The OSI reference model in communication processors

By Donald S. Taylor and Liviu Pinchas

The explosive growth of networking necessitated the standards bodies to develop a standard architecture and ensure interoperability between the vast array of hardware, software, and protocols, both public and private. The result was the Open Systems Interconnection Reference Model (OSI/RM), published in 1984. This communications architecture breaks the entire networking scenario into seven distinct, manageable functions, now accepted as the de-facto standard. It is vital for anyone working in the networking industry to have a solid, fundamental grasp of the OSI/RM for two reasons: 1) to understand the big picture of networking communications, and 2) to understand where one's product or service fits into the networking world. The purpose of this article is to introduce the seven OSI/RM layers in the context of communication processing. The Motorola MPC8260 is used as an example to illustrate how an integrated communication processor handles data in the context of the OSI/RM. Such topics as connection-oriented and connection-less communications and common networking terminology are discussed. Each of the seven layers of an OSI/RM are identified and illustrated.

Common terminology

The networking industry has an overabundant amount of terminology, acronyms, and jargon for people to remember. The following basic terms are useful to understand before we begin our discussion of the OSI/RM, as they are used repeatedly.

- Architecture — a set of layers, protocols, and interfaces that define how a system is constructed and define modularity to allow communication between modules, e.g., the company
- Layer — a hierarchically arranged grouping of related communication functions and services implemented with well defined interface and usage rules, extending across all systems that conform to the network architecture, e.g., the floors
- Protocol — the implementation rules and procedures by which layers interact to permit the orderly exchange of information within and across the network. Commands are sent horizontally (L2/System1 -> L2/System2), e.g., talk between departments
- Primitive — interactive commands that are sent vertically (e.g., L2/System1 -> L3/System1) through the architecture between a layer service user and layer service provider, e.g., talk to management
- Delimiting — discovering frames of information in the data stream

Making the connection

Table 1 shows some examples of connection-oriented and connection-less links:

	Connection-oriented	Connection-less
Reliable	voice/video pay-per-view movies	email, RPC, commands, alarms, distance learning
Unreliable	free internet long-distance, CUCME	spam

Table 1

Networking communications are often referred to as being either connection-oriented or connection-less. Connection-oriented implies handshaking, set up and tear down of communication necessary for streaming data, as with voice and video. The most well known example is the telephone system, after which connection-oriented communications are modeled. Connection-less implies "packetizing," or sending datagrams that may or may not arrive in order. The letter mail system (snail mail) is the original connection-less communication, after which connection-less communications are modeled. Each service is further characterized by Quality of Service (QoS). An in-depth study of QoS is beyond the scope of this article, so a simplified characterization is defined here as reliable or unreliable. The two current approaches to supplying more data are improving the QoS by making more efficient use of existing bandwidth and/or increasing the raw bandwidth.

The OSI/RM

The OSI/RM is an international standards effort of the International Organization for Standardization (ISO – 1983) and ITU-T (CCIT – 1984). Its purpose is to promote end-to-end compatibility between communicating subsystems, and it is a seven-layered communications architecture, not a protocol. The functionality of the OSI/RM layers is conceptual. It is the first major (and most successful) effort toward defining internationally standardized networking architecture. The goal is to make the layers big enough to minimize the amount of information passed between the interfaces, yet not so big that they are difficult to handle. The OSI/RM does not tell how particular protocols and services work in each layer; it defines precisely what they do.

The Big Picture

The 7 layers of the OSI/RM have distinct, independent responsibilities: (See Figure 1.)

- L7. Application
- L6. Presentation
- L5. Session
- L4. Transport
- L3. Network
- L2. Data Link
- L1. Physical

The configuration of layers in which a system is operating is determined by *the functions that the system is able to handle.* The reader can tell a certain amount about what is happening at each layer just by its name.

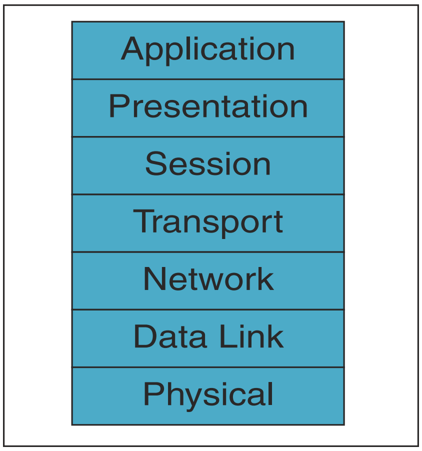

Figure 1

Characteristics of the OSI/RM:

- Each layer provides services, yet is oblivious, to how the adjacent layers work.
- All layers involve some form of error detection or correction.
- Known erroneous data are always discarded.
- Medium and user programs are not part of the OSI/RM.
- Protocols convey horizontal commands between peers through the architecture (e.g., TCP/IP).

Note: Primitives convey vertical commands through the architecture layers, e.g., upward error alarms.

