The 6TiSCH Protocol Stack

Figure 1 shows the 6TiSCH protocol stack. It is composed of standards developed by the IEEE[1] and the IETF.[2] Together, these standards achieve IPv6-based end-to-end connectivity while meeting the determinism, robustness, and low-power operation required for battery-operated devices targeted at industrial process monitoring and control applications [1].

This section provides a brief introduction to each layer in the 6TiSCH stack — from the bottom up — highlighting the educational potential of each.

IEEE 802.15.4 defines the physical and data link layers for low-power wireless communication between battery-operated devices. It offers an appropriate trade-off between transmit power (0–10 dBm), data rate (250 kb/s), and maximum payload size (127 bytes). The new IEEE 802.15.4 TSCH mode is targeted at demanding industrial applications. TSCH combines network-wide synchronization and channel hopping to achieve over 99.999 percent end-to-end reliability and over a decade of battery lifetime.

TSCH is a basic but complete link layer protocol to teach students the basics of multiple channel access, frequency diversity, scheduling, and coexistence. It trades off throughput with packet error rate and delay by scheduling more or less redundant transmissions. Students can derive equations and perform simulations to learn how to do the performance analysis of TSCH-enabled networks of various sizes.

The IETF 6top Protocol (6P) [2] is being standardized by the 6TiSCH Working Group. It defines a distributed scheduling protocol whereby neighbor nodes negotiate to add/remove one or multiple cells in the TSCH schedule. Each cell is a "communication opportunity" for the neighbor nodes to exchange a link layer frame. Adding more cells increases the bandwidth and lowers the end-to-end latency, while at the same time increasing the nodes' power consumption.

6P is a simple protocol that allows students to not only see how the TSCH schedule is managed "down to the wire," but also touch on notions such as schedule consistency, network stability, and network churn.

IETF 6LoWPAN [3] allows long IPv6 packets (up to 1280 bytes) to fit into short IEEE 802.15.4 frames (at most 127 bytes). It is composed of two main mechanisms. First, it defines rules for compacting the IPv6 header. This is done by:

1. Removing fields that are not needed
2. Removing fields that always have the same contents
3. Compressing the IPv6 addresses by inferring them from link layer addresses

The result is that the 40-byte IPv6 header gets compacted down to a couple of bytes in the most favorable case. A low-power border router (LBR) sits at the edge of the low-power wireless network and is responsible for doing the transparent IPv6→6LoWPAN and 6LoWPAN→IPv6 translation: a computer outside the low-power wireless network interacts with a low-power wireless directly with its IPv6 address. Second, it defines fragmentation rules so that multiple IEEE 802.15.4 frames can make up one IPv6 packet.

6LoWPAN allows students to really understand every single bit in the IPv6 header and feel the power of the Internet. That is, once the devices implement 6LoWPAN correctly and the LBR is running, just by injecting a correctly formatted packet into the Internet, the tiny low-power wireless device sitting on the student's desk can interact with a computer halfway around the globe.

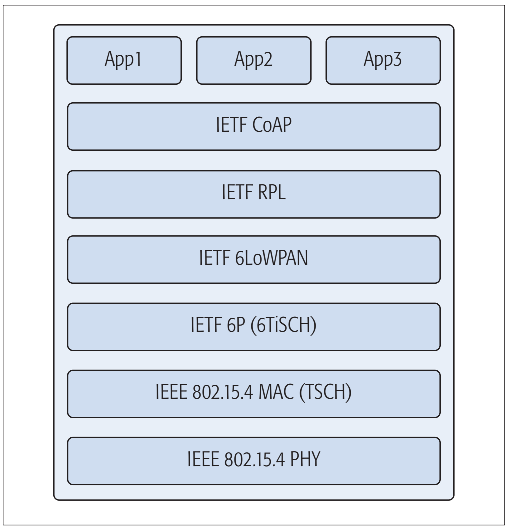

Figure 1. The IETF 6TiSCH protocol stack, composed of IEEE 802.15.4, IETF 6P, 6LoWPAN, RPL, and CoAP.

CoAP is not particularly complicated from a protocol point of view; it's header is 4 bytes long and it is "just" an application protocol. But by using this protocol, students can "put everything together" and really get that interacting with a 6TiSCH devices is just as easy as interacting with a web browser.

IETF RPL [4] is an intra-domain routing protocol for low-power wireless mesh networks. RPL organizes the network into a directed acyclic graph (DAG) rooted at a gateway device that connects to the Internet. As with other distance vector protocols, devices regularly advertise their distance to the root, allowing neighbors to compute their own.

Despite being "simple" (there are only two required packet formats), by playing with RPL students can understand the complexity of maintaining a coherent multihop routing structure in a network made up of "lossy" wireless links.

IETF Constrained Application Protocol (CoAP) [5] is the "HTTP for constrained devices." It turns every low-power wireless device into a web server and a browser, and allows web-like interactions. A constrained node can publish its sensor readings onto a server on the Internet, or a smartphone can operate smart blinds, all by using the communication paradigms of the Internet. Extensions to popular browsers and open-source libraries make adding CoAP support to an computer application easy.

CoAP is not particularly complicated from a protocol point of view; its header is 4 bytes long and it is "just" an application protocol. But by using this protocol, students can "put everything together" and really get that interacting with a 6TiSCH devicesis just as easy as interacting with a web browser. Moreover, thanks to standardization, there is no need to learn exotic protocols, as third party libraries and tools are readily available.

Success Stories and Relevance

The 6TiSCH stack did not come out of thin air; it is the result of a rigorous multi-year standardization effort. 6TiSCH is the latest generation of protocols exploiting TSCH technology, and inherits from the lessons learned from TSMP (2006, proprietary protocol), WirelessHART (2008), and ISA100.11a (2011).

[1] https://www.ieee.org/

[2] https://www.ietf.org/