Exploring Application Layer Protocol Relationships in SoftSwitch

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Abstract: Relationships between application layer protocols in softswitch are explored in this paper. Two notions, i.e. protocol relationship and protocol grouping, are proposed, which are not clearly defined and even not paid much attention to before. On the basis of a well known protocol relationship named protocol conversion, three novel protocol relationships including protocol collaboration relationship, protocol cooperation relationship and protocol independent relationship are presented, so that protocol relationships are classified into four types. According to the functionality and purpose of each protocol, main protocols related to softswitch are divided into five groups. As to protocol conversion in softswitch, information flow trail (IFT) is utilized to facilitate problem solving. A decision rule for protocol conversion mode is proposed to guide how to choose between direct conversion and indirect conversion. A property of protocol relationships in softswitch is induced from all kinds of service scenarios of softswitch. This property summarizes protocol relationships within each protocol group or between two specific protocol groups. A merit of protocol grouping together with classification of protocol relationship is also presented. The effort of this paper pushes the protocol engineering to go ahead.

Key words: protocol relationship; protocol grouping; softswitch; information flow trail

I. INTRODUCTION OF SOFTSWITCH TECHNOLOGY

In recent years, a novel conception named next generation network (NGN) was proposed in telecommunications industry. The conception draws an increasingly transparent blueprint for the new telecommunications network which is expected to be deployed in the near future. In fact, the NGN covers all aspects of telecommunications network, including the next generation access network, the next generation optical transport network, the next generation softswitch network, the next generation service network and so on. Among them, some key technologies are regarded as symbols of NGN and softswitch is an important one. The softswitch technology is the evolution of intelligent network (IN) technology. The philosophy of IN is separation of service control from call control and that of softswitch is to further separate bearer control from call control. After these two separations, the call control becomes more pure.

In general, occurrence of any new network does

not mean that the traditional network becomes obsolete immediately. There are two cases. One is to maintain two independent networks. Along with the growth of the new network, the old network shrinks gradually. The other is to construct a hybrid network involving the old one and the new one. The new portion interworks or integrates with the old portion. The existing telecommunications networks include switch networks such as public switched telephone network (PSTN), integrated services digital network (ISDN), switch network of global system for mobile communications (GSM), switch network of code division multiple access (CDMA), core network of H.323, core network of session initiation protocol (SIP) and so forth, access networks such as access network of PSTN/ISDN, radio access network of GSM, radio access network of CDMA, Internet protocol (IP) based access network and so on, and service networks such as fixed IN, broadband IN, mobile IN, wireless IN (WIN), Internet IN (IIN), etc. One point is sure that before considering innovations, the softswitch network must be the inheritor of these legacies first. In other words, the softswitch network must interwork or integrate with the above mentioned legacy networks, with the result that the softswitch needs to support a large number of communication protocols. Besides, the softswitch itself introduces some new protocols. Thus it can be seen that there are many communication protocols coexisting in the softswitch network and the relationships between protocols will be very complex.

The arrangement of the rest of this paper is as follows. Section II discusses relationships between application layer protocols in softswitch. In this section, subsection 2.1 proposes two notions: protocol relationship and protocol grouping, classifies protocol relationships into four types; subsection 2.2 describes the networking scheme of NGN, as the basis of subsequent discussion; subsection 2.3 carries out protocol grouping according to the functionality and purpose of each protocol in softswitch; subsections 2.4 and 2.5 discuss protocol re-lationships in class 4 softswitch (C4-SS) and class 5 softswitch (C5-SS), respectively; subsection 2.6 lays emphasis on protocol conversion relationship, solves the problem by using information flow trail (IFT) and proposes a decision rule for protocol conversion mode. Based on section II, section III induces a property of protocol relationships in softswitch, which summarizes protocol relationships within each protocol group or between two specific protocol groups. In section IV, a merit of protocol grouping together with classification of protocol relationship is presented. From the methodology's point of view, the effort in this paper pushes forward protocol engineering. Besides, section IV points out the future works based on this paper. That is, to develop softswitches and Parlay gateway (GW), let the property guide the development first, and then to prove the property using practical operation experience.