Theory vs. the "real world"

Previous reference models had a varied number of layers. Seven layers were chosen for the OSI/RM, perhaps for political reasons. Still, the OSI Reference Model is a theoretical model that actual hardware systems and protocol suites routinely violate. Real implementations break the layer boundaries for various reasons, including the existence of legacy systems that predate the OSI/RM, and the omission of services for efficiency. Actual systems do not necessarily provide every service defined in the OSI/RM; yet, the OSI/RM establishes a well-defined ideal standard. It also provides the means to manageably divide and conquer the vast amount of networking requirements.

Three absolute rules of an OSI/RM

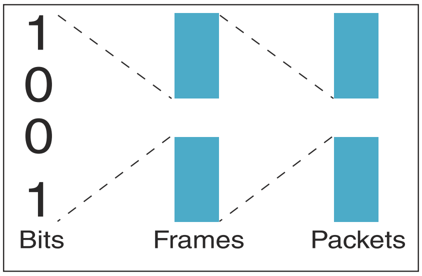

Figure 2

The unit is information defined for a particular layer and is referred to as the Protocol Data Unit. The overhead (Protocol Control Information) is stripped off and used by that layer. The remaining information (Service Data Unit) is the payload, which becomes the Protocol Data Unit for the next higher layer. (See Figure 3.)

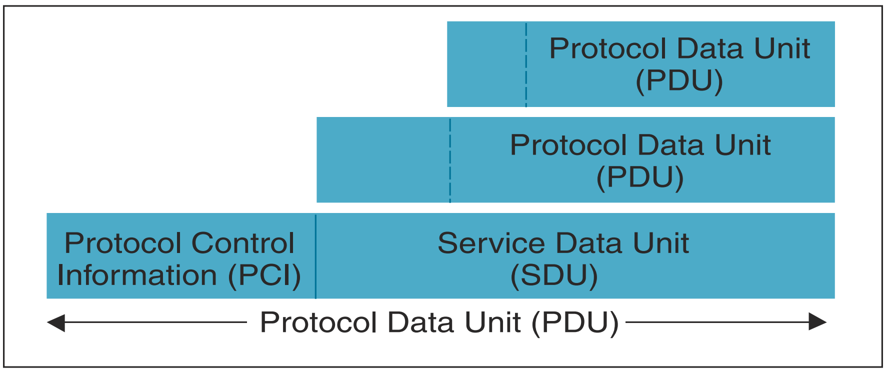

Figure 3

The end result is seamless communication from end-user to end-user. (See Figure 4.)

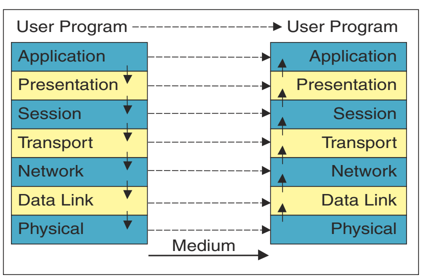

Figure 4

The three rules of the OSI/RM are:

1. No intermediate system (relays) can have protocols above Layer 3.
2. Each layer views the layer below it as the connection.
3. The software in a layer can only modify the protocol information for that layer.

Note: Rules 2 and 3 are implemented by encapsulation, which makes the architecture modular.

Lower level (networking) layers

The lower level (networking) layers function at intermediate nodes. Communications can switch between connection-oriented and connection-less up to and including Layer 3. This includes the bottom 3 OSI/RM layers (See Figure 5.)

- L1. Physical
- L2. Data Link
- L3. Network

L1 – L3 are implemented in hardware and/or software.

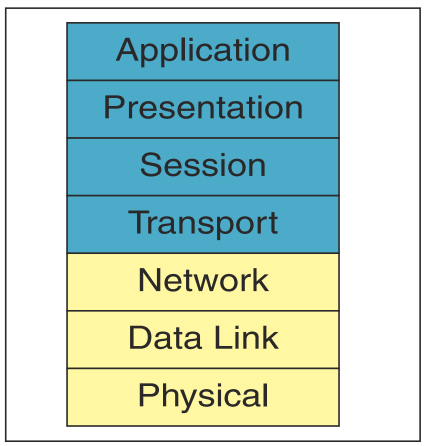

Figure 5

The OSI reference model in communication processors

Layer 1: Physical

The goal of Layer 1, the Physical Layer (see Figure 6), is to get bits (1's and 0's) from point A to point B with as few errors as possible in a single, simple, raw digital bit pipe. Units are measured in *bits (e.g.,* 1010001010…). The main points to consider are:

- Physical transmission medium to use
- Transmission rate in bits per second (BPS)
- How it is connected
- Full/half duplex

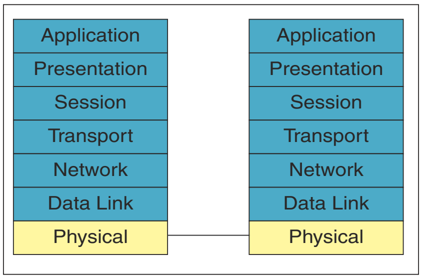

Figure 6

The Physical Layer is the realm of the engineers, physicists, and material scientists.

