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A Survey of Computer Network Communication Protocols and Reference Models

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ABSTRACT: *Importance of protocols to information communication from one entity (Computer, router, person, etc) to another cannot be over emphasized. In this explorative research we examine various definitions of protocols and their implication in a computer network where information in form of texts, images, videos and voices may need to be transmitted from one end to another. A comprehensive review of the fundamental functions of protocols and requirements for their implementation are discussed. Of particular interest is the relationship between the Open Systems Interconnection (OSI) model and protocols. It is stressed that the OSI reference model or any other reference model are not protocols but have strata of layers, each of which is implemented by defined protocols. A table that illustrates the functions of each of the seven layers of OSI reference model and the corresponding protocols for their implementation is presented. Data flow within the 7 layers of the OSI model is clearly depicted with illustration of the obvious increase/decrease of overhead as data flows from Application layer down to the physical layer and vice versa. In this work we establish the rationale for the overwhelming acceptability of TCP/IP reference model over the OSI model for computer network data communication..*

Keywords: *Data Flow, Entity, Layers, Overhead, OSI model, Protocols, TCP/IP model*

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I. INTRODUCTION

A communication protocol is a set of conventions governing the format and control of interaction among communicating functional units e.g. for system-on-chip memory, floating point arithmetic unit and similar components [1]. Park , et al [2] also defined protocol "as a set of rules governing the exchange of data between a transmitter and a receiver over a communication link or network". Simply put, a protocol is an agreed-upon or standardized method for transmitting data and/or establishment of communications between different devices.

Protocol definition and functions are summed up by Lloret_Mauri [3] here: "A network protocol can be formally defined as a set of rules, conventions and data structure which is used by network devices to communicate with each other across a network". The conventions or rules cover communication synchronization, semantics and syntax, packaging of data into messages to be transmitted and received at the other ends. It also involves means for identifying, controlling and making connections and transfer of data from one end to another.

Some of the concerns in network protocols include issue of fast data transmission, data security and error free delivery of data between two communicating entities. Protocols implementation is either one or combination of the following: firmware, software or hardware. Some of the essential functions performed by protocols according to Lloret_Mauri [3] are:

- Need for a common language for all the cooperative devices.
- Medium sharing with other devices.
- Modality for message starting and ending.
- Modality for message sending and receiving.
- Need to negotiate characteristics of various connections.

- Identification of medium for data transmission.
- Priority establishment and Encapsulation.
- Flow control, sequencing and handshaking.
- Termination of the session and/or connection.
- Multiplexing, Security and privacy, data compression and routing.
- Procedures on formatting and segmenting a message.
- Rectification of errors pertaining to wrongly formatted or corrupted.
- Prompt detection of loss of connection.
- Acknowledgement of message.

"In a sense, protocols are to communication what algorithms are to computation. An algorithm allows one to specify or understand a computation without knowing the details of a particular CPU instruction set. Similarly, a communication protocol allows one to specify or understand data communication without depending on detailed knowledge of a particular vendor's network hardware" [4]. Cherry [5] indirectly highlighted the importance of protocol to effective communication in his book, "On Human Communication" where he stated that "… to destroy communication completely, there must be no rules in common between transmitter and receiver – neither of alphabet nor of syntax".

As stated by Green [6] and Stallings [7] there are three elements in network protocols: a) syntax which is the commands' structure and responses in either character string or field-formatted form; b) semantics stands for the series of requests made, actions taken and the responses by the parties involved in the communication; c) timing specification for the events order (also called synchronization). Green continued that "the precise definition of functions that a computer network and its components should perform is its architecture. Exactly by what software code or hardware these functions are actually performed is the implementation, which is supposed to adhere to its architecture". Deduction from the foregoing is that there must be understandable protocol before two or more entities (persons, computers, etc) can communicate effectively together. Implication of this is that only persons, computers or equipment with only agreed or installed protocols could communicate together. This further means that only communication devices from same vendor would be able to communicate.