II. PROTOCOL RELATIONSHIPS IN SOFTSWITCH

2.1 Two notions

Just before in-depth discussion, two new notions should be made clear. One is protocol relationship, the other is protocol grouping. Although these notions are so simple, it has not been stated definitely hitherto.

Definition 1: The protocol relationship mentioned in this paper means interaction between two protocols, in other words, from a protocol's point of view, in order to reach a mutual objective, the role that another protocol plays. The protocol relationship only exists between two protocols belonging to the same layer of the OSI network reference model, but not between two protocols belonging to the same protocol stack.

In this paper, we focus protocol relationships on application layer. So far, the most frequently investigated protocol relationship in the open literature is protocol conversion. Here, we will propose three novel protocol relationships; they are protocol col-

laboration relationship, protocol cooperation relationship and protocol independent relationship.

Definition 2: The protocol conversion relationship means that two communication protocols with the same functionality, purpose and objective, such as call control, concatenate each other in a gateway to interconnect heterogeneous networks. Most of the information in a protocol is transferred to the other protocol. Denote by $P_1 \overset{con}{\sim} P_2$ the protocol conversion relationship between protocol P_1 and P_2. However, except the gateway, other network elements are unaware of the existence of another protocol.

Definition 3: The protocol collaboration relationship means that in a complex heterogeneous network environment, two communication protocols with different functionalities and purposes collaborate with each other to transfer information, which is explicit in the form of information element of protocol data unit (PDU), and realize their own original protocol objectives. Denote by $P_1 \overset{col}{\sim} P_2$ the protocol collaboration relationship between protocol P_1 and P_2. In general, no modification to protocols is needed in this relationship. For example, message B of protocol P_2 can be sent out only after message A of protocol P_1 is received and information element b of message B is assigned according to the value of information element a of message A.

Definition 4: The relationship that is similar with the protocol collaboration relationship but only involving implicit information transferring such as time sequence cooperation and without explicit information transferring in the form of information element of PDU is protocol cooperation relationship. Denote by $P_1 \overset{coo}{\sim} P_2$ the protocol cooperation relationship between protocol P_1 and P_2. For example, message B of protocol P_2 can be sent out only after message A of protocol P_1 is received.

Definition 5: The protocol independent relationship means there is no protocol conversion relationship, protocol collaboration relationship or protocol cooperation relationship between two specific protocols. In other words, the protocol independent relationship is a kind of "relationship" without any relationship. Denote by $P_1 \overset{ind}{\sim} P_2$ the protocol independent relationship between protocol P_1 and P_2.

We can arrange the four relationships in a descending order of degree of tightness: protocol conversion relationship, protocol collaboration relationship, protocol cooperation relationship and protocol independent relationship, as Figure 1 shows.

To the authors' knowledge, all the above three novel protocol relationships have not been proposed before. It seems that there are two articles related to protocol relationship. The first one[1] describes a mechanism to modify two fault tolerance protocols to make synergistic coordination between them. With this mechanism, software fault tolerance and hardware fault tolerance can be realized simultaneously in a system within a distributed computing environment. The term "protocol-coordination" is used to depict this mechanism. Protocol-coordination means to modify protocols and compromise mutually in order to eliminate ill impact and reach the goal of adaptation between two protocols which are in different application scope although with similar functionality and purpose. It is noticeable that the modifications on two protocols are prerequisite. A more important point is that these two fault tolerance protocols are not real communication protocols. It may be more suitable to call them algorithms or techniques. The second one[2] discusses an implementation of a management agent to support multiple management models and protocols at the same time. The
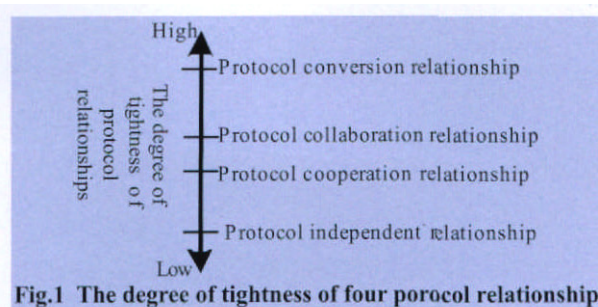