Layer 1 activity occurs whenever one detects 1's/0's, reshapes, retimes or channels bits (asynchronous operation). The Physical Layer serves to define the serial interface specifications:

- Functional — what the pins do
- Logical — what defines a 1 or 0, what the voltages mean (e.g., 1=5V and 0=0V)
- Electrical — the voltage levels for 1 and 0 (e.g., high=5V±10% and 0V±10%)
- Procedural — start/stop timing sequences, how a bit is registered (e.g., 8B/10B encoding)
- Mechanical — physical implementation, socket type, form factors, pin counts, etc.
- Bit Handling — check for errors in address field, non-autonomous routing

Common Physical Layer specifications include I.430/I.431, EIA232 and EIA422/423. Well-known hardware implementations are wire, cable, fiber, RF, and smoke signal. Layer 1 switching is often called Circuit Switching, which sets up a fixed connection such that every bit inserted into the input channel port exits the output channel port throughout the session (e.g., time division statistical multiplexers (TDM), concentrators, T1 channel banks, CO's. PBX's).

Layer 1: Repeaters

The repeater is the simplest Physical Layer networking device (see Figure 7). A repeater is defined as a device used to amplify or reshape signals to extend the distance of the transmission. The repeater cannot interpret the signals it repeats; it simply copies bits from hardware to hardware. A multipoint repeater is referred to as a dumb hub.

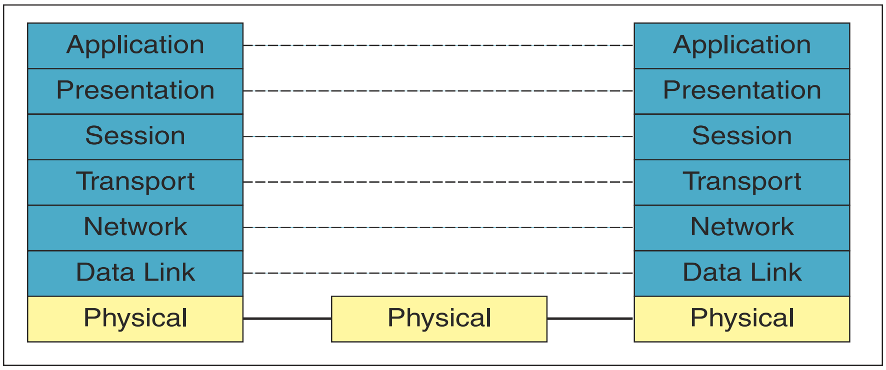

Figure 7

Layer 1: Data rates

Since the oldest networks originated in the telephone systems, many standard data transmission rates have their origins in multiples of the bit rates used to transport digitized voice channels (see Table 2). The point-to-point link data rate provided by POTS (Plain Old Telephone Service) is 64 BPS, defined as DS0. A T1 line consists of 24 DS0 lines. The data rates are further grouped as T3, T4, etc., in the United States and Japan, as shown in the table. Europe defines data rates in terms of E1, E3, etc.

Layer 1: SONET

SONET (Synchronous Optical Network) was introduced by Bellcore to make international internetworking possible. It provides a high-speed transport container, organized in 90 columns of octets x 9 rows. The Optical Carrier (OC) Rate and its electrical equivalent Synchronous Transport Signal (STS) are used interchangeably. The primary SONET rate, OC-1, is defined as 8000 frames/sec @ 810 bytes/frame (51.84 Mbps). All SONET rates are multiples of OC-1 (see Table 3).

Layer 2: Data link

The Data Link Layer is typically de-fined in units of *frames* (composed of bits), which include stop and start delimiters (see Figure 8). The Data Link Layer's goal is to convert a simple raw digital bit pipe into a single error-free, framed point-to-point digital bit pipe. The Data Link Layer functions include framing, error detection/correction, synchronous operation flag delimiting, management of delivery between adjacent nodes (every bit inserted into input appears at output), character synchronization, character-based protocols (BISYNC),

DS-0	64 kbps	Bipolar digital signal transmitted at level zero. A DS-0 channel is the basic pipe in the T1 digital transmission hierarchy and can be used for transporting one channel of digital pulse code modulated (PCM) voice.
T1 DS-1	1.544 Mbps	24 DS-0 channels
E1	2.044 Mbps	32 DS-0's, European Digital Signal 1 - 32 DS-0
T3 DS-3	44.736 Mbps	28 DS-1 channels (672 DS-0 channels)
E3	34.368 Mbps	16 E1 channels
T4 DS-4	274.176 Mbps	144 DS-1 channels (4032 DS-0 channels)

Table 2. Examples of standard data rates

OC-1	51.84	28
OC-3	155.52	84
OC-9	466.56	252
OC-12	622.08	336
OC-18	933.12	504
OC-24	1224.16	672
OC-36	1866.24	1008
OC-48	2488.32	1344
OC-192	9953.28	5374

Table 3. SONET rates

and sequence control. This layer also maintains management of messages transmitted out of sequence, flow control (speed up, slow down), access line control and arbitration (who talks next?), and addressing on single network (Internet addressed on L3). Common Data Link Layer protocols include HDLC, SDLC, LAPB, LAPD, PPP, BISYNC, ATM, UART, and PPP/SLIP.

