Computer Network Architecture and Software Engineering

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Abstract—**In this paper we use Software Engineering methods and Shannon's Communication Model to investigate computer network architecture. We get a new type of computer network architecture and some significant conclusions. At the first phase of the life cycle of Software Engineering, that is, requirement analysis, we get a series of unexpected conclusions. For example, a variety of computer network architectures could be established and evaluated. And the best architecture could be derived. What is more, protocol stack/ framework could be established and evaluated in order to satisfy special function demands. If the other phases of the life cycle of Software Engineering are executed, the end system and router (switches) in special OS environment could be achieved.**

Keywords- **Software Engineering, Communication Model, computer network architecture, protocol stack/ framework**

I. INTRODUCTION

Software Engineering theories, methods and tool kits were constructed at the end of the seventies of last century, which could be used to develop large-scale software. As computer network software is one kind of large-scale software, we used software engineering methods to develop computer network. Although the development of computer network in the past did not adopt Software Engineering methods, there are still a variety of networks such as TCP/IP、OSI、ATM、X.25 and frame relay that have been developed successfully and then rich experiences and lessons are accumulated. Nowadays TCP/IP has achieved great success and got a dominating status. As we all know, the Internet has already come into all walks of life around the world. So it is entirely feasible to use Software Engineering to develop large-scale software from scratch.

Requirement analysis phase in the development of other software will face a difficult situation, in which the users do not understand software and developers do not understand business. But those developers who use Software Engineering to do requirement analysis for computer network are researchers that are familiar with the network and software and have engaged in the network research for many years. Furthermore, the merits and demerits of TCP/IP are well known.

Shannon proposed Communication Model in the literature [1]. He presented that Communication Model is composed of five components including Information Source, Transmitter, Channel, Receiver and Destination. In another literature [2] of Shannon one pair of Information Source and Destination is expanded to two pairs in Communication Model. He investigated the efficiency of forwarded data in the network when there are two inputs at the same time in the channel. Based on Shannon's research, some scholars expanded the two pairs of Information Source and Destination into several pairs. They investigated the case that several customs send or receive data at the same time [3-7].

Network architecture is the most basal task in the research of network. It is very important to the performance and development of network. Some literatures [8-10] have made detailed analysis and definitions on network architecture. The literature [8] gives architectural principles of the Internet. The literature [9] suggests that network architecture is a set of high-level design principles that guide the technical design of the network, especially the engineering of its protocols and algorithms. The literature [10] investigated the philosophy, architecture, technical characters, outside properties and application history of Internet. In addition, the developing trend of the architecture and technologies of future Internet is discussed in this paper.

Nowadays the architecture of Internet does not satisfy the further development of Internet applications. As we have

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seen, it is impeding the development of Internet applications. So some scholars have investigated new network architectures. The main works include Object-Oriented Network Architecture framework [11-14], Role-based network Architecture [15], GENI project of America [16-18], FIND project and so on.

Using Software Engineering methods, we investigate Shannon's Communication Model and General Network Model in detail and get a new type of computer network architecture and a series of unexpected conclusions.

II. GENERAL NETWORK MODEL

In 1948, Shannon put forward the communication model in the literature [1] and established information theory using it. The correctness of the communication model has been proved by the development of thousands upon thousands of communication devices. In 1961 one pair of Information Source and Destination in Communication Model was expanded to two pairs in the communication model by Shannon. Later they are expanded to several pairs and Network Model is formed. Network Information Theory is established based on Network Model.

Validity of General Network Model has been proved by the extensive applications.

- General Network Model is used in wireless network. Wireless mobile communications originated in the 80s of the last century and now have entered the third generation.
- General Network Model is used in cable network, where the channel must have switches which could forward information to the appointed destination. Then telephone system (based on circuit switch), telegram system (based on message switch) and computer network system (based on packet switch) are some applications.

So we take General Network Model as the basis of requirement analysis when using Software Engineering methods to develop computer network system.