Fig.1 The degree of tightness of four porocol relationships

multiprotocol management agent supports two models and two corresponding protocols. They are Internet-standard structure of management information (SMI), simple network management protocol (SNMP), and enterprise management architecture (EMA) entity model and digital network architecture (DNA) common management information protocol (CMIP). In a network device, management agent is divided into three parts: common agent, management access daemon (MAD) and subagent. The common agent screens some management-model-specific and management-protocol-specific information. The MAD further screens more specific information. Thus the subagent just needs to handle generic management model and generic management protocol. SNMP and DNA CMIP are independent with each other, and they only have a few indirect connections through the management agent. However, the focus of our paper is just relationships between communication protocols of application layer, so these two articles are unrelated.

Definition 6: Protocol grouping means to assign protocols to different groups according to their functionalities and purposes.

In order to determine more conveniently what relationship between two given protocols is, protocol grouping in advance is helpful. In the following, we will see that main protocols related to softswitch will be put into five protocol groups.

2.2 Softswitch classification

Figure 2 illustrates the networking scheme[3] of the next generation service network, the next generation softswitch network and the next generation access network. The softswitch network looks like an up-side-down tree as a whole. We classify softswitches into four types[3]; they are routing softswitch (R-SS), C4-SS, C5-SS and IP private branch exchange softswitch (IP-PBX-SS). The terms class 4 and class 5 are derived from legacy network domain. It is noticeable that the former three types of softswitches are carrier-grade and the fourth one is enterprise-grade. Since IP-PBX-SS is not carrier-grade, it is not mentioned in Figure 2. We divide the softswitch network architecture into four levels. They are gateway and terminal level, baseline softswitch level, interim softswitch level and top softswitch level from the bottom up. Kinds of gateways whatever media gateway or signalling gateway (SG) reside in level 1. These gateways, for instance, access gateway (AG), wireless gateway (WG), trunking gateway (TG) and SG, are used to connect to legacy networks such as PSTN, public land mobile network (PLMN) and signalling system No.7 network (SS7). At the same time, terminals such as H.248 terminal and media gateway control protocol (MGCP) terminal are within level 1 too. Level 3 may be divided into several

Fig.2 Networking scheme of NGN
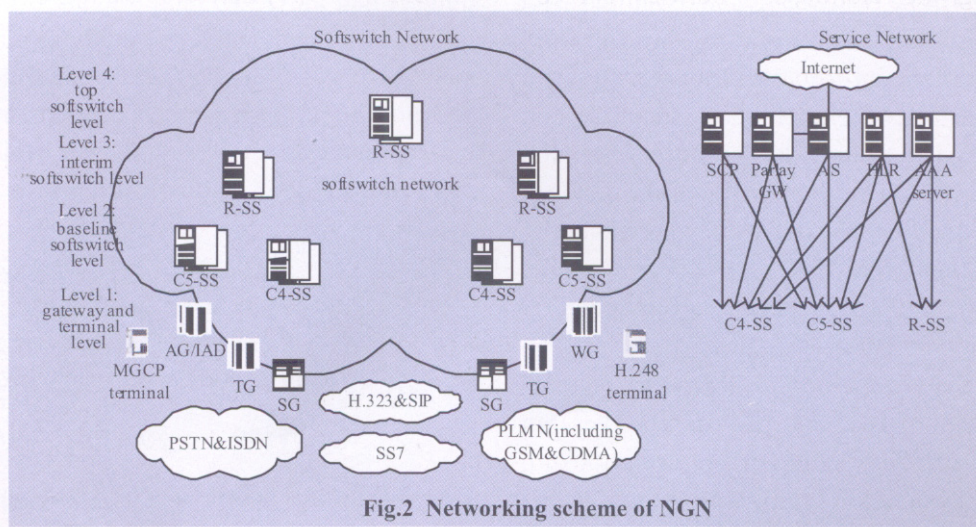
sub-levels when network scale is not so small.

There are lots of interfaces between kinds of softswitches and kinds of network elements in the next generation service network and the next generation access network, as Table 1 shows.

