Network Protocols

After this chapter you should be able to: label the protocol layers, PDU, SDU, peer layers and the flow of data through a protocol stack diagram; determine what data is seen by each layer of a protocol stack; determine which of the lowest four OSI protocol layers could provide a specific function; and decide if a network is a LAN or PAN.

Protocols

Protocols are rules that devices must follow to communicate. These rules are specified in interoperability standards published by various organizations.

Protocol Layers

Protocols are divided into layers, each providing specific services such as framing, error detection, encryption, routing, etc.

A layer is said to operate "on top of" a second one if it uses services provided by the lower one. For example a layer responsible for routing might use framing provided by a lower-level protocol.

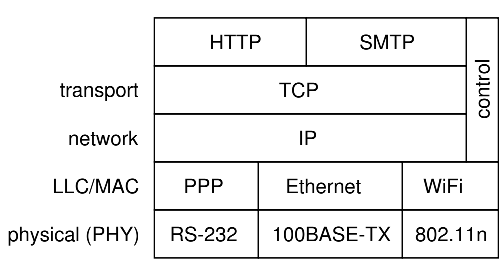
The division of functionality between layers and their naming is protocol-dependent. Some commonly-used terminology is described in the next section.

The main advantage of protocol layering is that one implementation of a protocol layer can be substituted for another without affecting the layers above it or below it.

For example, the TCP/IP protocol is able to operate over any lower-level protocol layer that provides framing. These include Ethernet, WiFi or PPP. However, TCP/IP can't run directly on top of a layer that does not provide framing, such as RS-232.

Protocol Stacks

Diagrams such as the following are often used to describe how protocols are layered on a device:

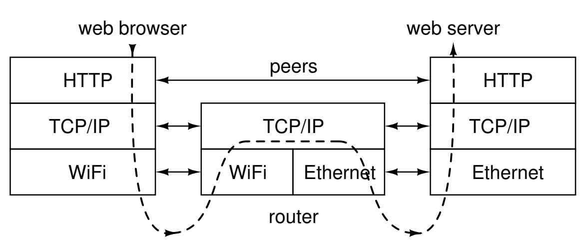


This "protocol stack" diagram for a hypothetical device shows two application-layer protocols: HTTP (HyperText Transfer Protocol, used to retrieve web pages) and SMTP (Simple Mail Transfer Protocol, used to send e-mail). Both of these run over (make use of) the TCP "transport-layer" protocol. TCP in turn runs over the IP "network layer" protocol. And on this device IP packets can be sent and received over any one of three different link-layer protocols: PPP (IETF RFC 1661), "Ethernet" (IEEE 802.3) or "WiFi" (IEEE 802.11). Each of these operates over a different physical-layer protocol (in this example it's RS-232, 100 Mb/s Ethernet over twisted-pair and the "802.11n" WiFi PHY).

Layering is sometimes violated for practical reasons. In the example above the application layer can interact directly with the WiFi PHY layer to control it. For example, to set the radio channel or the encryption key.

Peer Layers

The following figure shows how the protocol levels on several devices interact. On the device with the web client, data flows down through the protocol stack to the WiFi interface. Then on the router it flows back up to an IP layer for routing and then back down to an Ethernet PHY layer. At the web server, packets are received on the Ethernet PHY and flow up the protocol stack to the web server.



Two implementations of the same protocol at the same level are said to be "peers." In the above example the TCP/IP implementations on the client and server devices would be peers.

Implementation

Protocol layers can be implemented in hardware or software. Lower-layer protocols (PHY, MAC) are typically implemented in hardware while higher-layer protocols (routing, transport, and application) are typically implemented in software.

Interfaces between protocol layers are sometimes called SAPs (Service Access Points). Requests and responses passed over SAPs are abstractions and might refer to anything from a hardware signal (e.g. a "carrier detected" indication from the PHY) to a function defined in an API (e.g. a "send this frame" request to the LLC layer).

Exercise 1: Mark the location of these SAPs on the protocol stack diagram.

OSI Protocol Layers

The OSI[1] defined a model for network layers whose terminology is commonly used although the layering model isn't strictly followed. The lowest layers of the OSI model are:

Physical Layer is the lowest layer (layer 1). It defines physical features such as connectors, voltages, currents, waveforms, frequencies, modulation formats, line codes, bit orders, etc. An example of a physical layer is 10BASE-T which is the PHY used for 10 Mb/s Ethernet over twisted pair.

Data Link Layer is layer 2 of the OSI model. It is often considered to include two sub-layers, the **Logical Link Control** (LLC) layer and the **Medium Access Control** (MAC) layer, although both together are often called the "MAC" layer. The LLC layer is responsible for transferring frames between two devices that are connected – by a cable or wirelessly. The MAC is responsible for coordinating access to a shared medium. Data link layer functions include framing and often addressing within a LAN, error detection and flow control. The IEEE 802.3 "Ethernet" standard is a Layer 2 ("MAC") protocol which operates over various layer 1 "PHY" layers (e.g. 10BASE-T or 1000BASE-T).

