traffic explosion. Currently, competing and complementary technologies like long-term evolution (LTE), IEEE 802.11 (WiFi), and IEEE 802.15 personal area networks (PANs) are developing standardized solutions. In particular, IEEE 802.15.8 is developing an international standard on device-to-device (D2D) communication networks that is infrastructure-less (devices do not need to access infrastructure for network synchronization, discovery, and communication), with distributed coordination and multicast/multigroup communications.

Peer-to peer communications or D2D is an active field of research and development as it has some interesting and important use cases. Indeed, in mission critical communications from public safety to highly reliable wireless systems in scenarios where access to infrastructure does not exist or was shut down due to natural disasters, D2D communications can offer real-time communication services infrastructure-less. On the other hand, D2D communications allow offloading traffic from LTE and WiFi networks for a group of neighboring users. This use case would be relevant in social networking, gaming, or emergency communications.

The current state of the art includes device-to-device communications for proximity services by LTE. WiFi Direct aims to replace the WiFi ad-hoc mode and proprietary systems such as FlashLinQ by Qualcomm. However, these systems still rely on infrastructure for (network) synchronization and/or discovery and management.

The IEEE 802.15.8 Peer-Aware-Communications (PAC) Task Group (TG8) aims to develop ad-hoc D2D communications, infrastructure-less, and with fully distributed coordination. This standard supports multicast sessions for group communications. Also, the proposed standard includes a in the recently released sub-GHz band, which allows the use of unmanned aerial vehicles (UAVs). Thus, PAC networks can combine aerial, terrestrial, and mobile D2D group communications.

The draft standard is currently under letter ballot, awaiting comments from the IEEE 802.15 and IEEE 802.19 Working Groups. The standard is expected to be published in the first quarter of 2017. The products envisioned in the standard range from gaming and social networks to emergency search and rescue operations. In the academy, the standard offers areas of research in distributed network synchronization, group communications, distributed MAC, etc.

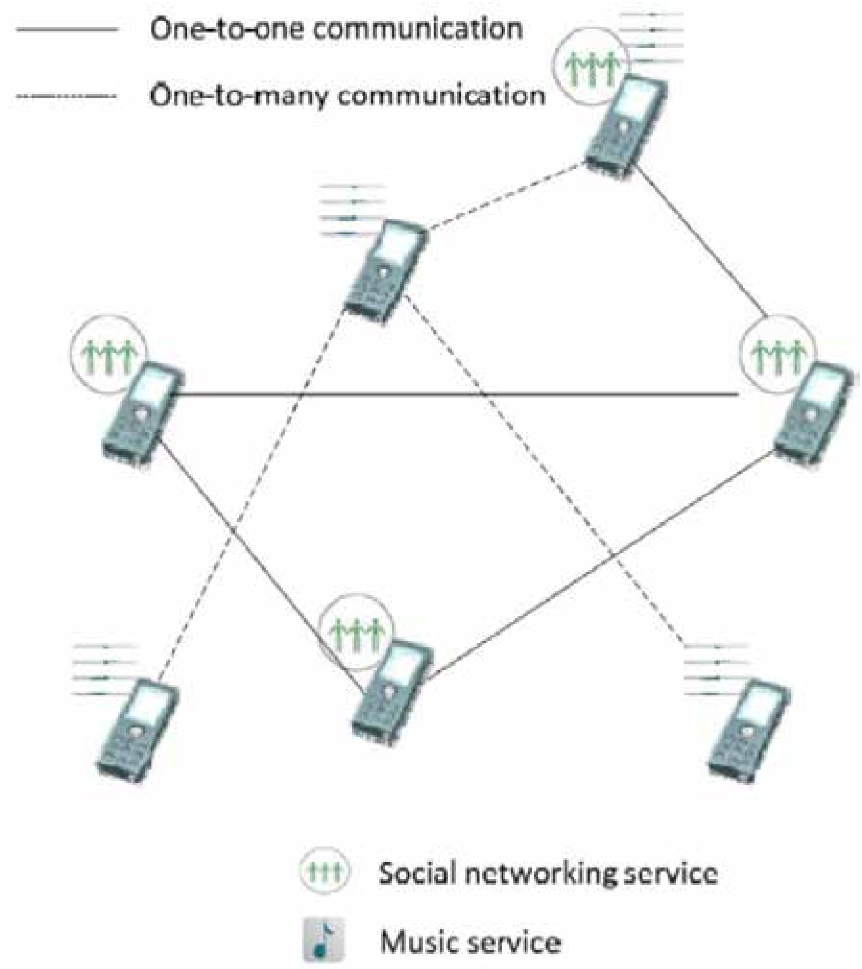

Fig. 1. Topology of D2D communications in IEEE 802.15.8 standard.

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Automotive Ethernet

by Steven B. Carlson

The automobile was not thought of as a high-technology device during the last 50 years. "High-tech" meant Silicon Valley—computers, microcircuits, advanced networking, smartphones, things that were defined by advanced electronics and software. Cars may have been high-tech by the standards of mechanical engineers, with "exotic" materials such as aluminum replacing steel and iron in the engine block and car body, but they did not define any sort of cutting-edge technology.

This has changed. Electronics have become the dominant force driving innovation in automotive technology. Silicon Valley is driving (pun intended) the 21st century automobile, with firms like Google, Tesla, and (it's rumored) Apple, creating autonomous cars that are in turn connected to the Internet to share and exchange a wide variety of data. The so-called "Internet of Things" will really be the "Internet of cars" by the early 2020s.

Cars will become mobile data centers, with supercomputer levels of processing power. Such processing power requires ultra-high performance networks, and the IEEE 802 LANMAN Standards Committee has developed a variety of solutions specifically directed at the automobile.

How did cars go from being the province of mechanical engineers to something that has millions of lines of computer code running on dozens of processors? If we step back in time to the middle 1950s, the average car had no electronics. The car had electrical systems, of course, but these were purely electrical or electromechanical (i.e., head lights, tail lights, brake lights), and had not changed much since the dawn of the automobile. A vacuum-tube AM radio was likely the only electronic device in a 1950s car, and radios were costly options in those days. Some luxury cars had electric-eye automatic headlight dimmers or under-dash record players (!), but that was about it.

Standards in automobiles were either:

- Manufacturer-specific (standards set within a car maker, e.g. General Motors, Volkswagen, or Honda) for particular items,
- De facto standards (standards adopted across manufacturers due to market acceptance),
- Standards bodies created to support the auto industry, or
- Standards set by legislative bodies; these were usually directed at safety or the environment.

In the 1960s, electronics became a larger part of the automobile, as was occurring in every technology area, especially consumer electronics. Simple electronic intermittent windshield wipers, cruise control, 8-track tape and cassette systems, EFI (electronic fuel injection), and sequential tail lights appeared in the late 1960s. In many cases, these early electronic systems were notoriously unreliable. Car makers were learning how to design and build systems that could survive in what was considered one of the most hostile environments for electronics—automobiles.

By the 1980s, AM/FM cassette stereos, cruise control, heated seat controls, in-car mobile phones, preset mirror and seat position memory, and electronic engine, powertrain, and brake control systems were being introduced. The first automotive "network" the CAN (controller area network) bus, was introduced by Robert Bosch GmBH in 1981. The CAN bus tied the various control electronics together via a 1 Mb/s serial data bus. CAN quickly became the dominant in-car network.

The 1990s saw much more sophisticated in-car entertainment, with DVD players with multiple displays, multichannel audio systems, remote door lock/unlock, airbags, and driver personalization (i.e., memory mirrors, seats, radio stations). The engine, drivetrain, and brake electronics were also becoming much more powerful.

By 2010, the average car had around 45 microprocessors, with some high-end cars having over 130. Advanced driver assist systems (ADAS) provided intelligent cruise control, lane departure warnings, proximity alerts (i.e., following too close, backing into an object), navigation, traffic alerts, night vision, heads-up displays, radar (for safe driving in the fog)—the modern car seemed more like an advanced aircraft than something to be driven to the grocery store. ADAS were the stepping stone to the fully-autonomous car.