In Table 1, INAP, CAP, MAP, SCP, API, AS, HLR, RADIUS, COPS, AAA and IAD stand for intelligent network application part, CAMEL (stands for customised applications for mobile network enhanced logic) application part, mobile application part, service control point, application programming interface, application server, home location register, remote authentication dial in user service, common open policy service, authentication authorization accounting and integrated access device, respectively. However, the interfaces between R-SS and outside are less than that between C4-SS/C5-SS and outside, as in Figure 2. Also as a fact, softswitch may have interfaces towards short message service center (SMSC), gateway mobile location center (GMLC), mobile positioning center (MPC), management station with management application, etc. Considering the purpose of this paper is to probe typical protocol relationships while not to list all the interfaces and make the problem more complex, these interfaces will not be mentioned any more in the rest of this paper. Similarly, the H.248/MGCP interfaces between softswitch and media server will not be discussed either. In the following, the relationships between call related protocols will be focused on.

2.3 Protocol grouping

The softswitch related protocols can be divided into the following five groups; they are horizontal call control protocol group S_h, vertical and downward call bearer control protocol group S_{v-d}, vertical and upward service control protocol group S_{v-u-1}, vertical and upward mobility management protocol group S_{v-u-2} and vertical and upward AAA protocol group S_{v-u-3}. The horizontal or vertical direction here is designated by convention, according to most of the NGN figures that we can find in kinds of publications. Figure 3 illustrates protocol groups in NGN, which includes service domain, softswitch domain and bearer domain. In the service domain, there is no horizontal protocol group. In the bearer domain, the bearer control protocol group has no direct relationship with softswitch, so it is beyond the scope of this paper.

1. Call control protocol group S_h={ISUP[4, 5], BICC[6, 7, 8], SIP-T[9, 10, 11], SIP[12, 13], H.323[14, 15, 16]}, where ISUP, BICC and SIP-T stand for ISDN user part, bearer independent call control and SIP for telephones, respectively;

2. Call bearer control protocol group S_{v-d}={H.248[17], MGCP[18]};

3. Service control protocol group S_{v-u-1}={INAP[19, 20], CAP[21, 22, 23], WIN MAP[24, 25, 26, 27], Parlay API[28]};

4. Mobility management protocol group S_{v-u-2}={GSM MAP[29], ANSI-41 MAP[30, 31, 32]};

5. At present, the AAA protocol mainly refers

Table 1 Kinds of interfaces between kinds of softswitches and outside			
	R-SS	**C4-SS**	**C5-SS**
SCP/Parlay GW	N/A	INAP/CAP/WIN MAP	INAP/CAP/WIN MAP
AS	N/A	Parlay API	Parlay API
HLR	GSM MAP/ANSI-41 MAP	GSM MAP/ANSI-41 MAP	GSM MAP/ANSI-41 MAP
AAA server	RADIUS/DIAMETER/ COPS	RADIUS/DIAMETER/ COPS	RADIUS/DIAMETER/COPS
TG	N/A	H.248/MGCP	N/A
AG/IAD/WG/H.248 terminal/MGCP terminal	N/A	N/A	H.248/MGCP

to RADIUS[33, 34] protocol and DIAMETER[35] protocol. In the future, COPS[36] protocol may be included, and even SNMPv3[37-45] protocol. However, SNMP is not appropriate enough as a kind of AAA protocol, so the AAA protocol group S_{v-u-3}= {RADIUS, DIAMETER, COPS}.

Within some peripheral software modules of softswitch, it is expected that all protocols in a protocol group are converted into a generic protocol, so that the core module needs to handle five generic protocols only. This is somewhat like the idea in article [2]. Design of generic protocols is a key point of softswitch. These five generic protocols are generic call control protocol, generic call bearer control protocol, generic service control protocol, generic mobility management protocol and generic AAA protocol, respectively.

Considering that the functionality set of C4-SS and that of C5-SS are two supersets of that of R-SS and the functionality set of C5-SS is a superset of that of IP-PBX-SS, we will take C4-SS and C5-SS as examples to investigate protocol relationships.