In order to make it possible for communication equipment from any source or vendor to communicate with any other in a computer network (i.e. interoperability), the International Standards Organisation (ISO) in 1978 developed an Open Systems of Interconnection (OSI) Model. With this development, communication equipment from any manufacturer that is compliant with the standard can be used interchangeably. Hence, major benefits of open systems of communication are broad availability of equipment, involvement of several vendors in manufacture, ease of integration with other components and reasonably low prices. OSI is primarily a structure for management of data communication that breaks data communications down into a hierarchy of manageable seven layers. The model framework clearly defines the functions or services that each of the seven layers provides [8].

Zimmermann [9], in his paper titled, "OSI Reference Model – The ISO Model of Architecture for Open Systems Interconnection" explained in details the OSI Reference standards in order to grasp its underlying principles. Prior to development of OSI model, TCP/IP Protocol architecture has been in existence and it is being still widely used for internet communication devices. Highlight of specific layers of each of the two models follows.

II. METHODOLOGY

The research approach adopted in this work is to consult various literature on the subject such as pertinent online and printed journals, text books and oral discussions with colleagues and lecturers on the subject. Using these resources, the following are deduced.

2.1 Open Systems of Interconnection (OSI) Model

The OSI consists of seven layers as shown in fig. 1 and illustrated along with expected functions of each layer in Table 1. As shown by the vertical bidirectional arrows in fig. 1, each layer renders specific layer to the layer above it and receive service from the layer below it. The horizontal bidirectional arrows that stretch from one side of the figure to the other represent the protocols required for packets/frames communication from the entities at one end with those at the others (Fig. 1.). Table 1 shows the services standards and the protocols interaction from one layer of an entity to the corresponding layer on the other entity. As stressed by Tanenbaum and Wetherall [10], while services relates to the interfaces between layers, protocols relate with packets sent between peer entities on different machine. In summary three concepts are central to OSI model: i) Services, ii) Interfaces and iii) Protocols.

A The Seven Layers of OSI Model

Starting from the bottom, the layers are briefly described as follows:

Physical Layer

This layer contains the standards that control data stream transmission over specific medium, at the level of modulation methods, coding, signal durations, voltages and frequencies. It is concerned with transmission of bits across the medium (communication channel) with ultimate end of ensuring that the transmitted and received that are the same. However due to the characteristic of most media, distortion or loss still remains a challenge (Fig. 1 and Table 1).

Data Link Layer

Here, the standards that specify the way the transmission medium is shared and access by devices (Media Access Control – MAC) in order to guarantee reliability of the physical connection, that is, the Logical Link Control (LLC). Its tasks are three-fold: a) masking of the transmission errors from other layers, b) regulating the traffic on the network such that congestion is minimized and c) control of access to the shared channel – Medium Access Control mentioned earlier.

The Network Layer

This layer comprises the standards that concern network connections management such as routing, terminating of connection between nodes and relaying (Table 1). Functions of this layer can be summarized into determination of how packets are routed from source to destination, handling of congestion in collaboration with the layers above and resolve of all network bottleneck that could hinder interconnection of heterogeneous networks. Routing problem are simple generally in broadcast networks, hence the network layer is either thin or completely absent.

Transport Layer

The layer contains standards necessary to ensure that data transfers are reliable, taking care of data flow control, recovering of errors and ensuring successful arrival of all data packets. Transport layer accepts data from the layer above it, split into smaller units if necessary, passes these to the layer below – the network layer and ensures that the pieces are safely delivered at the destination. The layer is responsible for error-free point-to-point channel transport connection that delivers bytes or messages in order of their transmission. While the transport layer as an end-to-end layer carries data through from source to destination, the lower layers below it each protocol is between an entity and its immediate neighbours and not between the source and the final destination that may be separated by several routers [10].

Session Layer

These standards manage the communication between the presentation layers of the source and the destination – the sending and receiving entities. Communication between the entities is achieved through the establishment, management and termination of the sessions. Among the services of session are control of dialog, management of tokens and synchronization.