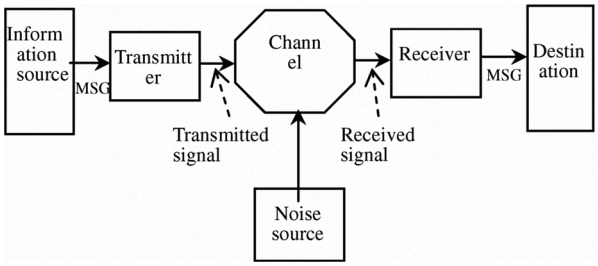

Figure 1. Communication Model of Shannon

Communication Model of Shannon is shown in Figure 1. Communication Model is composed of five components: Information Source, Transmitter, Channel, Receiver and Destination.

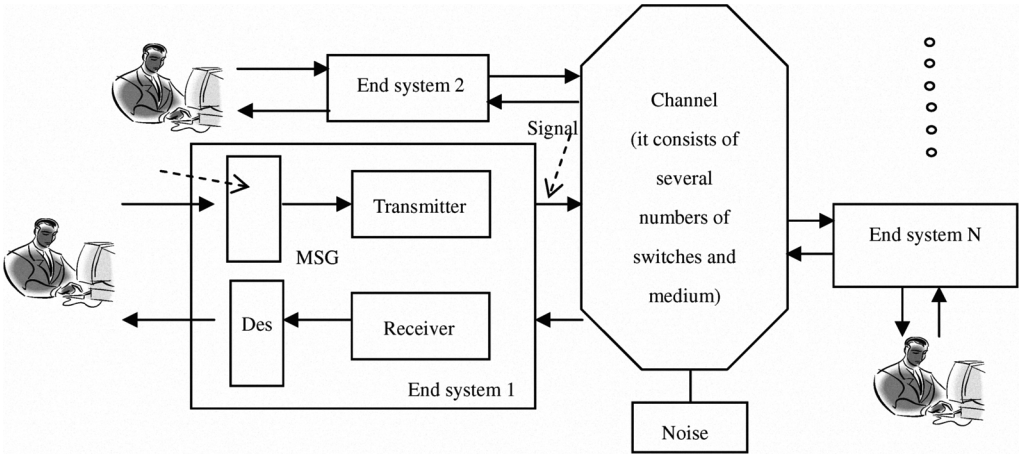

Figure 2. General Network Model

General Network Model is shown in Figure 2. The function descriptions of the components of Network Model are as follows:

- The function of Resource and Destination in General Network Model is as same as that of Communication Model of Shannon. But they are replaced by persons and the matters that are used by persons.
- The function of Transmitter and Receiver is as same as that of Communication Model of Shannon.
- Network Channel is constituted by medium and switches. There are several pairs of entrance and

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exit in the channel. The function of switch is to switch signals to the appointed exit. The telephone network, telegram network and computer network are based respectively on circuit switch, message switch and packet switch.

- The End System of telephone network, telegram network and computer network are respectively telephone, electrograph and computer.

III. GENERAL REQUIREMENT ANALYSIS OF COMPUTER NETWORK

Because terms between Communication Model of Shannon and Software Engineering are quite different and this paper mainly discusses communications and network problems, this paper uses terms of Communication Model of Shannon.

TABLE I. COMPARISONS OF KEY TERMS BETWEEN COMMUNICATION MODEL OF SHANNON AND SOFTWARE ENGINEERING

Communication Model of Shannon	Software Engineering terms
General Network Model figure	Data flow diagram
Input / out signal, the input / out message	Data flow
Explanation of a variety of signals and information in uplink	Data dictionary
component	process
components Description	Entry components
Tables including routing tables	documents

A. General Requirements of Computer Network

General requirements of computer network are as following:

1) Packet switch

Currently computer network adopts duplex packet switch. Packet is composed of header and content.

2) Intelligentized

Computer network provides customers operation system and permits them to write application software. Though other networks have many kinds of software, they don't permit customers to write software, except for developing system.

According to the general requirements described above we can get general model of computer network.