2.4 Protocol relationships in C4-SS

Based on Figure 2, we can further draw Figure 4 about interfaces of the C4-SS. The entities in the service domain, the softswitch domain and the bearer domain are represented by different icons
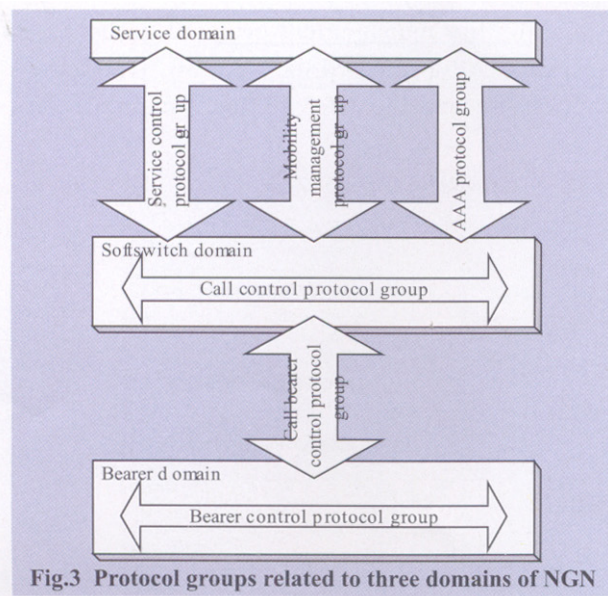
respectively. There are ten main interfaces between the C4-SS and outside. The C4-SS can provide basic services by itself and other intelligent services jointly with the SCP, Parlay GW or AS. It is obvious that the C4-SS should handle lots of service scenarios. There are more than twenty service scenarios of basic services merely considering different call control protocols in the calling party side and the called party side. If the two call bearer control protocols, four service control protocols, two mobility management protocols and three AAA protocols in Figure 4 are all considered together with the five call control protocols, the number of service scenarios will be a large one. Therefore, it is impossible to discuss all the service scenarios in this paper. In the following, a typical service scenario is taken as an example.

Figure 5 is the message sequence chart (MSC) with a PSTN terminal as calling party and a GSM terminal as called party. Only those signalling messages received or sent by the C4-SS are illustrated in Figure 5. The protocols between the SG, TG, HLR, SCP, R-SS and the C4-SS are ISUP, H.248, GSM MAP, CAP and SIP-T, respectively. In order to keep the call setup time as short as possible, the C4-SS should concurrently handle messages of different protocols to the greatest extent. For example, the C4-SS should send out send routing
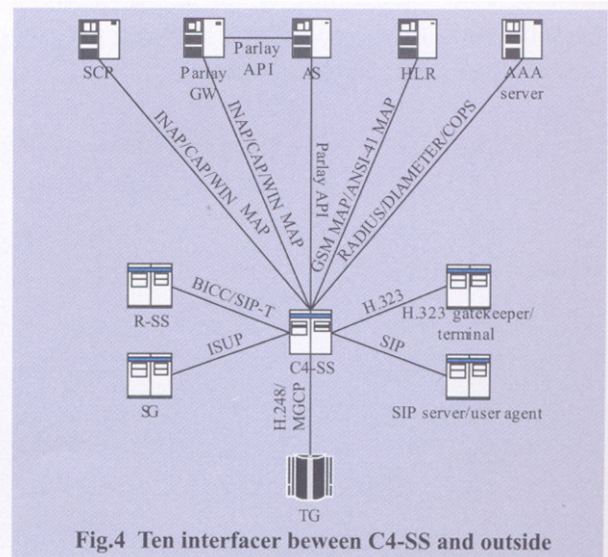

Fig.3 Protocol groups related to three domains of NGN

Fig.4 Ten interfacer beween C4-SS and outside

information (SRI) message closely after two Add messages, while not send out SRI till the two Add. reply messages are received. However, sometimes a prerequisite of message sending is receiving another message. For instance, the InitialDP message must be sent out after receiving the first SRI ack message. The reason is that the C4-SS needs to judge whether to establish dialogue relationship with an SCP or not, and with which SCP if necessary, according to information in the first SRI ack message. In such cases, messages of different protocols are handled in series.