The Presentation Layer

These are standards that control the translation of incoming and outgoing data from one presentation format to another. The layer's concern is the syntax and semantics of the information being transmitted.

The Application Layer

The Layer specifies standards for service provision to the application software such as checking resource availability, users' authentication, etc.

Most protocols used on the internet are contained in the application layers. Examples are HTTP (HyperText Transfer Protocol) – the backbone of World Wide Web, Network News, electronic mail and file transfer protocols (Table 1).

B OSI Model Message Passing and Headers

As depicted in fig. 2, the message emanates from the source computer and passes from the very top layer which is the application layer down to the lowest layer, the physical layer where it is transmitted through the physical medium. Along the path from the application layer, header is added to the message. Application layer adds AH (Application Header). This moves to the Presentation layer where PH (Presentation Header is added. At the session layer, SH (Session Header) is added. This followed by Transport Layer where TH (Transport Header) is added. At Network layer NH (Network Header) is attached, then Data Link Layer DH

(Data link Header) is attached. Only the Physical layer does not affix header. Deducible from fig. 2 are the following:

Table 1: The Seven Layers of the OSI Model

Layer	*Description*	*Standards and Protocols*
7 — Application layer	Standards to define the provision of services to applications — such as checking resource availability, authenticating users, etc.	HTTP, FTP, SNMP, POP3, SMTP
6 — Presentation layer	Standards to control the translation of incoming and outgoing data from one presentation format to another.	SSL
5 — Session layer	Standards to manage the communication between the presentation layers of the sending and receiving computers. This communication is achieved by establishing, managing and terminating "sessions".	ASAP, SMB
4 — Transport layer	Standards to ensure reliable completion of data transfers, covering error recovery, data flow control, etc. Makes sure all data packets have arrived.	TCP, UDP
3 — Network layer	Standards to define the management of network connections — routing, relaying and terminating connections between nodes in the network.	IPv4, IPv6, ARP
2 — Data link layer	Standards to specify the way in which devices access and share the transmission medium (known as Media Access Control or MAC) and to ensure reliability of the physical connection (known as Logical Link Control or LLC).	ARP Ethernet (IEEE 802.3), Wi-Fi (IEEE 802.11), Bluetooth (802.15.1)
1 — Physical layer	Standards to control transmission of the data stream over a particular medium, at the level of coding and modulation methods, voltages, signal durations and frequencies.	Ethernet, Wi-Fi, Bluetooth, WiMAX

Source: Rackley [11]

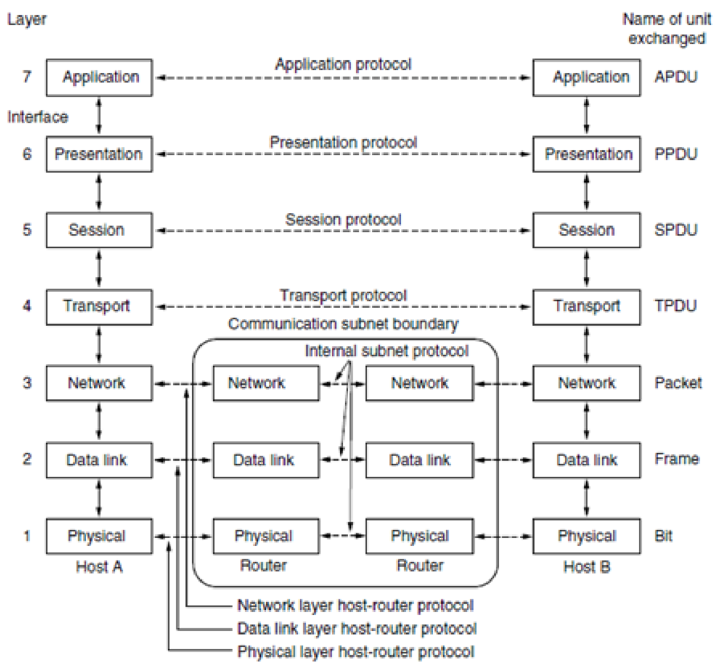

Fig. 1: The OSI Reference Model
Source: Tanenbaum and Wetheral [10]