All of this functionality came with a big problem. The automotive networks developed by the car industry had not kept pace with the needs of these advanced systems. The 1 Mb/s CAN bus and its follow-on, the 10Mb/s FlexRay bus, simply couldn't provide the performance required to support ADAS and infotainment. The electronic architecture of the car had become an unsustainable mess, with many different "networks" cross connected in crazy ways to try and work around the deficiencies of the outmoded automotive network technology. The network performance would have to improve dramatically to make self-driving cars a reality.

Silicon Valley came to the rescue, in the form of a wake-up call to the auto industry. Electric car start-up Tesla had been using Ethernet in the Model S since its introduction in 2011, as had Google in its test autonomous vehicles. The most advanced vehicles on the planet were not being built by traditional car companies. Tesla couldn't build cars fast enough to satisfy demand. Something needed to be done, and fast.

In 2012, a group of visionaries from the automotive industry, working with long-time experts in the IEEE 802.3 Ethernet working group, started a project for a special version of 1Gb/s Ethernet specifically tailored for the automotive market. The project involved individuals from major auto companies, Tier 1 automotive suppliers (the major companies that build subsystems for cars), and the major Ethernet semiconductor vendors. IEEE Std 802.3bp-2016 was approved in June 2016 and is being designed into the cars that will appear in the early 2020s.

But there is much more to the story. The 802.3bp project generated so much interest that the P802.3bu Power over Data Lines project was started to provide DC power over the same single twisted wire pair used for 802.3bp-2016. P802.3bu is expected to be completed in early 2017. A proprietary 100Mb/s Ethernet solution, the Open Alliance BroadR-Reach, was brought into the IEEE 802.3 Ethernet working group and standardized as 802.3bw-2015. In addition, work on a 1Gb/s solution on plastic optical fiber (POF) is being done in P802.3bv, with an expected completion date in 2017.

The 802.1 working group's Audio/Video Bridging/Time Sensitive Networks (AVB/TSN) Task Force has been adding time awareness to Ethernet networks for a number of years. 802.3br-2016 provides hardware mechanisms to support some functions provided by 802.1 TSN standards, e.g. 802.1 qbu for high-priority traffic. Many cars will have an on-board 802.11 Wi-Fi system to allow the user to use their smart phone for navigation, entertainment, and hands-free calling, as well as surfing the web (hopefully passengers only).

These IEEE 802 standards will allow the designers of future cars to create a true networked architecture, with all data available everywhere. The block diagram of an automotive system will look just like the block diagram of an enterprise network—and that's the point: to use the vast array of knowledge, experience, and software that runs networks around the world to run the networks in your car.

Tier 1 suppliers will no longer need to create separate solutions for each car company. Instead, they can build common hardware platforms with IEEE 802 networking that can be customized by software. Costs will go down and reliability will go up, which will make the finance department smile (perhaps for the first time). Designers within car companies can pick and choose, just like their counterparts in mainstream networking, the best solution from a number of vendors.

The automotive industry has always had standards of one kind or another. Moving forward, IEEE 802 standards will be a big part of the leap to the truly autonomous car.

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Guidance for a Massively Interconnected World: A Rerenence Model for IEEE 802 Access Netwokrs

by Max Riegel

Introduction

At the end of the twentieth century, the massive proliferation of the Internet initiated a revolution in our everyday lives. Time-consuming and complex processes like booking a flight became easy. Using e-mail instead of letters printed out on paper helped speed our way of doing business and allowed for dealing with many more customers simultaneously. Having access to all the knowledge of the world at your fingertips enabled much higher productivity throughout the global economies.

The Internet revolution was initially driven through powerful communication servers and performance desktop PCs in highly centrally managed networks. Today, it moves on and spreads out into increasingly smaller devices and many more heterogeneous networks. SmartGrid, IoT (Internet of Things), and Industry 4.0 are all examples of a huge number and high variety of communication networks aimed to interconnect devices of any size to achieve better coordination and get faster access to the operating parameters of their environment.

IEEE 802 technologies like Ethernet (IEEE 802.3), Wi-Fi (IEEE 802.11), WiMAX (IEEE 802.16), and Zigbee (IEEE 802.15.4) are the predominant interfaces used for the increasing density and variety of local and metropolitan area networks. Due to their modularity and interoperability, IEEE 802 technologies are not limited to deployment in a single arrangement like a 4G cellular network. These technologies can be combined and arranged in various ways to accommodate nearly any requirement or operational model.

However, the flexibility and variability of IEEE 802 technologies creates new challenges. While it is common in the established cellular networks to have a single terminal connected through a single radio interface to a single cellular network of a single operator, the IEEE 802 networks do not follow this model. For example, Wi-Fi/IEEE 802.11 is commonly used by individuals who employ multiple devices to receive Internet connectivity through a variety of Wi-Fi access networks consisting of a single or a number of access points; these access points could be used at a home, university, or company, or they could be accessed at stores, coffee shops, or other public places.

Moreover, it is not unusual for all of the Wi-Fi access networks to be designed, built, and operated by completely different people and organizations. As an indication of missing widespread knowledge, many of the networks provide only very basic service, not leveraging the full capabilities of Wi-Fi that are available through different devices and access points.

Network Standardization Approach and its Application to IEEE 802 Access Networks

Standardization is a means to provide guidance to designers, manufacturers, and operators with the knowledge to realize interoperable solutions beyond the most basic connectivity. Creating a standard is a process in which a group of engineers and researchers with different opinions and technical ideas creates a description of a common technical solution. The process becomes particularly difficult when the topic is complex, like with communication networks, and the number of participants is large.

Before the development of the Integrated Services Digital Network (ISDN) in the 1980s, the International Telegraph and Telephone Consultative Committee (CCITT), now known as ITU-T, created a set of standards on standardization of communication networks to make this process more manageable. The basic ideas are described in the recommendation, ITU-T I.130. This recommendation defines a three-stage process starting with the collection and specification of service and deployment requirements, which finally leads to detailed protocol specifications for the implementation of the interfaces of telecommunication networks. The second stage develops a logical and functional model to identify the types and functions of the open interfaces in the network. This document has remarkable value beyond just being an intermediate step towards the protocol specification. It provides a highly informative

Fig. 1. Different deployment scenarios for IEEE 802.11/Wi-Fi.

picture of the overall network architecture and operation, which is essential for implementers and operators to gain comprehensive end-to-end understanding of the network, as well as to facilitate market communication for the delivery of services and components by showing how the different pieces fit together.

IEEE 802 adopted the three-stage standardization approach for most of its bigger standardization projects for completely new interfaces, and IEEE 802 working groups commonly create requirement specifications before stepping into the design of the protocol details. However, even when networking requirements have been documented by the projects and all requirements can be fulfilled by the existing IEEE 802 protocol standards, there is no IEEE 802 specification presenting an overall access network architecture and providing an end-to-end functional description. This was not a major issue when IEEE 802 technologies were mostly deployed in smaller isolated networks built and operated by experienced corporate IT departments.

The OmniRAN P802.1CF Project

Today, IEEE 802 technologies are much more widely used and are deployed in higher numbers. The lack of a common approach for the IEEE 802 access network leads to inferior technical solutions missing many of the possible capabilities, and it hinders IEEE 802 networks from growing together and being smoothly interconnected to build the backbone for the massively connected world.

In 2013, this gap was identified by the IEEE 802 OmniRAN Executive Committee Study Group and a new project, P802.1CF, was initiated in May 2014 to create a recommended practice called Network Reference Model and Functional Description of IEEE 802 Access Network. The IEEE 802.1 OmniRAN TG (task group) has completed the first draft specification, and after review and revisions the project will progress to the Working Group ballot.