B. The Selection of Requirement Analysis Methods

Communication Model proposed by Shannon is actually the data flow diagram of Software Engineering, which emerged 30 years later because that: 1) It has time sequence, which includes Information source, Send converter, channel, receive converter and destination. 2) There are not only data but also control signal and they are all special realization of information. General Network Model that is expanded from Shannon's Communication Model is also a data flow diagram. If we take the models as data flow diagrams to do Structured Analysis (SA), the problems that usually emerge in general Structured Analysis will not emerge. We then adopt obvious, visual and easily-understood SA methods, which make it convenient to compare network architectures and protocols/schemes.

C. General Model of Computer Network

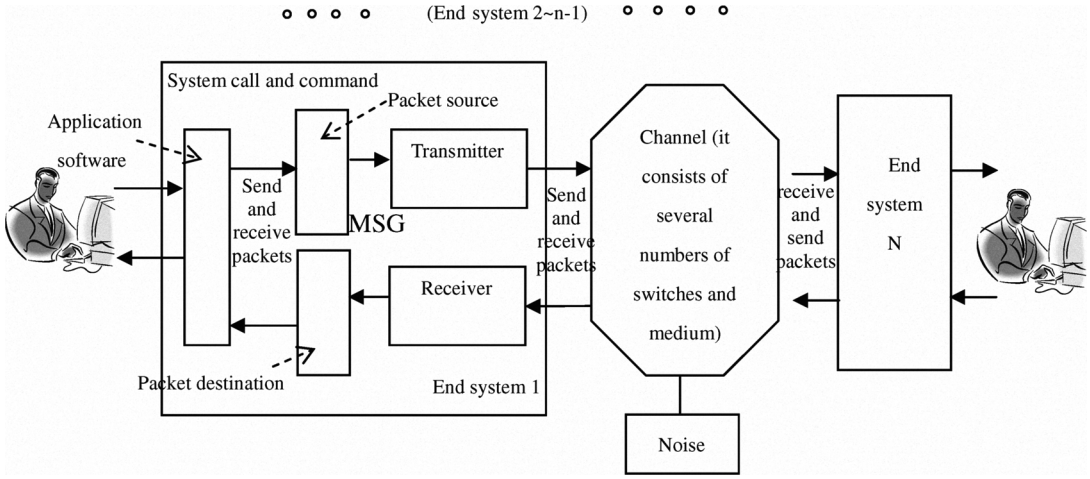

Figure 3. General Model of Computer Network

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General Model of Computer Network is shown as Figure 3. The function descriptions of the components are as follows:

1) Packet Source is the producer of message packets. It turns user's data into packets or produces control packets.

2) Send Converter is also known as the Transmitter. It turns message packets into signal packets that are suitable for transmission in the channel, NIC for instance.

3) Network Channel is composed by medium and routers (or switches) that are based on packet switching, similar to the telephone channel, which is composed by medium and program-controlled switches on a basis of circuit switching. Here noise drawn outside the channel refers to exterior interference, interior noise and distortion.

4) Receive Converter is also known as the Receiver. It receives packets which are infected by noise, interference and distortion transmitted by the channel and recovers the original message packets. The operation of it is contrary to that of send converter.

5) Packet Destination is the receiver of message packets. It receives packets and turns it into user's data or receives control packets and deal with them.

The actions of producing packets by a Packet Source and receiving packets by a Packet Destination are started by system calls or customer's commands.

D. Modularization of General Model of Computer Network

General Model of Computer Network could be decomposed as the top-level data flow diagram, which includes a lot of end systems and router/switch. Then two types of sub data flow diagram come into being, which include end system general data flow diagram and router/switch general data flow diagram.

E. End System General Model

End system general model is shown in Figure 4.