In such a service instance (or call instance), the C4-SS acts as a gateway of call control protocols and protocol conversion between call control protocols is done in it. In general, a service instance relates to only one protocol in each protocol group besides call control protocol group, such as CAP in service control protocol group, GSM MAP in mobility management protocol group, H.248 in call bearer control protocol group, etc.

During the call setup phase, $\mathrm{ISUP} \overset{col}{\sim} \mathrm{H.248}$ since the C4-SS determines which TG to send two Add messages to based on information in initial address message (IAM). Also, $\mathrm{ISUP} \overset{col}{\sim} \mathrm{GSM\,MAP}$ since

the C4-SS determines the called party's HLR according to the called party number in IAM. $\mathrm{H.248} \overset{ind}{\sim} \mathrm{GSM\,MAP}$ since there is no information transfer and time sequence cooperation between them. For example, it is not important whether the two Add messages are sent before the first SRI or not. Similarly, $\mathrm{H.248} \overset{ind}{\sim} \mathrm{CAP}$. $\mathrm{GSM\,MAP} \overset{col}{\sim} \mathrm{CAP}$ since the C4-SS gets the called party's home SCP address and service key from the HLR by GSM MAP, and then initiates an interaction with the SCP. Another reason is that the C4-SS sends out a request for mobile station roaming number (MSRN) to an appropriate HLR according to the information named DestinationRoutingAddress in the Connect message. The appropriate HLR is just the same HLR as that previously mentioned. $\mathrm{ISUP} \overset{col}{\sim} \mathrm{CAP}$ since the InitialDP message includes the calling party number and the called party number which are got from the IAM message. Also, $\mathrm{H.248} \overset{col}{\sim} \mathrm{SIP\text{-}T}$ since the C4-SS gets a user datagram protocol (UDP) port to be used by real-time transport protocol (RTP) in the TG using H.248, and then sends the UDP port together with the IP address of the TG to the R-SS using SIP-T, then gets the IP address and
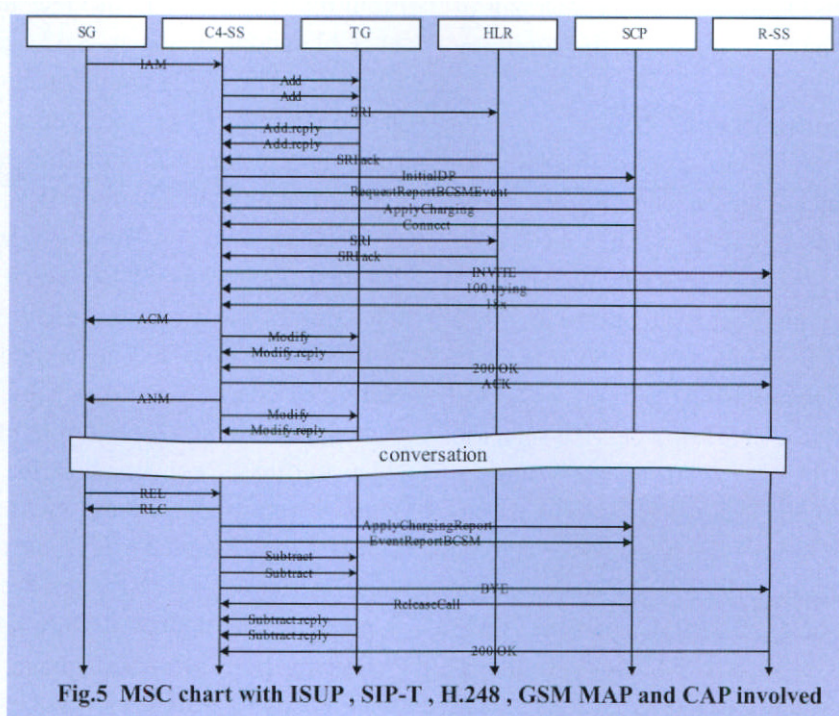

Fig.5 MSC chart with ISUP , SIP-T , H.248 , GSM MAP and CAP involved

UDP port of another media gateway on the called party's side using SIP-T, and finally sends the IP address and UDP port got from the R-SS to the TG using H.248. $\text{GSM MAP} \overset{col}{\sim} \text{SIP-T}$ since the INVITE message carries the MSRN got from the second SRI ack message. In Fig. 5, $\text{CAP} \overset{ind}{\sim} \text{SIP-T}$. If the call is initiated in the reverse direction, that is, from the R-SS to the SG via the C4-SS, $\text{CAP} \overset{col}{\sim} \text{SIP-T}$ since the C4-SS needs to get the calling party number and the called party number from SIP-T message and then put them into the InitialDP message.