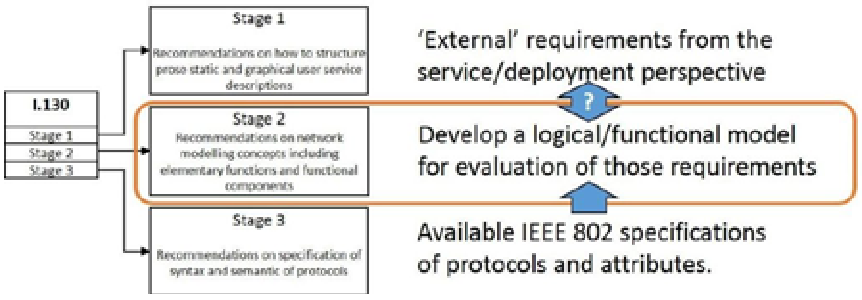

Fig. 2. Three-stage network specification according to ITU-T I.430 and its application to IEEE P802.1CF.

As shown in Fig. 2, the project closes the Stage 2 gap for the IEEE 802 network protocol. Instead of following the sequential order, the project derives the architectural model and functional description not only from the service and deployment requirements, but is also re-engineered from the existing IEEE 802 protocols and common implementations in the market.

The aim is to demonstrate that highly functional and fully managed access networks can easily be built within the existing family of IEEE 802 protocols, and that all needed functions are already available in the IEEE 802 protocol specification. The main purpose of the specification is to establish better understanding and a common view on IEEE 802 access networks. A recommended practice without strict statements for interoperability has been chosen, also recognizing that there is not a single solution for all deployment cases. If demand for more compliance arises in future, a complementary standard with strict compliance statements for that particular deployment case could be created as a profile based on 802.1CF.

Definition of IEEE 802 Access Network

An IEEE 802 access network is characterized by a user plane forwarding Ethernet frames between the network interface in the terminal and the network interface at the access router, where the link is terminated. The specified model should allow for the building of heterogeneous access networks, which may include multiple network interfaces, multiple network access technologies, and multiple network subscriptions, aimed at unifying the support of different interface technologies, enabling shared network control and the use of software defined networking (SDN) principles. It adopts the generic concepts of SDN by splitting the network model into an infrastructure layer and a control layer with well-defined semantics for interfacing with higher layer management, orchestration, and analytics functions. The specification assumes a clear separation of operational roles for the access network, the subscription service, and the IP service to support various deployment models including leveraging wholesale network services for backhaul, network sharing, and roaming.

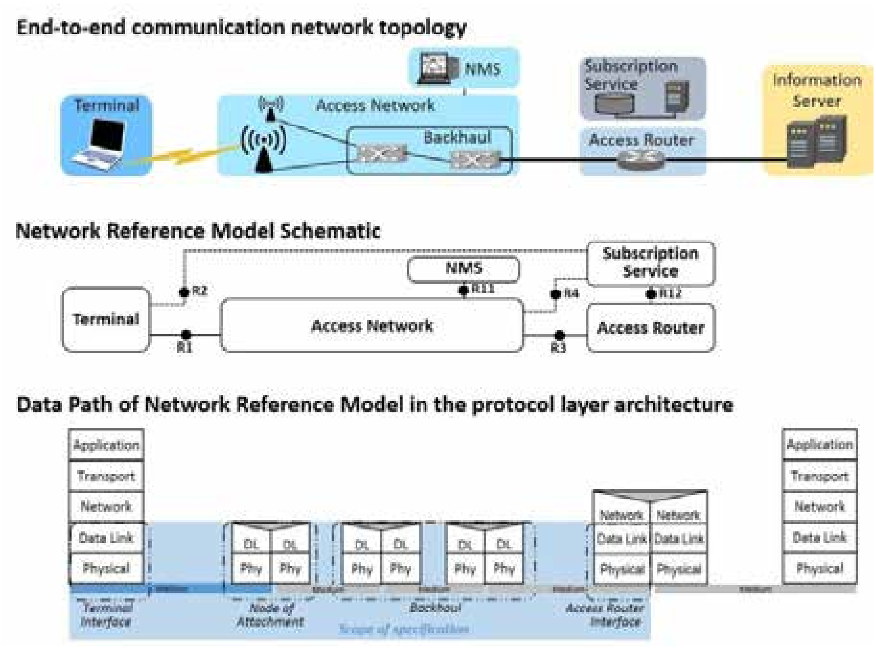

Fig. 3. Mapping of the network reference model to real topologies and its relation to the end-to-end data path.

As part of the end-to-end network model for providing access to IP services, the P802.1CF deals with the communication link between the IP interface in the terminal and the access router. User plane traffic is forwarded based on the MAC addresses in the frames, even when the Ethernet frames are tunneled over some other transport technology in the backhaul. Due to deploying Ethernet in the access network, the functional separation of the user plane and the transport plane in the access network can be avoided, and a combined control model for backhaul connectivity and subscriber specific connectivity can be deployed.

Network Reference Model for IEEE 802 Access Network

At a glance, the network reference model for the IEEE 802 access network consists of the terminal; the access network comprising the node of attachment; the backhaul and the network management system; the access router providing the IP connectivity; and the subscription service dealing with authentication, authorization, and accounting; as well as subscriber-specific policy functions. All of the communication interfaces between the entities are made visible and are denoted by R1 for the interface between the terminal interface and the node of attachment up to R12 for the control interface between the subscription service and the access router control.

Fig. 4 presents the complete NRM, which also exposes the terminal control function in the terminal and the control function in the access router; both are connected to the access network control function. In addition, an entity denoted coordination and information service is provided for the management of shared network resources among multiple access networks such as a spectrum database for controlling access to spectrum in the case of TV white space or licensed shared access, and the network management service is also depicted to enable the description of the functions of a fully-managed access network.

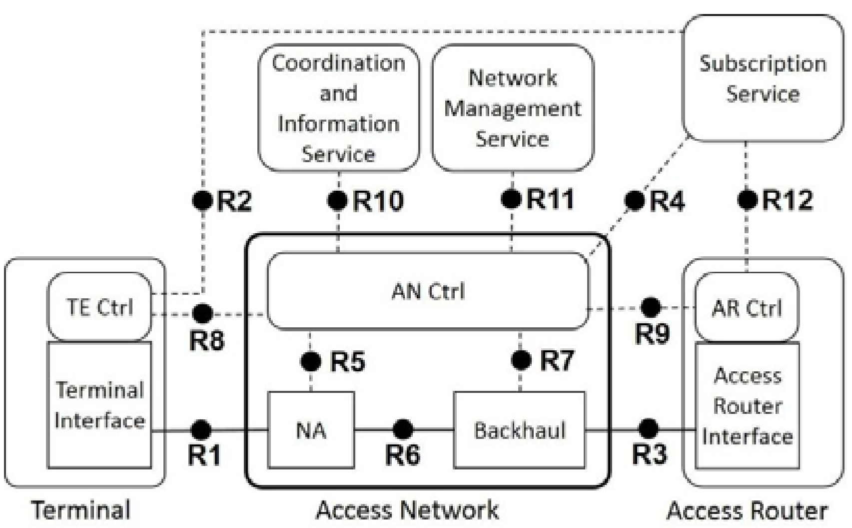

Fig. 4. IEEE 802 access network reference model.

The reference points in the NRM denote either data path interfaces forwarding Ethernet frames (R1, R3, R6) or control interfaces for IEEE 802 related parameters, which may be carried either within IEEE 802 protocols or through IP-based protocols (R2, R4, R5, R7, R8, R9, R10, R11, R12). For the case where IEEE 802 specific identifiers or configuration information is carried through IP protocols, the selection of the particular IP protocol is beyond the scope of the specification. The scope of P802.1CF is limited to the specification domain of IEEE 802 comprising only the PHY and LINK layer of the ISO-OSI 7-layer model. Nevertheless, the comprehensive functional description of the message exchange between the entities of the NRM provides strong guidance for the selection of the IP protocols for the control interfaces.

Achievements and Outlook

Even though the specification is still in its infancy, an architectural and functional description of the IEEE 802 access network is already proving valuable. In a SDN and NFV white paper of the Wireless Broadband Alliance, as well as in the discussions regarding IEEE engagements in the development of 5G converged networks, initial P802.1CF results were used to depict and to reference the network part, which is required to leverage IEEE 802 technologies for providing communication services to subscribers or devices.