Network Layer is layer 3 and is responsible for routing frames (typically called "packets" at this layer) between local area networks. Layer 3 networks consist of point-to-point links between LANs. Addresses are usually hierarchical to assist with routing between LANs. IP (Internet Protocol) is by far the most common Layer 3 protocol and can operate over many different Layer 2 protocols such as Ethernet, SONET, WiFi, etc.

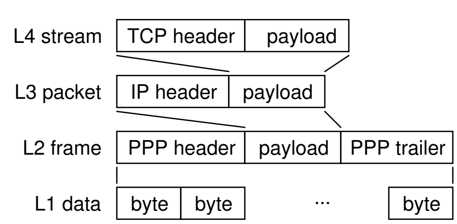
Transport Layer is layer 4 and is responsible for end-to-end transport of byte streams rather than individual packets. This layer needs to split up sequences of bytes into individual packets at the sender and reassemble them in the correct sequence at the receiver. This layer may also handle retransmissions and flow control. TCP is the most common transport protocol.

Certain functions, such as error control, may be performed at multiple layers. For example, a WLAN may include it's own retransmission protocol because errors are relatively common on wireless networks.

Exercise 2: What might be some drawbacks of relying on higher-level protocols for error detection and retransmission?

Encapsulation

The following diagram shows an example of how each layer "encapsulates" the data provided by the layer above it by adding a header and sometimes a trailer. The example is of a TCP connection running over an RS-232 PHY.



The data stream between two applications (e.g. a web browser and server) is broken up into individual packets and a TCP header is added to each one so that

[1] Open Systems Interconnect, a defunct group sponsored by the ISO and ITU. It defined complex protocols that were widely ignored in favour of the simpler TCP/IP protocols.

the packets can be reassembled in the right order at the destination.

An IP header is then added to each TCP packet to create an IP packet. The IP header contains the source and destination IP addresses so the packet can be routed to the correct destination.

A PPP header and trailer are then added to the IP packet so that the start and end of the frame can be determined.

Finally, each byte of the PPP frame is transmitted as a signal over a physical connection (for example, an RS-232 serial interface).

Headers are added and then removed as data flows down and back up a protocol stack and down the protocol stack. Thus each protocol layer only sees its type of packets. For example, the IP layer only deals with IP frames and IP headers. The IP protocol layer never sees the headers of the protocol layers below it and ignores the contents of the payload (the payload is said to be "opaque").

Exercise 3: What part of a packet does an IP router examine?

The type of people who call bytes "octets" also like to use acronyms and so they call a frame or packet a PDU (Protocol Data Unit) and they call a payload an SDU (Service Data Unit).

Exercise 4: Label the PDUs and SDUs in the diagram above.

Interoperability Standards Organizations

Here is a brief list of some organizations that promote telecommunications interoperability standards (sometimes called specifications):

IETF : The Internet Engineering Task Force publishes standards related to the Internet. Membership is open to all. It publishes RFCs (Request for Comments) which become de-facto standards if widely adopted. Popular examples include TCP/IP and HTTP.

IEEE : The Institute of Electrical and Electronics Engineers' standards group 802 (LAN/MAN standards) publishes LAN standards. Membership is open to anyone. IEEE 802 publishes standards after approval by voting (active) members. Popular IEEE standards include "Ethernet" (802.3) and "WiFi" (802.11).

ITU The International Telecommunications Union is part of the UN and is divided into the ITU-R (for wireless-related standards) and ITU-T (for others). Only countries are voting members. ITU primarily publishes standards related to communication that have international scope. Examples of its "Recommendations" include the V.90 56kb/s voice-band modem, and G.992 ADSL.

3GPP The 3G Partnership Project is an industry group that publishes digital cellular radio standards from the 2G GSM standard onwards. Popular examples include the 3G (UMTS) and 4G (LTE) cellular standards.

industry groups Companies often group together to develop and promote specific standards. Examples include the Bluetooth SIG (Special Interest Group) funded by Bluetooth equipment manufacturers and DOCSIS (Data over Cable Service Interface Specification) whose development is sponsored by cable operators.

Most of these organizations make their standards available for free. However, royalties must be paid to companies whose IP (Intellectual Property, typically patents) are required to implement the standard.

LAN, PAN, WAN

Local Area Networks (LANs) are networks that transfer data between devices that are with about 100 m of each other. Typically all of these devices are within one building and all are owned and controlled by one entity such as one company.

By analogy, the term Personal Area Network (PAN) refers to networks with a more limited range – often just a few meters around a person. PANs are often used to connect peripherals such as mice to computers or headsets to phones. The most common example is Bluetooth, a wireless PAN.

A Wide Area Network (WAN) is a network with wider span than a LAN, possibly thousands of km. WANs typically use fiber optic cables although a data network provided by cellular service provider is an example of a wireless WAN. Other -AN terms you may hear occasionally are MAN (Metropolitan), BAN (Body). The latter terms are not well-defined or widely used, although the networks may be.