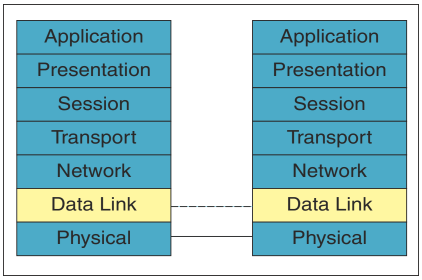

Figure 8

A Layer 2 bus switch is a digital multipoint circuit in which every bit inserted into the bus appears at *multiple* exit points (e.g., Ethernet, Frame Relay). Data is directed by address field in the frame through route and relay data links. The Data Link Layer establishes and releases the connection and provides framing, transparency, data transfer, alarms, monitoring of Layer 1, and controls or detects errors. It also provides sequence, flow, line, and time-out controls.

The Data Link Layer is further divided into two sublayers (IEEE 802):

1. Logical Link Control — This sublayer establishes reliable link control. It includes error detection and correction (CRC, checksums), flow control (sliding window), data transfer, and link management.
2. Media Access Control (MAC) — This sublayer establishes reliable sharing of transmission medium, including addressing, framing, and access control.

Layer 2: Bridges

The basic Layer 2 device is the bridge (see Figure 9), which is defined as a LAN station that relays frames of data between similar LAN segments (bus topology) or rings (ring topology). Bridges deliver messages based on the hardware or MAC (L2) address of the receiving station. Many bridges filter traffic and relay only messages intended for remote stations, rather than for all LAN traffic. Bridges convert L2 frame formats between intranetwork links. A multiport bridge is referred to as a hub. Layer 2 switching refers to traffic direction through hardware bridging.

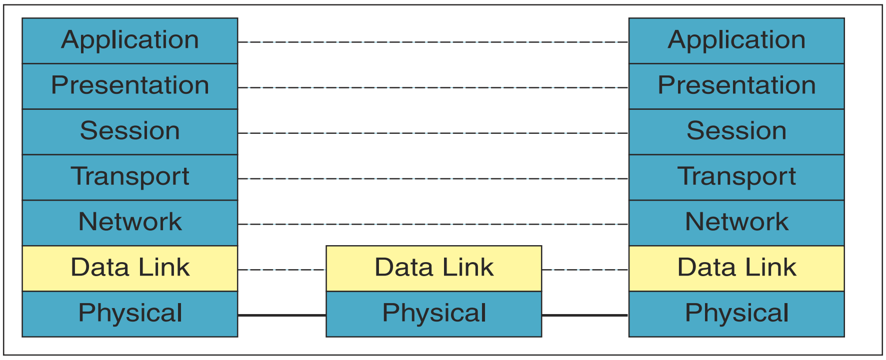

Figure 9

Layer 3: Network

Layer 3, or the Network Layer (see Figure 10), is often defined in units of *packets* (composed of frames). The goal of this layer is to convert single error-free, framed point-to-point digital bit pipes into a *chain* of simple digital data pipes. Network Layer functions include congestion control, receive and forward switching, and internetworking of heterogeneous network systems (with different vendor and address formats).

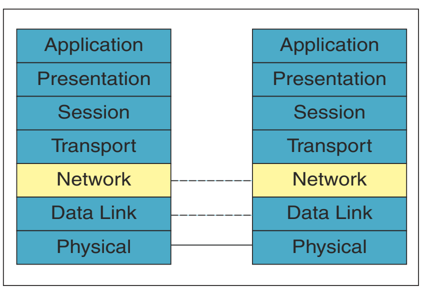

Figure 10

The Network Layer provides routing decisions (that route to take), and autonomous routing decisions that are made as data passes from node to node. The Network Layer must also handle packets lost, corrupted, and received out of order. Layer 3 tasks occur whenever autonomous routing decisions are made based on header information. Common Network Layer protocols include Internet Protocol (IP) and X.25 packet switching.

Internet protocol

The Transfer Control Protocol and Internet Protocol (TCP/IP) suite predates the OSI/RM, and is integrated; that is, the header of the Transport Layer (TCP) contains information about the Network Layer. Therefore, TCP and IP are inseparable and the suite violates the OSI/RM. Attempts to replace TCP/IP with OSI/RM conformal protocols have largely failed, and TCP/IP continues to prevail and proliferate. IP is a “best effort” delivery service. It does not detect or correct drops, data corruption, or sequencing errors; UDP or TCP are responsible for these functions. IP is connection-less, and there are typically no QoS services offered. Practically any medium that can deliver bits may utilize IP.