Interestingly, the chosen approach for the network reference model has shown remarkable applicability and flexibility. Advanced deployment scenarios like network virtualization or slicing, or advanced implementation techniques like SDN, could be described without any modification to the NRM. These initial experiences with P802.1CF provide strong evidence that the final specification will be able to provide guidance for future IEEE 802 networking and will foster more widespread deployment of managed IEEE 802 access networks, thus making the massively connected world feasible.

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He has been involved with IEEE 802 standardization for more than 15 years, participated in various projects and committees, and is currently chair of the IEEE 802.1 OmniRAN TG, as well as voting member of the IEEE802.11. Previously, he supported IEEE DySPAN-SC as vice-chair and parliamentarian, was the vice-chair of the networking working group in the WiMAX Forum, and led the Ethernet over cellular systems specification work in IETF 16ng WG.

IEEE 802.11AH (WI-FI in 900 MHz Licence-Exempt Band) For IOT Application

by Yongho Seok

The IEEE 802.11ah Task Group (TG) is developing a standard specification for targeting the Internet of Things (IoT) and extended range (ER) applications. The TG started the standardization activity in November 2010, and is currently in the last phase of the IEEE ballot procedure. The publication of the IEEE 802.11ah amendment is expected at the end of 2016.

The IoT is the next major growth area for the wireless industry, with applications including home and industrial automation, asset tracking, healthcare, energy management, and wearable devices.

Unfortunately, the market is fragmented with multiple non-interoperable technologies, some with coverage issues, some with non-user-friendly network configuration and deployment issues, and some with scalability issues. 802.11ah addresses these deficiencies with an optimized design which operates in the sub 1 GHz spectrum that is available worldwide for the IoT use case. The 802.11ah use cases shown on Fig. 1 cover a variety of indoor and outdoor IoT applications [1].

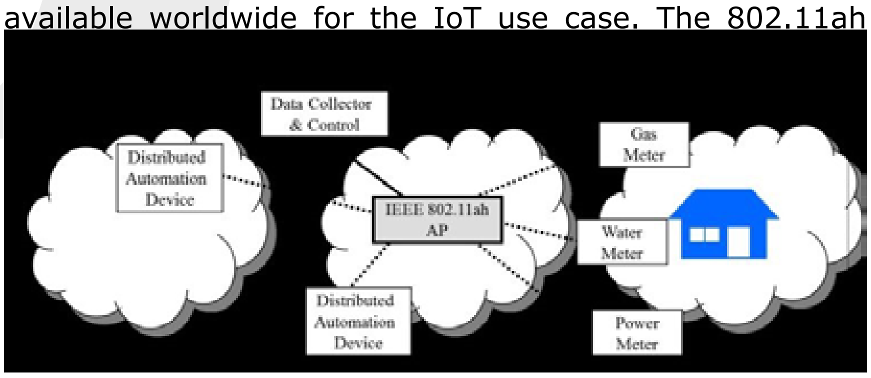

Fig. 1. 802.11ah use cases.

The 802.11ah amendment defines a narrow-band orthogonal frequency division multiplexing (OFDM) physical layer (PHY), i.e., 1/2/4/8/16MHz, operating in the license-exempt bands below 1 GHz that enable an extended range WLAN (wireless local area network) with significantly lower propagation loss through free space and walls/obstructions, augmenting the heavily congested 2.4 GHz band and the shorter-range 5 GHz bands used today. Fig. 2 shows two categories of the 802.11ah bandwidth modes. The 1/2MHz bandwidths are mandatory modes of all 802.11ah STAs (stations) and will be used as globally interoperable modes for sensor networking. However, the 4/8/16MHz bandwidths are optional modes and will be used for an ER application requiring higher data rates.

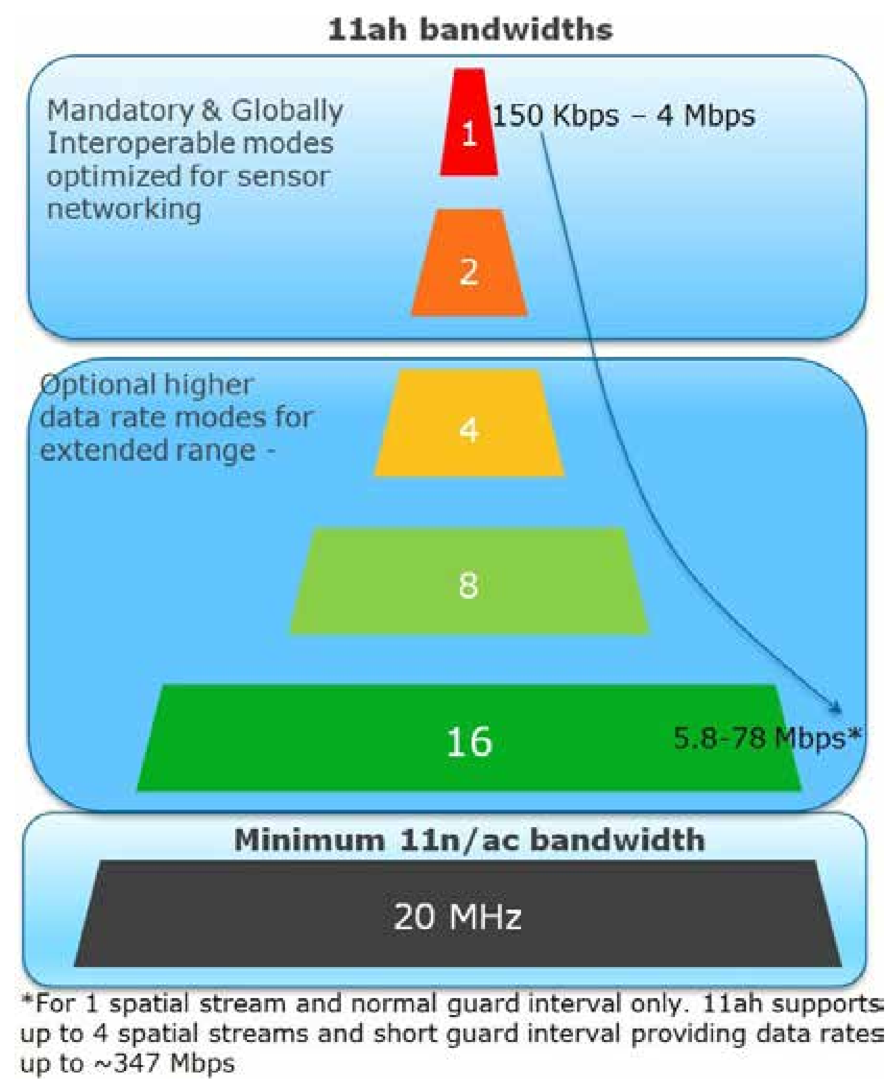

Fig. 2. 802.11ah bandwidth modes.

802.11ah has enabled multiple low-rate modes (starting from 150 Kbps) and higher-rate modes (up to 346 Mbps for 4 spatial streams). Low rate modes, suitable for IoT applications, provide whole-home coverage for battery operated, small-form-factor devices such as temperature and moisture sensors. Higher-rate modes, suitable for ER applications, support plug-in devices with a power amplifier, such as video security cameras. Users can now deploy 11ah sensors in attics, backyards, basements, and garages, and have them directly connect to a single 11ah access point (AP). Table 1 summarizes the characteristics of the 802.11ah amendment for IoT applications.

Table 1. Characteristic of 802.11ah.