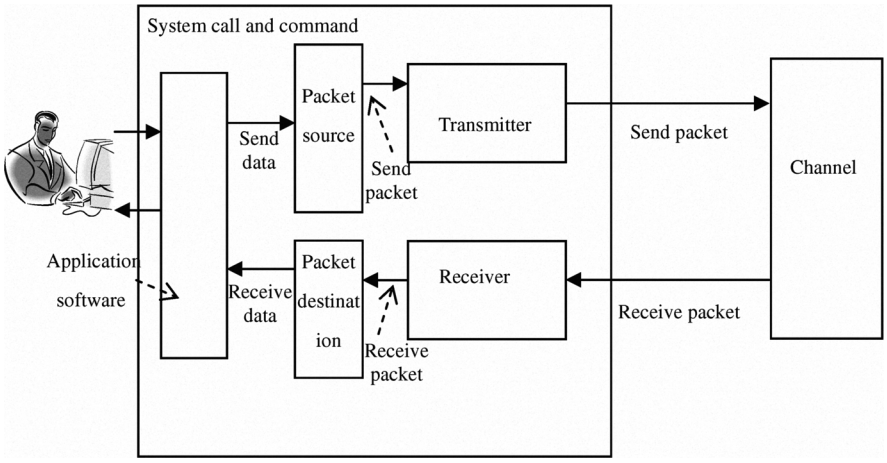

Figure 4. End system general model

F. Router/switch General Model

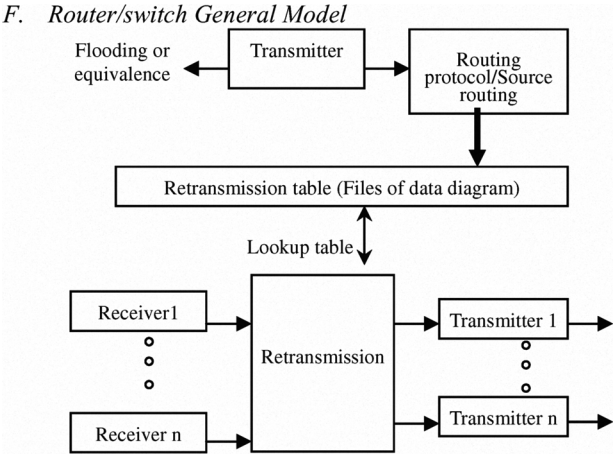

Figure 5. Router/switch general model

Router/switch General Model is shown in Figure 5.The function descriptions of router/switch are as follows:

1) The forwarding tables are produced by software.
2) Transmit packets according to forwarding tables. Router is composed by software and buses. The transmission function of switch is executed by switch matrixes.

In this model, we put Source Trees instead of Routing Tables in the routers. A Source Tree is denoted simply by the nodes and some pairs of brackets. Through this sequence, you can quickly and easily find the best paths. Compared with Routing Tables, Source Trees sequences occupy a small storage capacity. It is about a half of that of

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the Routing Tables. If considering the mask, it is about a quarter of that of the Routing Tables. While it contains much more messages than the Routing Tables. Furthermore, there is no necessary to transform Source Trees into Routing Tables.

There are two types of packet transmission manners: datagram transmitting manner and VC transmitting manner. A forwarding table of the former is called routing table. Take IP for example, it produces routing table by protocols of OSPF, RIP and BGP. When a packet needs to be transmitted, a switch (router) will search the routing table according to the destination address for the next hopping address and port by longest address prefix matching approach. Then the packet is enveloped by MAC. The forwarding table of VC transmitting manner is called VC table. For example, when a packet needs to be transmitted in ATM and MPLS network, the next hopping VC number and port number will be gained by searching VC table according to the VC number of the packet. Then the VC number of the packet is rewritten and the packet is transmitted to the next port.

G. Definition of Computer Network Architecture

Definition 1: Computer network architecture is defined as the precise description of a modularized computer network general model figure and functions of the models and relationship among models. This definition quite is similar to specification requirements of Software Engineering in the requirement phase.

According to this definition, models of layered network architecture are layers. The relationship of layers is that one layer receives the services of the lower layer and provides value-added services to the upper layer added with the functions owing to the layer itself.

Also according to this definition, we can see that the end system general model and router/switch general model and the functions of them and relationship among them obtained from modularization of computer network general model talked above is a type of computer network architecture. We called this network architecture as Shannon Architecture. The models include Packet Source, Packet Destination, Send/Receive Converter, Services Units used to switch packet and generate forwarding tables, which are called Services Unit for short. The relationship among Services is Service Combination, which could provide packet communication services.