Layer 3: Routers

The basic Network Layer device is the router, defined as a station that connects different networks including LAN and WAN. (See Figure 11.) The router is not aware of a connection state. Its goal is to provide media-independent, dynamic packet fowarding and switching. Routers deliver messages to appropriate networks based on L3 addresses and protocols, such as IP. An IP router must have at least two IP-capable network interfaces, and pass data between networks according to routing tables contained in cache. Routing decisions are performed by software. Routers support connections spanning multiple (possibly autonomous) networks and may also perform repeater (L1) and bridging (L2) functions.

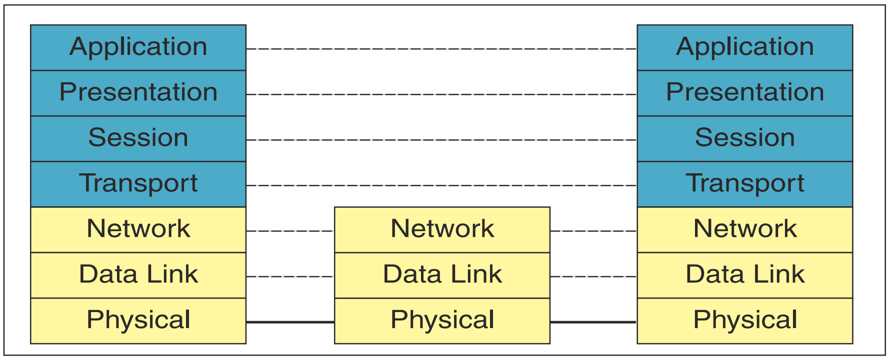

Figure 11

Layer 3: Switching

Layer 3 switching occurs when bridging (L2) and routing (L3) are combined into a single switch (see Figure 12).

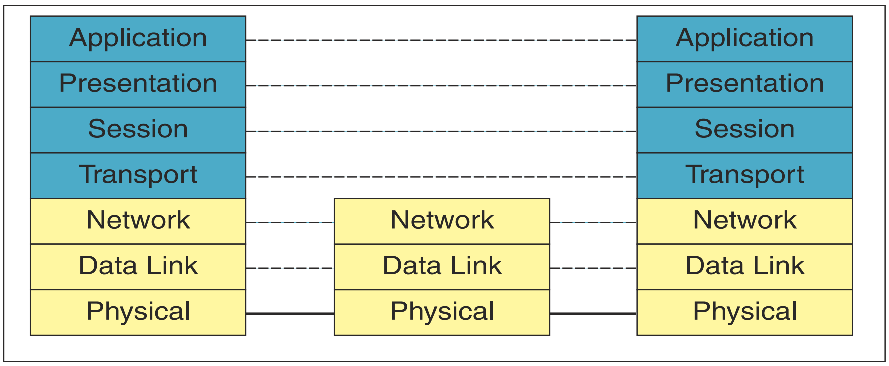

Figure 12

IP addressing decisions are performed by hardware (usually ASICs) for wire-speed routing. Layer 3 switching must support the most common routing protocols, such as OSPF and RIP.

Upper Layers: End-user teleprocessing layers

The four upper layers, including the Application, Presentation, Session, and Transport Layers of the OSI/RM are referred to as the end-user teleprocessing layers, and function at the end terminals (see Figure 13). Communications do not generally switch between connection-oriented and connection-less in the higher level layers.

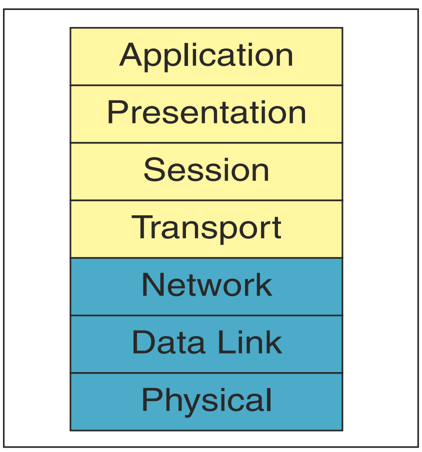

Figure 13

Layer 4: Transport

The Transport Layer is typically defined in units of segments or datagrams that are composed of packets (see Figure 14). Its goal is to convert a chain of simple digital data pipes into a chain of error-free pipes. It is ultimately the application-to-application connection. Transport Layer functions include splitting, multiplexing, end-to-end error control, sequence control, flow control, data service, and virtual circuit management. Splitting means breaking up large files to transmit over multiple circuits, and reassembling at the end destination. Conversely, multiplexing is the sharing of several separate transmissions over one circuit. End-to-end error control means the Transport Layer is the last chance for error detection. Sequence control is the handling of messages received out of sequence, and flow control handling of data that arrives faster than the receiver can handle. Data service defines datagram (connection-less) versus stream (connection-oriented) communication.