Frequency Band	License-exempt bands below 1 GHz, excluding the TV white spaces – Example: 863-868.6 MHz (Europe), 915.9 -928.1 MHz (Japan), 755-787 MHz (China), 917- 923.5 MHz (Korea), 866-869 MHz, 920-925 MHz (Singapore), and 902-928 MHz (U.S.)
Channel Width	1/2/4/8/16 MHz
Range	Up to 1Km (outdoor)
End Node Transmit Power	Dependent on regional regulations (from 1 mW to 1 W)
Packet Size	Up to 7,991 bytes (without aggregation) up to 65,535 bytes (with aggregation)
Uplink Data Rate	150 Kbps ~ 346.666 Mbps
Downlink Data Rate	150 Kbps ~ 346.666 Mbps
Devices per Access Point	8,191
Governing Body	IEEE 802.11 working group
Status	Targeting 2016 release of standard
End node roaming allowed	Allowed by other IEEE 802.11 amendments (e.g., IEEE 802.11r)
Topology	Star, Tree

- The 11ah MAC layer is optimized for long battery life and a large number of STAs with the following features:
- Scalability up to 8,191 devices per AP: Restricted access window (RAW) operation and hierarchical traffic indication map (TIM) structure,
- Efficient frames and transmissions: Short frame format, short control/management frames, asymmetric and bi-directional transmissions,
- Reducing power consumption: Non-TIM operation, target wake time (TWT) mechanism, extended sleeping and listen interval,
- Relay operation: Tree-based multi-hop network.

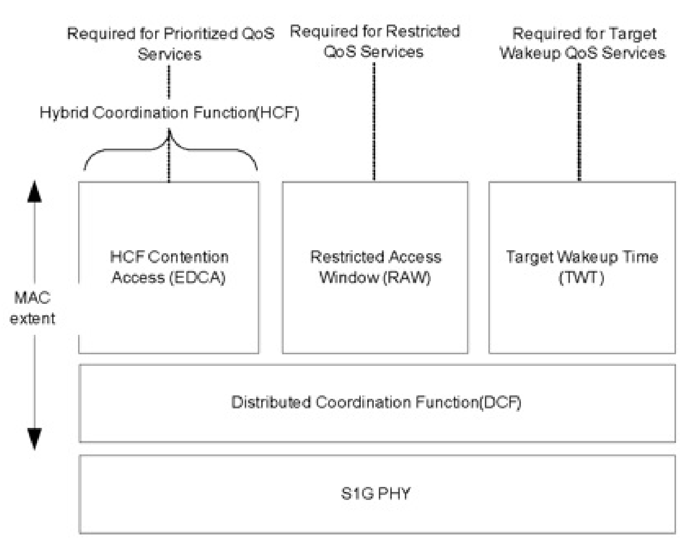

Fig. 3. 802.11ah medium access control (MAC) architecture.

Fig. 3 shows 802.11ah MAC architecture. The RAW and the TWT have been introduced in 802.11ah as a key channel access procedure for enabling an IoT application in a wireless LAN.

For an outdoor smart grid network, the number of STAs can number in the thousands. Many STAs at the edge of the coverage area could be hidden to each other for uplink transmissions. Restricting uplink channel access to a small number of STAs and spreading their uplink access attempts over a period of time might improve the medium's efficiency by reducing collisions.

A basic concept of RAW and TWT is to spread out the uplink transmissions over a long period of time.

802.11 carrier sense multiple access (CSMA) mode can be regarded as the P-persistence CSMA mode. When a STA is ready to transmit a frame, it senses a wireless medium for idle or busy. If the wireless medium is idle, then it transmits a frame with probability p. However, in the RAW operation of 802.11ah, when the wireless medium goes idle, a STA waits for its time slot in accordance with its assigned transmission schedule.

Also, TWT allows STAs to manage activity in the basic service set (BSS) by scheduling STAs to operate at different times in order to minimize contention and to reduce the required amount of time that a STA using a power management mode needs to be awake.

Fig. 4 shows the 802.11ah link-level performance with an AP and a STA implemented with a real silicon chip [2]. This experiment data was measured in an outdoor non-line-of-sight (NLOS) environment for a point-to-point link of 1Km distance. For modeling the IoT application, a packet length of 100 bytes and a transmit power of 25dBm at the antenna connector were used. Through this result, it is verified that 802.11ah STA can have a reliable communication up to 1Km.

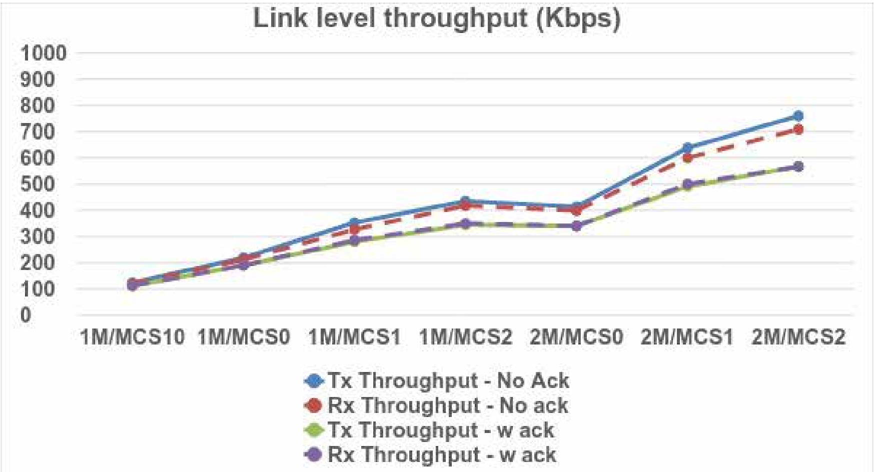

Fig. 4. 802.11ah link level performance.

For ER applications, 802.11ah provides whole-home coverage for voice and video-call applications. Users don't have to deal with dropped calls due to handoffs with multiple APs in a home or to a wireless WAN (wide-area network), and also benefit from improved voice quality. 802.11ah scheduled access and low-rate modes also enable significantly lower power consumption. Finally, the coexistence between these varieties of devices targeting IoT and ER applications has also been considered as an integral part of the IEEE 802.11ah design.

At the beginning of 2016, the Wi-Fi Alliance announced a new low-power Wi-Fi solution which is known as the Wi-

Fi HaLow™[3]. Wi-Fi HaLoW™ is based on IEEE 802.11ah technology. Through Wi-Fi HaLoW™, the Wi-Fi Alliance enables a variety of new power-efficient use cases in the Smart Home, connected car, and digital healthcare, as well as industrial, retail, agriculture, and Smart City environments.

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Yongho Seok received the B.S. in computer engineering from Handong University and the M.S. and Ph.D. in computer engineering from Seoul National University, in 2000, 2002, and 2005, respectively. From Oct. 2005 to Sep. 2006, he was a post-doctoral researcher with the PLANETE group, Inria, France. From Nov. 2006 to June 2014, he served as a delegate of LG Electronics for the IEEE 802.11 standardization meeting. During that period, he actively worked in TGac (very high throughput below 6GHz), TGaf (TV white space operation), and TGz (tunneled direct link setup), and received IEEE 802.11ac, IEEE 802.11af, and IEEE 802.11z outstanding contribution awards from IEEE-SA. Currently, he is serving as a MAC delegate for Newracom Inc. for the IEEE 802.11 standardization meeting. In TGax (high efficiency WLAN), he is actively leading the technical development for high-efficient MAC/PHY protocol design in a dense environment and researching the next generation Wi-Fi technology for various Wi-Fi applications (e.g., Wi-Fi aware and Wi-Fi positioning). Also in TGah (sub 1GHz), he serves as a task group chair and is contributing to a commercialization of Wi-Fi IoT (Internet of things).

IEEE Std. 802: Smart Cities, Smart Homes, Smart Cars, Smart Energy and Smart People

by Daniela Solomon and Janet L. Gbur

I. Introduction

IEEE standards play a role from smart cities to smart devices. Our standards drive "the functionality, capabilities and interoperability of a wide range of products and services that transform the way people live, work and communicate." [1] What does smart mean? There is no standard definition. In my opinion, the required functions include external environment sensing, internal processing, memory, data analysis, and external action and/or output. IEEE has standards covering all of these functions, but it is where these functions are distributed among different devices that IEEE standards for communications networks and their protocols become critical for interoperability and transmission of information between different devices and people.

Examples

For the infrastructure of smart cities, communications is key to:

- The management of utilities such as the smart grid as described in IEEE 2030-2011-IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), end-use applications, and loads;
- Education (within schools, remotely, and in MOOCs (massively open online courses));
- E-government between officials and citizens including access to open data;
- Telemedicine;
- Management of traffic and transit systems;
- Law enforcement.