During the call release phase, $\text{ISUP} \overset{coo}{\sim} \text{CAP}$ since the release (REL) message has time sequence co-operation with CAP, resulting in sending out of ApplyChargingReport and EventReportBCSM. Based on the similar fact that the REL message leads to the two Subtract messages to be sent out, $\text{ISUP} \overset{coo}{\sim} \text{H.248}$. Like the case during the call setup phase, $\text{ISUP} \overset{con}{\sim} \text{SIP-T}$. Besides, $\text{CAP} \overset{ind}{\sim} \text{H.248}$, $\text{CAP} \overset{ind}{\sim} \text{SIP-T}$, $\text{H.248} \overset{ind}{\sim} \text{SIP-T}$. It is possible that during the call setup phase and the call release phase, the relationship between two specific protocols may be inconsistent. Here we would like to emphasize the main relationship, i.e. the tightest relationship referring to Figure 1, between each pair of protocols. Thus, Figure 6 illustrates the summary of these relationships.

2.5 Protocol relationships in C5-SS

The interfaces of C5-SS are almost the same as that of C4-SS which are illustrated in Figure 4. The only different point is that C5-SS has an H.248/MGCP interface towards AG/IAD/WG/ H.248 terminal/MGCP terminal but have not an interface towards TG. In the following, an example is taken to explain protocol relationships within C5-SS.

Figure 7 is the MSC chart of a service scenario with an MGCP terminal as calling party and an H.323 terminal as called party. The protocols between the MGCP terminal, the AAA server and the C5-SS are MGCP and RADIUS, respectively. The protocol between the H.323 gatekeeper, the H.323 terminal and the C5-SS is H.323, including registration, admission and status (RAS), Q.931 and
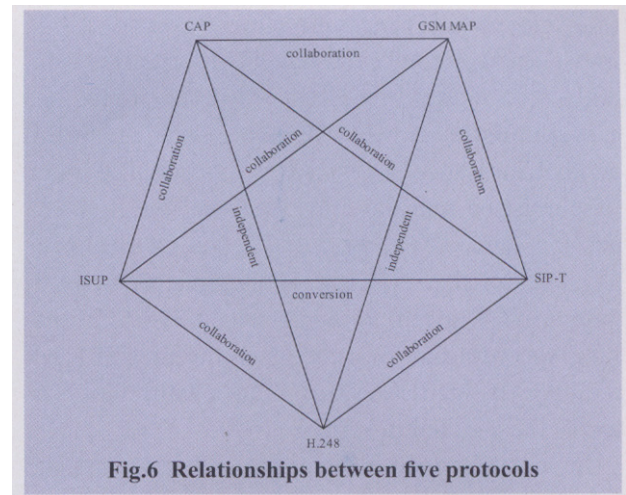

Fig.6 Relationships between five protocols

H.245. Those non-call related MGCP messages before the call setup phase or after the call release phase are omitted in Figure 7. During the call setup phase, since the number of H.245 messages (including master-slave determination, capability exchange and logical channel signalling procedures) is not so small and the H.245 messages do not help to explain the relationships between H.323 and other protocols, they are omitted too. While during the call release phase, two H.245 messages, namely EndSessionCommand, are presented in Figure 7. From the H.323's point of view, the C5-SS acts as an H.323 endpoint and an H.323 gatekeeper simultaneously. The H.323 endpoint should register with the coexisting H.323 gatekeeper. Between H.323 endpoints, direct call signalling while not gatekeeper routed call signalling is adopted. In Figure 7, there are two Accounting-Request messages. The first one means the beginning of charging and the value of the attribute named Acct-Status-Type in this message is 1. The second one means the ending of charging and the value of the attribute named Acct-Status-Type in this message is 2. Besides, during the conversation, the C5-SS may also send Accounting-Request messages with Acct-Status-Type assigned with 3 to the AAA server; these messages, which are not presented in Figure 7, mean interim update of charging information.