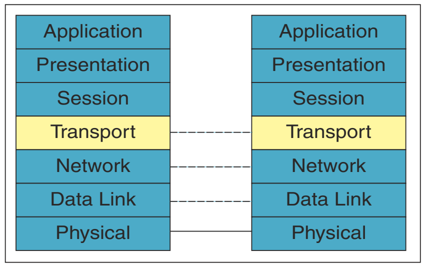

Figure 14

The most well known Transport Layer protocols are Transmission Control Protocol (TCP), which is connection-oriented, and User Datagram Protocol (UDP), which is connection-less. It is important to note that TCP/IP and UDP/IP suites are inseparable, which violates the OSI/RM. Considerations involving the Transport Layer include the network choice (FR, SMDS, ATM, etc.), depending on the amount of money the customer is willing to spend, bandwidth, speed, and availability requirements. UDP is a best-effort delivery service with message boundary; that is, messages are sent in self-contained datagrams. The benefits of UDP over TCP are lower overhead, and no requirement of acknowledgements, making it more suitable for broadcast and multicasting services. The drawbacks of UDP are error detection only (no correction), non-guaranteed sequencing, and no flow (end-to-end) or congestion (network) control. Alternatively, TCP is a reliable, connection-oriented transport protocol providing byte-oriented full-duplex stream delivery over IP. The buffering size is controlled by TCP, and the connection state only exists in the end stations, not in the routers. TCP offers reliability, in-sequence delivery, and flow and congestion control.

Layer 5: Session

Layer 5, the Session Layer (see Figure 15), typically expresses units as *mes-*

sages, as do Layers 6 and 7. Its goal is to set up and tear down connections between two applications. The Session Layer is sometimes referred to as a "controversial" layer, and its functions may better be defined in the Transport Layer. The Session Layer functions as interaction management, providing full and half-duplex communication (internationally referred to as Two-Way Simultaneous and Two-Way Alternate). The Session Layer is also responsible for checkpointing to format markers at intervals in the data stream to back up to the last mark if the network breaks, and for quarantining data to load all information into buffers before passing on. The Session Layer never processes a partial file.

The Session Layer provides the application's connection access and saves the machine state in case of a catastrophic event.

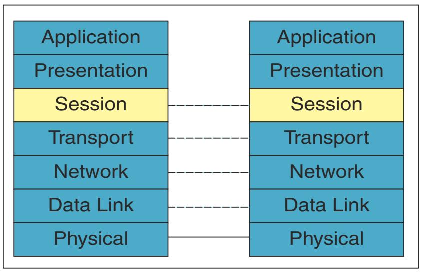

Figure 15

Layer 6: Presentation

The goal of Layer 6, or the Presentation Layer (see Figure 16), is to establish syntax (how data is represented) and semantics (what data means). Its functions include data character encoding (HEX, ASCII, EBCDIC), facsimile (fax) representation, image representation (.jpg, .bmp, etc.), encryption (security, cryptography, authentication), and compression. Conversion between heterogeneous formats (word size, endian-ness) is also performed in the Session Layer.

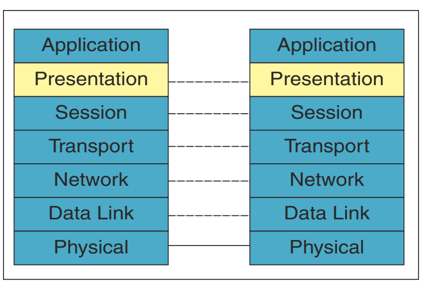

Figure 16

Layer 7: Application

The goal of Layer 7, the Application Layer (See Figure 17), is to provide seamless end-to-end communication, regardless of end or networking equipment or format (infrastructure). Its functions include:

- Availability — of networks, data, resources
- Authority — to communicate, establish an account, email, etc.
- Authentication — of budget, passwords, etc.
- Resource Adequacy — how long, much may use network
- Accounting — track costs
- Scheduling — when to use network, day/night rates
- Options — depends on amount of error tolerable (speech, data)

The Application Layer TCP/IP services include Hypertext Transfer Protocol (HTTP), Domain Name Service (DNS), Telnet, Networked File Service (NFS), File Transfer Protocol (FTP), Remote Procedure Call (RPC), Electronic mail (SMTP), and Point-of-Presence. The Application Layer OSI services include File Transfer, Access, and Management (FTAM), Virtual Terminal Protocol (VTP), and Common Management Information Protocol (CMIP). Layer 7 can be implemented in both hardware and software. A Layer 7 device is a gateway that provides L7 interconnection between heterogeneous applications, such as file servers and mail systems.

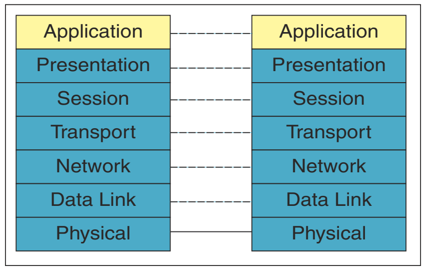

Figure 17

Implementation of the 7 layers in an OSI/RM

The implementation of the OSI/RM is illustrated here with the MPC8260 Integrated Communications Controller (see Figure 18). This is a versatile communications processor that integrates (on one chip):

- a PowerPC™ RISC microprocessor to run software that implements Layers 3 and above,
- a Communications Processor Module (CPM) to run microcode implementing some one or more sublayers of Layer 2,
- a flexible system interface unit (SIU), and
- communications peripheral controllers that can be used in communications and networking systems applications.