For smart commercial buildings and factories, communications is key to:

- Business operations, energy management, and automated factory processes.

For smart homes, communications is key to:

- Energy management (e.g. for smart appliances) and connection of home entertainment and security systems.

For smart vehicles, communications is key to:

- Automated driver assistance systems (ADAS) (for safety or convenience), and receipt/transmission of information and entertainment.

For smart devices, communications is key to:

- Wearable health devices;
- Cell phones, tablets, etc.

Within the large set of IEEE communications standards, IEEE 802 standards are foundational to the applications mentioned previously, and provide connectivity for connected city infrastructure; connected commercial buildings; connected homes; connected vehicles; and connected people.

II. IEEE 802.3, IEEE 802.11, IEEE 802.15.4, and IEEE 802.15.1

Four of the most well-used IEEE 802 standards are IEEE 802.3, IEEE 802.11 (commonly referred to as WiFi), IEEE 802.15.4 (the basis for ZigBee), and IEEE 802.15.1 (based on the original Bluetooth specifications). The first is the Ethernet standard, of which the first version was approved over forty years ago. The second is the indoor and outdoor wireless local area network standard, which is ubiquitous in laptops, cell phones, and other personal devices, as well as in an increasing number of home and commercial building networked devices. The third, IEEE 802.15.4, was developed for low data-rate and low-power wireless personal area networks, and is expected to be an enabler for sensor networks and the Internet of Things (IoT). The fourth, IEEE 802.15.1, is the standard based on the original Bluetooth specifications 1.1 and 1.2, which provide short-range personal wireless connections for items such as headsets and printers.

IIa. Ethernet

- IEEE 802.3- 2015, IEEE Standard for Ethernet. Ethernet local area network operation is specified for selected speeds of operation from 1 Mb/s to 100 Gb/s using a common media access control (MAC) specification and management information base (MIB).
- One of the newest amendments to IEEE 802.3, IEEE 802.3bp for 1000Base T1, among numerous other applications, is also expected to provide video functions requiring high bandwidth for automotive Ethernet such as entertainment and ADAS.

IIb. IEEE 802.11 Series-Wireless LANs

- IEEE 802.11-2012, IEEE Standard for Information Technology. Telecommunications and information exchange between systems such as local and metropolitan area networks– Specific requirements- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications.
- For connected vehicles: IEEE 802.11p-2010, IEEE Standard for Information Technology-Local and metropolitan area networks-Specific requirements- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 6: Wireless Access in Vehicular Environments, was incorporated into the IEEE 802.11-2012 standard.

Beyond the existing 2.4 and 5 GHz bands, IEEE 802.11 is expanding into other wireless spectra depending on the need for higher throughput/bandwidth or extended range.

- IEEE 802.11ad-2012, IEEE Standard for Information Technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 3: Enhancements for very high throughput in the 60 GHz band.
- IEEE P 802.11ah, IEEE Draft Standard for Information Technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 2: Sub-1 GHz license exempt operation, useful for range extension such as for smart meters.

II.c IEEE 802.15.4-Low Data Rate Wireless PANs

- IEEE 802.15.4-2015, IEEE Standard for Low-Rate Wireless Personal Area Networks (WPANs) defines the "protocol and compatible interconnection for data communication devices using low-data-rate, low-power, and low-complexity short-range radio frequency (RF) transmissions in a wireless personal area network (WPAN)." One major application is used for home energy management. This forms the basis for a number of Zigbee standards. (In return, IEEE has published IEEE 2030.5-2013, which is based on the Zigbee smart energy profile 2.0 and may be used with IEEE 802.11 as well as IEEE 802.15.4.)

II.d IEEE 802.15.1-2005 IEEE Standard for Information Technology

- Local and metropolitan area networks-Specific requirements-Part 15.1a: Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs) incorporate Bluetooth specification 1.2.

III. Other Examples of IEEE 802 Standards

The IEEE 802.1 series of standards and standards projects under the IEEE 802.1 WG (working group) provides the 802 architecture and covers topics such as time sensitive networking, security, data center bridging, and OmniRAN.

For ubiquitous wireless connectivity, there are issues of how devices with different protocols in the same spectrum bands may coexist without interference. Here too, the IEEE 802 wireless standards groups take the lead. The IEEE 802.19 WG provides guidance standards for coexistence, and the IEEE 802.18 WG provides expert guidance on relevant national and international radio regulations.

For efficient use of radio spectrum, the IEEE 802.22 WG uses cognitive radio technology to determine, in real-time, available spectrum in specific geographic areas for wireless devices that could adjust to different bands. The IEEE 802.22 WG plans to take advantage of U.S. TV bands no longer in use by broadcasters, and similar technology is being considered for other spectrum bands and devices.

The following are examples of the IEEE 802.19 and IEEE 802.22 standards series:

- IEEE 802.19.1-2014, IEEE Standard for Information Technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements-Part 19: TV White Space Coexistence Methods, "radio technology independent methods for coexistence among dissimilar television band devices (TVBDs) and dissimilar or independently operated networks of TVBDs."
- IEEE 802.22-2011, IEEE Standard for Information Technology-Local and metropolitan area networks-Specific requirements-Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Bands.

For more information on IEEE 802 standards, the IEEE 802 LAN/MAN Standards Committee under the IEEE Computer Society encompasses the following topics, and the website includes links to the activities of its working and study groups.

IEEE 802 Working Groups and Study Groups

- 1 Higher Layer LAN Protocols Working Group
- 3 Ethernet Working Group
- 11 Wireless LAN Working Group
- 15 Wireless Personal Area Network (WPAN) Working Group
- 16 Broadband Wireless Access Working Group
- 18 Radio Regulatory TAG
- 19 Wireless Coexistence Working Group
- 21 Media Independent Handover Services Working Group
- 22 Wireless Regional Area Networks
- 24 Vertical Applications TAG
- 802 5G/IMT-2020 Standing Committee

Finally, through the sponsorship of the 802 LAN/MAN Standards Committee, the published standards noted here and many others are available for download at no charge through the IEEE Get Program.

Cherry Tom is Emerging Technologies Intelligence Manager for the IEEE Standards Association. In this role, she is seeking to establish IEEE communities in emerging technologies for standards and/or standards related projects. This involves collaboration with experts from other parts of IEEE, notably Technical Activities and IEEE societies, as well as organizations outside of IEEE including corporations, universities, government agencies, and consortia. Among current topics of interest are big data and artificial intelligence. Prior to joining IEEE, she worked for a large telecommunications company and a wireless startup where she managed standards and regulatory strategies and participated in U.S. and global standards developing organizations.

Globalization and Standardization

by Daniela Solomon and Janet L. Gbur

Prologue

In the spring of 2015, we decided to write an article on the relationship between globalization and standardization. Between us we have more than seven decades of experience in the world of globalization and standardization. Given the general understanding that standards control access to virtually every market in global commerce, and directly affect more than eighty percent of world trade, our basic conclusion is that the relationship between globalization and standardization is, or should be, a critical area of understanding for policy makers all over the world. To begin development of this article we sent invitations to substantially more than one hundred individuals and standards organizations who are expert in the field of globalization and standardization (academic, private sector, and public sectors) to submit their views and comments on this critical issue. To our surprise, only two standards organizations, the International Electrotechnical Commission (IEC) and DIN (the German national standards organization) accepted our invitation to submit comments. The conclusions from the IEC and DIN comments are set forth in this article. The complete IEC and DIN comments are set forth in their respective attachments to this article. These comments offer insights into the significance of the relationship between globalization and standardization. We encourage interested readers to review these comments.

Introduction

In his book The Lexus and the Olive Tree (1999), Thomas Friedman states that understanding globalization is one of the most important issues that must be understood by policymakers and executives all over the world. As stated by Mr. Friedman: Globalization is "The One Big Thing" people should focus on. Globalization is not the only thing influencing events in the world today, but to the extent there is a North Star and a worldwide shaping force, it is this system.

The purpose of this paper is to share some insights into the relationship between globalization and standardization, and to pose some issues relating to this issue for future thought and study.