Service Unit Based Network Architecture (SUNA for short) that we proposed fourteen years ago is quite similar to Shannon Architecture. The only difference is that we decompose the Send Converter model into encrypt model, compress model and digital signature model and the Receive Converter model into decrypt model, decompress model and Certification model respectively.

IV. SPECIAL REQUIREMENT ANALYSIS ON COMPUTER NETWORK

Special requirements on computer network include security, Qos, invulnerability, moving computing and depletion extent of address, etc. Currently there arise a lot of researches of new types of network architecture, including GENI of America and 973 and 863 projects of China. The reason of these researches is that TCP/IP protocol stack of current Internet could not satisfy these special requests talked above. The aim of setting off the researches is to establish a new network that could satisfy all the special requests talked above.

Originally the requirements of TCP/IP were forwarding text data stream and isolated data. Security was not considered at all. Now the network academia has reached a consensus that TCP/IP is an insecure network and could not guarantee Qos. It could only provide best effort service.

"Guarantee Qos" refers to not only guarantee Qos of transmitted text data stream and isolated data but also guarantee Qos of real-time data.

A. Key Mechanisms of Computer Network

These key mechanisms are:

1) Packet switch manner

There are two packet switch manners: datagram manner, which is difficult to reserve resources and VC manner, which is easy to reserve resources.

2) Congestion control method

There are two congestion control methods: closed-loop (traffic shaping) and open-loop (gap shaping).

3) Department of node identification and address

There are two situations: node identification and address are used together and identification is independent from address. An address could be (Network number, Hosts number) structured and could be no structured.

4) Type of topology

There are two types of topology: bus based topology and

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point to point based topology.

There could be many types of combination by various key mechanisms. But the most common combinations are as follows:

1) Combination 1: datagram packet switch manner, closed-loop congestion control method, structured address in end system and router and bus based topology. This is the combination of TCP/IP and could not satisfy the special requirements mentioned above.

2) Combination 2: VC packet switch manner, reserving resources, open-loop congestion control method, unstructured address based on position in router, identification independent from positioning end system and point to point based topology. This combination could satisfy the special requirements mentioned above.

B. Protocol Sstack/framework of Computer Network

Definition 2: Protocol stack/framework is the result of analyzing the special requirements of computer network such as security, Qos, invulnerability and moving computing. It determines the key mechanisms of computer network. The modularized special model of computer network is derived from the modularized general model of computer network and the key mechanisms. Protocol stack/framework is the modularized special model of computer network plus corresponding descriptions. In layered computer network architecture it is called Protocol stack. In non-layered computer network architecture it is called framework.

Protocol stack/framework with Combination 1 of key mechanisms could satisfy the special requests mentioned above, such as TCP/IP. Protocol stack/framework with Combination 2 of key mechanisms could not satisfy or could not well satisfy the special requests mentioned above, which is a necessary protocol stack/framework in nowadays.

We can see from above that there not mechanisms or function units that map functions one by one. And satisfying special function requirements could not be realized by assembly or self-assembly. So the viewpoints of SILO and Object-oriented Architecture are open to question.

C. Model of Protocol Sack/framework

General Computer Network Model is the model of computer network architecture, which denotes the communication process of each packet. Special Computer Network Model is protocol stack/framework, which denotes the communication process of all kinds of data flow and isolated data sets.

For layered architecture, layer count must be specified in protocol stack model. For example, OSI has seven-layered reference model and TCP/IP has four-layered reference model. For non-layered architecture such as Shannon Architecture and SUNA, framework must specify the structure of send/receive converter and whether there are encrypt/decrypt, compress /decompress and signature/Certification mechanisms. Protocol stack/framework model is different from architecture model in that the forwarding table model of switch/router should be routing table or VC table. VC table should be established by source routing and routing table should be generated by routing protocol.