All functions of the 7 layers OSI/RM may be accomplished with this one

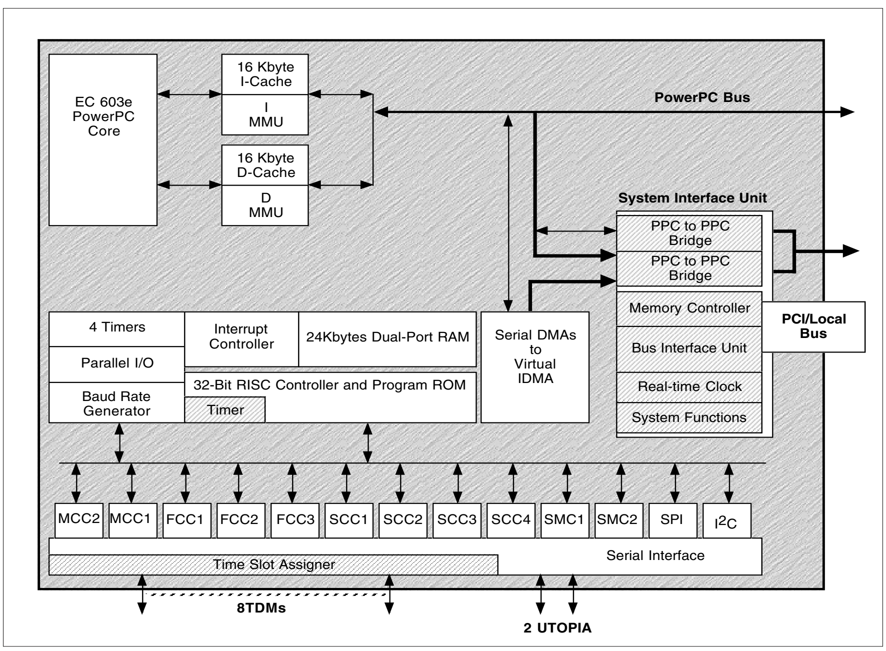

Figure 18

processor; therefore, methodology used here provides the reader with a framework to examine any networking or communications solution.

To complement all the communication resources and provide a true “System on a Chip” solution, an SIU was added to help interface glue-less many types of memory devices and peripherals. The SIU consists of a flexible memory controller that interfaces with almost any user-defined memory system and many other peripherals (hardware blocks that implement some of the Layer 1 and 2 sublayers of multiple protocols), making this device a complete system on a chip.

The CPM controls the communication peripherals and performs further tasks required by Layer 2 of the previously mentioned protocols. This function operates in time sharing, enabling one CPM to handle data provided by all the communication peripherals. The microcode that runs on the CPM is either stored in an on-chip ROM or can be downloaded during the chip initialization process in an internal RAM. This provides a great degree of flexibility in adding new protocols or modifying the protocols already implemented. To illustrate this, since the introduction of this device, special packages of microcode were created to support additional protocols as SS7 (Signaling System 7), CES (Circuit Emulation Service), AHDLC (Asynchronous HDLC) and IMA (Inverse Multiplex for ATM). All these protocols use the same communication peripherals released in the first revision of the device. The CPM simultaneously supports three fast serial communications controllers (FCCs), two multichannel controllers (MCCs), four serial communications controllers (SCCs), two serial management controllers (SMCs), one serial peripheral interface (SPI), and one I2C interface. The MCC can terminate up to 256 transparent SS7 or HDLC channels. The FCC (Fast Communication Controller) may transmit ATM (up to OC3 rates), Fast Ethernet, Transparent or HDLC protocols. The SCC can run a multitude of protocols including Ethernet, HDLC, AppleTalk, HDLC, UART, or Transparent. The SMC (Serial Management Controller) is used for UART and Transparent protocols. I2C (a 4-wire serial interface) and SPI (a 2-wire interface) are also provided.

A practical implementation of a data communication system based on the seven layers model is usually a combination of hardware and software, based on a best compromise between flexibility and speed. A hardware-based implementation is capable of providing the fastest data rates but is difficult to update to new emerging protocols. A software-based implementation provides a great flexibility (ability to change protocols by downloading new programs), however it is limited in speed by the processing speed of the processor(s) used.

Usually, the best compromise between flexibility and height data rates is achieved by implementing the lower layers of the model in hardware and the higher layers in software. The reason for this is the lower layers of the model require simple, but intensive, processing (the tasks are defined per bit or byte), while the higher levels of the model are implemented in much more complex tasks that require lower amounts of processing resources (the tasks are defined per frame/message/file/…).

The layer/sublayer where the hardware processing ends and the software processing starts is one of the important architectural decisions of an implementation. In order to optimize this transition and provide a significant level of programmability at hardware speeds, Motorola introduced a family of communication processors that includes a dedicated microprogrammed processing element placed at the hardware/software transition point.