Globalization

"Globalization is a process of interaction and integration among the people, companies, and governments of different nations, a process driven by international trade and investment and aided by information technology. This process has effects on the environment, on culture, on political systems, on economic development and prosperity, and on human physical we ll–being in societies around the world." (www.globalization101.org/what-is-globalization/) "Globalization is not new, though. For thousands of years, people—and, later, corporations— have been buying from and selling to each other in lands at great distances, such as through the famed Silk Road across Central Asia that connected China and Europe during the Middle Ages. Likewise, for centuries, people and corporations have invested in enterprises in other countries. In fact, many of the features of the current wave of globalization are similar to those prevailing before the outbreak of the First World War in 1914." (www.globalization101.org/what-is-globalization/) "A defining feature of globalization, therefore, is an international industrial and financial business structure. Technology has been the other principal driver of globalization. Advances in information technology, in particular, have dramatically transformed given all sorts of individual economic actors— consumers, investors, businesses—valuable new tools for identifying and pursuing economic opportunities, including faster and more informed analyses of economic trends around the world, easy transfers of assets, and collaboration with far-flung partners." (emphasis added) (www.globalization101.org/what-is-globalization/)

Standardization

"Standards govern the design, operation, manufacture, and use of nearly everything that mankind produces. There are standards to protect the environment and human health and safety, and to mediate commercial transactions. Other standards ensure that different products are compatible when hooked together. There are even standards of acceptable behavior within a society. Standards generally go unnoticed. They are mostly quiet, unseen forces, such as specifications, regulations, and protocols that ensure that things work properly, interactively, and responsibly. How standards come about is a mystery to most people should they even ponder the question." (From the foreword to Global Standards – Building Blocks for the Future, Report to Congress, Office of Technology Assessment).

Global Perspectives on the Strategic Value of Standards

For many years, it has been generally accepted that standards control access to markets. Consider, for example, the following statements. "The technology standard has become the source of a core competitive edge for industrial development. To some extent, a technology standard is a kind of development order and rule. Whoever controls the power of standard making and has its technology as the leading standard, commands the initiative of the market. Technology standards have become an important means of global economic competition, and directly influence the competitiveness of an industry, region or country. Therefore, as for Chinese enterprises, possessing the successful standard is a strategic choice to seize the leadership of the future industrial development." (Program, Conference on Information Technology, Beijing, China (May 2005); emphasis added) "Standards have become the new [international] battleground." (Phillip J. Bond, Undersecretary of Commerce for Technology Policy, New York Times article, "China Poses Trade Worry as It Gains in Technology," January 13, 2004; emphasis added)

Global Technology Base

Several years ago, the Institute for Electrical and Electronics Engineers (IEEE) estimated that 500,000 standards existed in the world that forms the technology foundation of the global marketplace. IEEE estimated that it costs at least $1.5 billion (US) annually to maintain these standards. Imagine a world in which the global marketplace will be significantly transformed by technological advancement in the next few years through the process of globalization, requiring the revision of thousands of existing standards and potentially affecting trillions of dollars (US) in international trade.

The Strategic Value of Technology Standards and International Trade

For several years, it has been generally accepted that technology standards directly affect at least eighty percent of international trade. For example, Joe Bhatia, President of the American National Standards Institute, estimated in 2011 that standards directly affected at least eighty percent of thirteen trillion dollars in international trade. (http://publicaa.ansi.org/sites/apdl/ Documents/ News%20and%20Publications/ Speeches/2-28-11%20 -%20Bhatia%20-%20 APEC%20Standards%20Education.pdf)

IEC and DIN Comments on Globalization and Standardization

IEC and DIN recently prepared comprehensive comments on Globalization and Standardization in response to our invitation. These comments are attached to this article. Set forth below are the conclusions from their respective comments.

IEC Conclusion

The global organization of trade and production is rapidly changing, especially in electrical and electronic goods. International manufacturing, trade, and investments are increasingly organized within global value chains where the different stages of the production process are located across different countries. (www.oecd.org/sti/ind/global- value-chains.htm). The emergence of these global value chains challenges traditional, integrated, vertical manufacturing. At the same time it provides new opportunities for small and medium companies in developed and developing countries. The key condition is that they work with universally accepted, harmonized rules—international standards—to be able to contribute efficiently at different points of the chain, while extracting maximum value for themselves and their national economies. For electronic and electric devices the world has truly become one market. (emphasis added)

DIN Conclusion

If "Economic 'globalization' is a historical process, the result of human innovation and technological progress… and the movement of knowledge (technology) across international borders," as the International Monetary Fund suggests, it is clear that international technical standards are at the very core of this process (International Monetary Fund, 2000, "Globalization: Threat or Opportunity?"). As standards play an important role in the diffusion of knowledge they not only support globalization, they also support the technological progress in developing and emerging markets. They can help businesses all around the world to reach a level playing field and get their share of economic success.

Issues to Think About

If standards control access to markets, and directly affect more than eighty percent of world trade, there are some important issues that should be considered by all parties in the world interested in global trade and economic development.

Global Competition and Control of the Global Standardization Process

Among the most important issues are global competition and who controls the global standardization process. This is a difficult issue to address because there is an absence of data on the effects of competition in the global standardization process. Moreover, since standards are typically developed by various groups or committees in the private and public sectors, it is difficult to discern who was sitting at the table during development of a particular standard, and whose interest did the participants represent. In short, global competition and control of the global standardization process operates in a rather cloudy environment. Should the global standardization process become much more transparent so that interested parties can more fully understand the potential competitive effects of particular standards, and exactly who are the interested parties developing a specific global standard?

Standardization Skills and Experience

The development of complex technology standards requires a multi-disciplinary set of skills and experience. Today's world is heavily dominated by engineering, science, and technology issues; however it is not sufficient to participate in a standardization project and depend on engineering, scientific, and/or technology skills alone. Effective participation in standardization projects requires a multi-disciplinary view that includes business, commerce, trade, and public policy issues such as health, safety, the environment, energy, sustainability, ethics, and potential legal risks. In short, participation in global standardization projects requires considerable preparation.

If success in the world of global standardization is of importance, development of multidisciplinary skills and a global perspective are essential to achieving success.

The Strategic Value of Standards Education

Prior to 2000, very little attention was paid to the role of standards education in the academic, private, and public sectors except for the role of On-The-Job Training (OJT) programs. Since 2000 there has been a virtual explosion of academic programs on the strategic value of standards education. At the present time, Asian countries such as South Korea, China, and Japan are leading the world in the establishment of university standards education programs. South Korea is estimated to have such programs at more than forty universities; China is estimated to have such programs at more than twenty universities; and Japan has at least twelve universities with standards education programs. China offers a master's degree in the Business School at Jailing University in which bright, talented graduate students can receive an MBA in Standardization.

Fortunately, the United States has made significant strides in recent years to substantially improve the standards education programs at various universities. For example, the National Institute of Standards and Technology has funded the creation of more than sixteen new standards education programs. The United States continues to rely heavily on the continued support of the private and public sectors that offer OJT and education programs.

In 2008, The Center for Global Standards Analysis published a report on The Strategic Value of Standards Education. In the Center's report, Professor Shiro Kurihara of Hitotsubashi University (Tokyo, Japan), offered the following comments on the need for standards education programs:

"The national economy of every nation depends upon its ability to develop and maintain an effective international standards system best suited to its needs. Given that standards are the essential building blocks by which every nation develops and maintains a competitive national economy, the challenge is to develop international standards education programs that meet the specific needs of a particular country in their private, public, and academic sectors. For decades, private corporations and government departments and agencies have carried the burden of standards education by preparing their best and brightest employees to work in the complex field of international standardization (in the form of "on the job" training). There is no question that international standards education programs offered by private corporations and government departments must be continued and expanded wherever possible. But in today's fast-paced and highly competitive world, are these efforts enough? A key question we must now address is whether nations need to make significant investments in creating academic opportunities for their best and brightest students to study the complex field of international standardization. (emphasis added)

Conclusion

The essential issue in the relationship between globalization and standardization is survival. The most basic question is whether individuals, companies, and governments are prepared to participate in the complex, multi-disciplinary world of global standardization. Consider the following proverb:

"Every morning in Africa, a gazelle wakes up. It knows it must run faster than the fastest lion or it will be killed… every morning a lion wakes up. It knows it must outrun the slowest gazelle or it will starve to death. It doesn't matter whether you are a lion or a gazelle…when the sun comes up, you'd better be running."