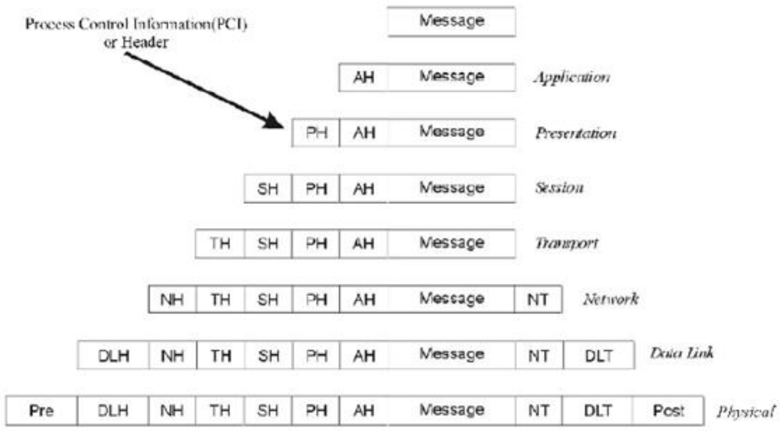

Fig: 2: OSI Message Passing
Source: Reynders and Wright [12]

1. The number of layers is directly proportional to the time it takes to traverse the entire layers from the Application layer to the Physical layer.
2. The control headers and tailers increase as the layer number increases so also is the overhead.
3. The larger the size of the control message and the message combined, the greater the medium bandwidth consumed. This in turn impacts on the network performance.

The TCP/IP Reference Model

TCP/IP Protocol Architecture, TCP/IP Protocol Suite or TCP/IP Reference Model are synonymous and refers to a large collection of protocols which have been published as Internet standards. The protocol suite is a result of research funded by U.S.A. Defense Advanced Research Projects Agency (DARPA) in early 70s. [7], [10].

The model as explained by Braden [13] is depicted in fig. 3. It comprises 4 layers. According to him, "a basic objective of the internet design is to tolerate a wide range of network characteristics – e.g. bandwidth, delay, packet loss, packet reordering and maximum packet size. Another objective is robustness against failure of individual networks, gateways and hosts using available bandwidth. Finally, the goal is full 'open system interconnection': an internet host must be able to interoperate robustly and effectively with any other internet host, across diverse Internet paths". The 4 layers and their functions are:

Application Layer

It is the top layer of the reference model. It combines the functions of the two top layers – Presentation and Application – of the OSI reference model.

Transport Layer

The layer provides communication services in end-to-end for the applications. The two protocols that currently implement the transport layer are Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). The former is a reliable connection-oriented transport service providing end-to-end reliable, re-sequencing and flow control. UDP is, however, connectionless transport service.

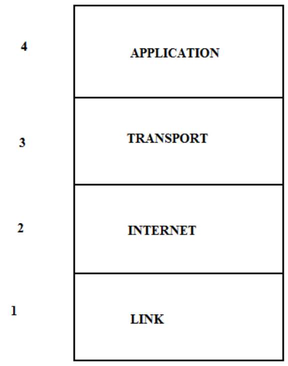

Fig: 3: TCP/IP Reference Model

Internet Layer

Internet Protocol (IP), implemented in this layer is used by all internet transport protocols to convey data from source host to destination host. As IP is connectionless, it does not an end-to-end delivery. Its datagrams might arrive at the host destination damaged, out of order, duplicated or not delivered at all. When reliable service delivery is required, the layer above IP is called upon. The protocol provides for service type specification, addressing, fragmentation and reassembly and security information. A basic characteristic feature of Internet Architecture is its connectionless nature.

Link Layer

A Link layer or media-access layer protocols are implemented by a host in order to communicate on the network directly connected to it. There are various types of link layer protocols according to different types of networks. Fig. 4 compares the OSI Reference Model with the TCP/IP reference Model. Differences are found in Presentation, Session and Physical layers that are in the former but absent in the latter. Fig. 5 is a more elaborate version of fig. 4, showing the various protocols being implemented on each layer of the TCP/IP protocol suite.