This processing element (CPM) is optimized to run Layer 2 tasks for many standard protocols. It is programmable, therefore, protocols can be easily added or modified by downloading microcode packages. And it has enough processing resources to run these protocols at speeds usually achieved by hardware elements.

Taking into account the CPM, there are now 3 stages of data processing used to implement the 7 layers:

- Hardware processing for Layer 1
- CPM for some or all sublayers of Layer 2
- Software processing for Layers 3 and above

The CPM is further integrated with a general purpose core used to run software that implements the upper layers and dedicated hardware used to run some of the Layer 1 sublayers to reduce the number of devices necessary to implement a full data communication system. The communications industry has implemented this architecture, introduced 13 years ago, in several generations of communication controllers; the latest of which is MPC8260.

Typical applications include ADSL modems, DSLAM, ATM switching and administration solutions, multichannel modem, LAN switching and routing, SOHO router, telecom switching and administration, digital cross-connection, and multiplexing.

Example of PQII-based implementation of an L3 switch

Figure 19 is an example of a Fast Ethernet (LAN) to ATM (WAN) switch and illustrates the role of different PQII blocks.

The 100BaseT PHY interfaces the switch to the LAN connection and performs L1 adaptation. The data is delivered to the FCC1 which, in conjunction with the CPM, performs L2 adaptation and stores the Ethernet frames in the external memory. Optionally, a CAM can be used for MAC address recognition. The Core processes the frames (L3 adaptation) and creates AAL5 frames ready to be transmitted to the WAN interface. The AAL5 frames are retrieved from memory by the CPM which, in conjunction with FCC2, performs the L2 adaptation for the ATM connection

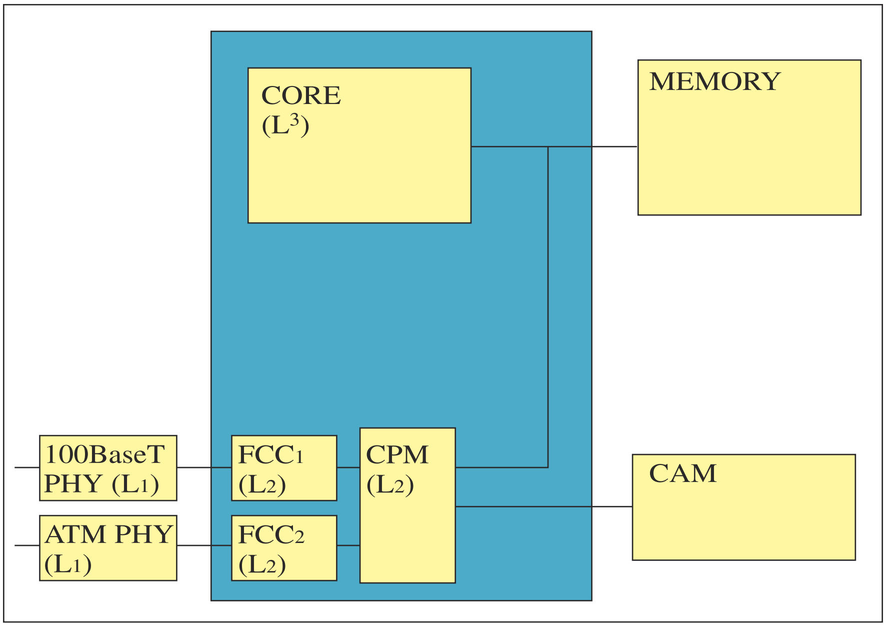

Figure 19

and segments the data in ATM cells that are transmitted to the ATM line using an ATM PHY.

In the opposite direction, the ATM PHY receives cells from the ATM line and performs L1 adaptation. Cells are transferred to FCC2 which, together with the FCC2, reassemble in AAL5 frames that are stored in the external memory. An optional CAM can be used to recognize the VPI/VCI of the incoming cells. The core processes the AAL5 frames and creates Ethernet frames that are forwarded to the CPM and FCC1 which perform the L2 adaptation and send the frames to the Ethernet PHY for L1 adaptation.
This process is only one of the many possibilities able to implement a switch using PQII. Some other WAN interfaces supported include T1/E1, T3/E3, Frame Relay, and ATM over T1/E1 (using the Inverse Multiples for ATM microcode). Others may be supported by new microcode packages that will be created.

Summary

In this paper we gave a brief overview of the 7 OSI/RM Layers:

- L1. Physical
- L2. Data Link
- L3. Network
- L4. Transport
- L5. Session
- L6. Presentation
- L7. Application

We also discussed some common terminology, data rates, and the devices used at the various layers (bridges, hubs, routers, switches, etc.). The objective of this article is to provide the reader a useful tool for putting vast networking terminology and hardware solutions into perspective. Furthermore, an example of a switch based on a Motorola PQII Communication Controller was detailed to illustrate an implementation of a device based on the OSI Reference Model.

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