Competition in the field of global standardization can be brutal if an individual, company or government agency is not prepared. Are you prepared?

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IEEE Brings Standards Education to the Capstone Design Conference. . . Updated Edition

by Jennifer McClain

As reported in the last issue of this eMagazine, the IEEE Standards Education Committee (SEC) sponsored a workshop at the Capstone Design Conference at The Ohio State University on 6 June 2016. The Capstone Design Conference, held every two years, offers a forum for faculty, administrators, industry representatives, and students to share ideas about improving design-based capstone courses. Capstone courses, also referred to as senior design courses, are for undergraduate engineering students in their last year of study.

The *Workshop on Technical Standards and Consensus Building* had 20 enthusiastic attendees, all educators involved in teaching capstone design courses at their colleges and universities. The two-hour session involved an interactive consensus-building exercise in which attendees took on the roles of different members of a standards working group and were tasked with developing new technical standards. The workshop's aim was to demystify how standards are developed and used, and provide ideas on how capstone instructors can bring standards that students are likely to encounter in the workplace into classroom and design experiences.

Jim Olshefsky, Director, External Relations, ASTM International, experienced the workshop for the first time as one of the facilitators. He noted, "the workshop provided a unique opportunity for teaching students about the standards development process. Participants clearly recognized the powerful synergies and other expertise that can be attained through a consensus-building exercise focused on technical standards."

A survey of the attendees was also conducted at the end of the workshop. One of the questions asked, "How helpful do you think a game based on this workshop would be as a teaching tool for undergraduate engineering students?" Seventeen attendees indicated that it would be helpful or very helpful, with two attendees saying it would be somewhat helpful. Additional comments included: "The game was enlightening to the deliberation process." "The simulation was a good learning tool to understand the complex issues behind standards." "It was fun."

The Workshop's Objectives:

- To facilitate a better understanding of the importance of standards to industry and demonstrate the fundamentals of standards development.

- To provide specific ideas for using standards and standards development in capstone courses.
- To discuss new ways for meeting some key Accreditation Board for Engineering and Technology, Inc. (ABET) criteria, including:
  - ◇ an ability to function on multidisciplinary teams;
  - ◇ an understanding of professional and ethical responsibility;
  - ◇ the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
  - ◇ a recognition of the need for, and an ability to engage in, life-long learning;
  - ◇ a knowledge of contemporary issues.
- To provide information on new standards education tools.
- To enable a fuller understanding of the economic, political, and technical realities of standards development.
- To put participants into the role of a working group member and to enable a better appreciation and understanding of motivation and dynamics in that environment.

The Workshop's Outcomes

At the end of the workshop, participants will:

- Have a better understanding of the importance of standards to industry, and see industrial standards as catalysts for technological innovation and global market competition.
- Have specific ideas for how to incorporate new standards education tools into capstone coursework.
- Have a better understanding of how these tools can help meet certain ABET criteria.

Facilitators:

- James Irvine, Ph.D., Reader in the EEE Department at Strathclyde University, Glasgow, UK
- Jennifer McClain, Senior Manager, IEEE Standards Education & Business Development
- Susan Tatiner, Director, Standards Education Programs, IEEE Standards Association
- James P. Olshefsky, Director, External Relations, ASTM International

How to request an IEEE Standards Education Workshop

This consensus-building workshop is one of a few different types of workshops offered through IEEE Standards University. The workshop has been run many times over the past few years with mostly university undergraduate and graduate students in attendance. This was the first time the content was tailored specifically for educators who may want to use the exercise to teach about standards as part of their coursework.

The IEEE Standards Education Committee encourages anyone wishing to bring education about standards into their classroom to please contact us at j.mcclain@ieee.org. Workshops or speaking engagements can be arranged and tailored on a case-by-case basis.

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Jennifer began her career at the IEEE in 1997 as Associate Editor for IEEE Transactions on Plasma Science and IEEE Transactions on Magnetics. She spent eight years with the IEEE Standards Association editing standards, aiding working groups with the standards development process, and as the Managing Editor of the Standards Information Network, publishing handbooks and guides to help with the implementation and understanding of standards. Now with IEEE Educational Activities, she manages all functions related to the Standards Education Programs and Committee, and as part of the business development team develops opportunities for IEEE Educational Activities.

Jennifer holds a B.A. with History and English Majors from Western Michigan University, Kalamazoo, MI, and attended the Masters of Education in Social Studies program at West Chester University, West Chester, PA, obtaining a Pennsylvania Secondary Education Teaching Certificate in Social Studies.

MOOC Explores Innovation & Competition: Succeeding Through Global Standards

by Jennifer McClain

The first of its kind massive open online course (MOOC) to focus on technical standards and standards development ran successfully between 29 March 2016 and 13 May 2016. The course, *Innovation & Competition: Succeeding through Global Standards*, was delivered on the edX.org platform.

The course offered a practitioner's view of technical standards, and was geared to students and professionals in the fields of engineering, technology, computing, business, economics, and law—particularly those working in all facets of product planning, development, and support.

This course was designed to enable learners to better contribute to their organization and to advance their careers. Topics included:

- Different types of standards;
- How standards impact trade and innovation;
- How standards evolve;
- Why companies participate in standards development;
- How standards change to meet emerging needs;
- Strategic implications of standards;
- How standards apply to product design and planning;
- Conformity assessment, regulation, and intellectual property issues.

Who attended?

- Total enrollment was 2,974 students.
- The median age of those enrolled was 30.
- 43% of the students had college degrees and 37.7% had advanced degrees.
- 4% of the enrolled students were women.
- Students from 136 countries registered, with enrollments from India making up the largest percentage at 16%, followed by the US at 15%. Geographic area enrollment from Asia equaled 37%, from Europe 20%, North America 18%, Latin America and the Caribbean 11%, and Africa 8%.

Who were the instructors?

Jeffrey Strauss was the lead instructor for the course. He was aided by 17 guest lecturers who donated their time to the critical subject of technical standards. Representing academia, industry, and government, such a diverse group offered expertise in their individual fields, providing a wide breadth and depth of material for the students that was simply not available previously. This unique offering also greatly broadened the reach of standards education

content worldwide.

Jeffrey Strauss indicated that "preparing the MOOC took considerable time because it required engaging and coordinating multiple speakers (and we ultimately had an amazing range of speakers), and introducing standards in such a way that course users from multiple countries (136!), native languages, goals in taking the MOOC, and prior experience could understand and appreciate. I think we succeeded—and I learned a lot!"

Strauss further noted that leading a MOOC was very different from teaching a traditional face-to face course, "I cannot see the students to gauge fluctuation in their interest and understanding and any interaction between them. Seeing and responding to later posted comments was useful but far less satisfying. My presentations were filmed and fixed to allow people everywhere to view at their convenience, so I could not make my usual on-the-fly adjustments to improve them. We also could not do team exercises. Especially given cultural differences and distance, I also had to restrain my tendency to use jokes or even facial or idiomatic expressions and movement. Despite all this, it was a terrific experience. I am gratified at the overall positive response from users and from others who review and hear about the MOOC (which is surprisingly frequent in meetings around the world). It was also invaluable to interact with IEEE staff (who were incredible), the Standards Education Committee, and the great speakers as it came together. I look forward to the next time the MOOC is offered."

How can you take the course?

The course is now open for registrations and will begin on 27 September 2016. All six hours of content will be available on-demand so students can engage with the course at their convenience. Once again, it will be offered free of charge, with Certificates of Completion available for a small fee.

Funding for this course was provided by the IEEE Foundation Fund and the IEEE Life Members Fund.
Visit all IEEE sponsored MOOCs at IEEEx.org/.

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Funny Pages

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by Rick Jamison