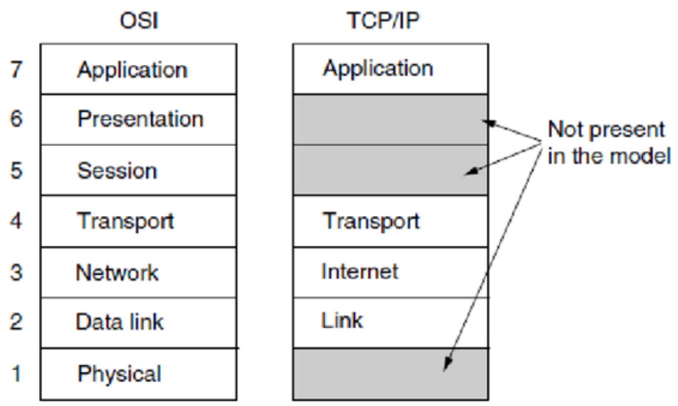

Fig. 4: The TCP/IP Reference Model compared with OSI Model
Source: Tanenbaum and Wetheral [10]

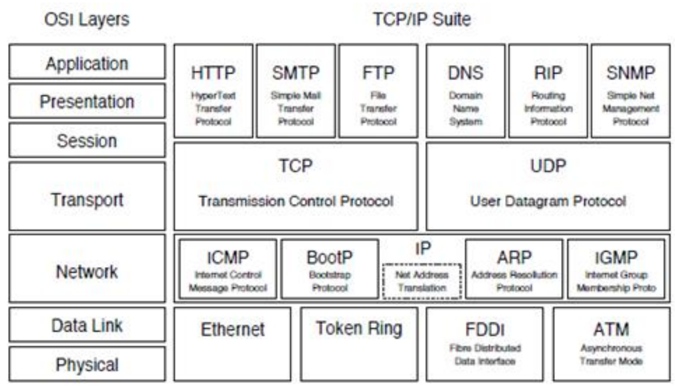

Fig.5: The TCP/IP Protocol Suite with the OSI reference model on the left for comparisons
Source: Cooper and Piumarta [14]

III. DISCUSSIONS

One of the major results of this research is the reinforcement of the significant role played by protocols in computer network which is summarized as "protocols are to communication what algorithms are to computation". This stresses the fact that as there cannot be useful computer programming without good algorithms in place, so also is protocols to communication. Its implementation may take any of three forms or its combination: firmware, software or hardware.

It is observed that there are more protocols for implementing the application layer than others. Examples of these protocols are HTTP, FTP, SNMP, POP3 and SMTP. This is followed by the link layer with examples of ARP, IEEE 802.3 and wireless (Table 1).

Also the following facts emerge:

a The number of layers is directly proportional to the time it takes to traverse the entire layers from the Application layer to the Physical layer.
b The control headers and tailers increase as the layer number increases so also is the overhead.
c The larger the size of the control message and the message combined, the greater the medium bandwidth consumed. This in turn impacts on the network performance.

As depicted in fig. 4 the TCP/IP reference model has only 4 layers as against the 7 layers of OSI model. This has the implication of lower overhead for TCP/IP in comparison with the OSI model. With these fewer number of layers it is still able to achieve two fundamental objectives of the internet design such as tolerance of network characteristics – e.g. packet loss, packet reordering, bandwidth, delay and network robustness against failure of hosts, individual networks and gateways.

IV. CONCLUSION

The significance of protocols, the need for reference models and the wide acceptability of the TCP/IP protocol suite over other reverence models has been established. This is so because of its application to the internet. While there are industrial process protocols such as Modibus and DNP 3 used in Supervisory Control and Data Acquisition (SCADA) with only three layers, these functionalities are limited to the process control, especially field devices.

How to reduce the number of layers in TCP/IP protocol suite so as to increase its efficiency further is an identified gap requiring the attention of researchers.

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