D. Analysis Model of Protocol Stack/framework Using Software Engineering

According to SA, routing/switch Model of protocol stack/framework is a typical transform-based data flow diagram and end system model is a typical transactional data flow diagram. There are mature approaches in SA to transform data flow diagram into process diagram. So we can process them.

Perhaps someone will ask why there are no “documents” in network model that exit in data flow diagram. Actually, routing table and VC table are “documents”. If we use “documents” and “processing” described in determine table to count the number of packages, we can do test and Network Management Agent in the network itself, but not in application layer, which could improve the efficiency. This is consistent with the view of GENI and corrects the mistake that applications do the tasks that should be done by network.

According to Software Engineering, all kinds of affairs are input into network from applications. For example, in connection establishing phase, the source sends a packet of the first handshake, the destination sends a packet of the second handshake and the source sends a packet of the third handshake. In another word, a system call corresponds to a kind of affair. A data flow corresponds to several system calls. If a data flow could correspond to a macro system calls, it will be more efficient and there are only three kinds of affairs, including isolated data sets, text data flow and

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real time data flow.

E. Rapid Prototyping Method

Because SA uses data flow diagram which could not run and tryout, we use rapid prototyping method to assist.

SUNA is quite like Shannon Architecture. If the Send Converter and the Receive Converter are respectively simplified as NIC in and NIC out, the SUNA is as the same as Shannon Architecture. We have developed the prototype of SUNA in the Linux environment.

This prototype has been tested by the third-party, in which the common software of TCP/IP such as FTP, E-mail, Web and IP phone could run.

V. Evaluation of Computer Network Architecture

Modularized General Computer Network Model is the model of computer network architecture, which expresses the communication process of each packet and it is an objective abstract. Modularization is the subjective express. The merits of the architecture depend on the quality of modularization.

There are detailed discussions on modularization in Software Engineering. The principle of division of modules in Software Engineering is that cohesion in one module is as much as possible and cohesion among modules is as little as possible. According to the principle, modules are divided into eight types, in which the best is Functional Module and the best is Contingency Module.

In Layered Architecture there are check, layer-address, layer-PRI and version number in each layer. So the modules in it are Contingency Modules. The interfaces between layers are complex and it is not in accordance with the principle of division of modules.

The modules in Shannon Architecture and SUNA are Functional Modules. One module completes one function and the interfaces between modules are packets. This is well in accordance with the principle of division of modules.

The targets of architecture include: Accuracy, completeness, efficiency, easy development, function scalability, understandability and precise meaning, etc.

VI. Evaluation of Protocol Stack/Framework

The merits of the protocol stack/framework depend on the functions of computer network, which include Qos, security, invulnerability, moving computing, etc. The most important protocol stack/frameworks are the two ones that respectively correspond to the two combinations of key mechanisms mentioned above.

We can see that the work in this paper could not only be used to evaluate the quality of computer network architectures but also be used to evaluate the quality of protocol stack/framework.

VII. The Shortages of Layered Architecture

A. Functional Redundancy of Layered Architecture

Functional redundancy of layered architecture of all kinds of protocol stacks is described as following:

1) The redundant check coding and decoding of different layers could not strengthen check ability. It is as same as the check ability of the strongest layer.
2) The repeated addresses of different layers. In fact there are only interface address and port address. The redundant overhead of ARP and RARP protocol is caused by the case that MAC address and IP address are all interface addresses.
3) If the PRI and classification of different layers are same, it will cause redundancy. Otherwise, it will cause confusion.
4) Multiple layers cause the overhead of repeated cutting. The identifications of different layers are redundant too.
5) The total length of headers of all the layers is too long, which reduces the efficiency. For example, In TCP/IP, if the options of TCP layer and IP layer and the filled bytes of Ethernet are not considered, the total length of headers of all the layers is 58 bytes.

B. Redundancy of the Model of Traditional Layered Architecture

Not only the function but also the model of traditional layered architecture is redundant. Generally OSI is thought as the most rigorous model of layered architecture. It includes data transmitting model and value-added service model between layers. But in Shannon general network model, Shannon Architecture and SUNA, there is only one model, which is an abstraction of all the information. In fact, the argument "A layer could receive the services form the lower layer and provide value-added services to the upper layer" is not correct in common situation. For example, a

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doctor treats a barber, but the illness of the customer who is shaved by the barber could not be healed.

The interfaces between layers in OSI are complex and there have four types of service primitive words. While in Shannon general network model, Shannon Architecture and SUNA, the interfaces between modules are packets.

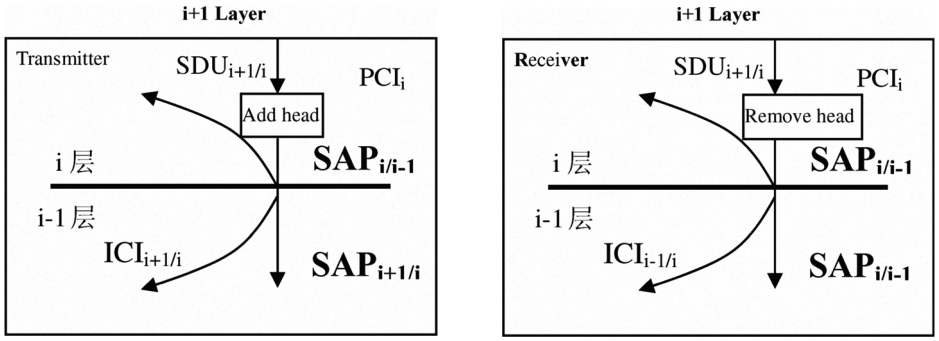

Figure 6. The interface between layers described by OSI model

The interface between layers described by OSI model is shown in Figure 6.

Definition 3: Information of the interface between layers: The interface of No. i+1 layer and No. i layer in OSI is composed by the interface control information $ICI_{i+1/i}$ on service access point $SAP_{i+1/i}$ marked by address of ith layer and service data unit $SDU_{i+1/i}$. PCI_i is handshaking information between layers, such as ACK、NAK、establishing connection and releasing connection, etc.

$$SDU_{i+1/i} = SDU_{i/i-1} \pm PCI_i \quad \text{(Send+, Receive-)}$$

Definition 4: Service primitive words: Services of OSI are combined with Request、Indication、Response and Confirm.

C. *Layered Architecture is Difficult to Understand*

S.Tanenbaum satirized that OSI likes a bandit who forces others to accept the incomprehensible "International standard". In fact, besides OSI, all the other protocol stacks, including TCP/IP, is more incomprehensible than Shannon's General Network Model, Shannon Architecture and SUNA.

Douglas Comer said that Layered Architecture has two types of models, including conceptual model and practical model. In fact the meaning of his words is that conceptual model, which generally refers to Layered Architecture model is not practical.

D. *Poor Scalability of Layered Architecture*

The layer number of all the protocol stacks of layered architecture is fixed. For example, there are seven layers in OSI, four layers in TCP/IP, four layers in ATM, seven layers in SPX/IPX. And the functions of every layer are predetermined. So the functions of network are fixed and the scalability of functions is poor. Any expansion of functions must be dealt by the same amount of layers, which is much inflexible. For example, there are almost no operations in Transport Layer, but it must get across Transport Layer.

VIII. INCLUSIONS

In this paper, Software Engineering methods are used to investigate and evaluate computer network architecture. First General Network Model is obtained, which is expanded from Shannon's Communication Model. Adding characteristics of computer network with General Network Model, we get Computer Network Model. If Computer Network Model is modularized from top to down, it becomes a variety of Computer Architecture. If the final models are layers, it is Layered Architecture. If the final models are SUs, it is SUNA.

From the data flow diagram of end system and router we can get standard program model diagram using transaction analysis and transform analysis of Structured Design. Program the program models using Structured Program, end system and router could be realized. In short, computer architecture and protocol stack/framework could be established and the network in some OS environment could be realized if methods of Software Engineering are used to develop computer network. What is more, it is simpler than developing general large-scale software using Software Engineering.

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