During the call setup phase, $\text{MGCP} \overset{col}{\sim} \text{RADIUS}$ since the Access-Request message includes infor-

Fig.7   MSC chart with MGCP , H.323 and RADIUS invoted
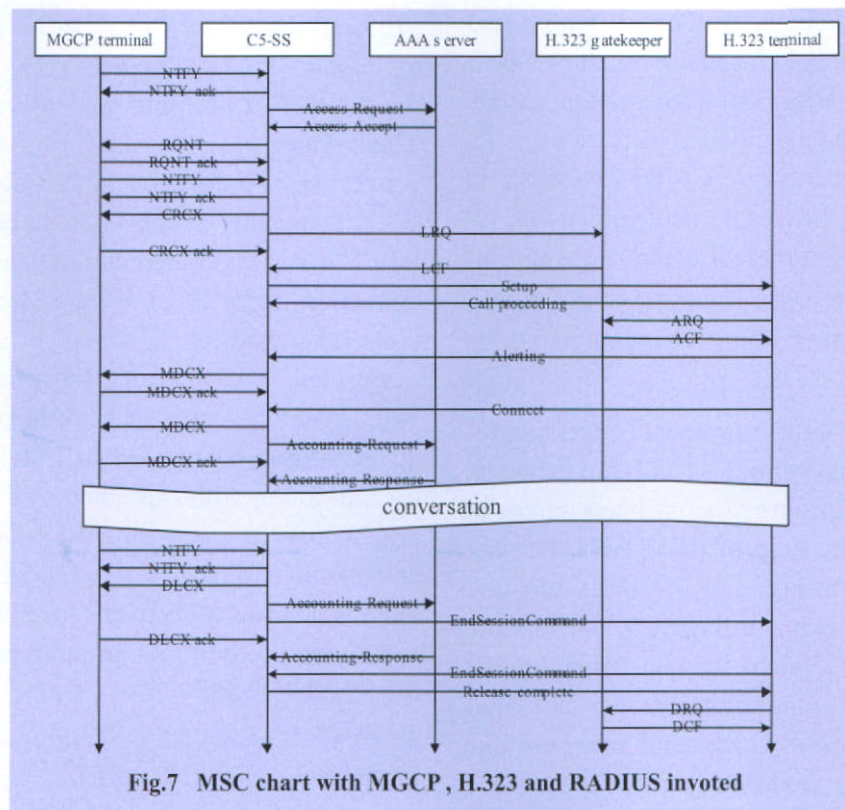
mation, such as the calling party number, which is got from the first Notify (NTFY) message. Besides, only after the C5-SS has received the Access-Accept message that means the calling party is authorized to initiate a call that the NotificationRequest (RQNT) message can be sent out. $MGCP \overset{col}{\sim} H.323$ since the called party number in the LocationRequest (LRQ) message is got from the second NTFY message. Besides, the C5-SS transfers the called party's IP address and the UDP port to be used by RTP from the Alerting message to the first ModifyConnection (MDCX) message. Anyway, there exists $MGCP \overset{coo}{\sim} H.323$ too since the C5-SS sends out the second MDCX message on reception of the Connect message. In Figure 7, $RADIUS \overset{coo}{\sim} H.323$ since the C5-SS sends out the first Accounting-Request message to initiate charging upon receipt of the Connect message. If the call is initiated reversely, from an H.323 terminal to an MGCP terminal, the C5-SS needs to get the calling party number and the called party number from the Setup message and then put them into the Access-Request message to send to the AAA server for authentication. In such case, $RADIUS \overset{col}{\sim} H.323$.

During the call release phase, $MGCP \overset{coo}{\sim} RADIUS$ and $MGCP \overset{coo}{\sim} H.323$ since the C5-SS sends out the second Accounting-Request message and the first EndSessionCommand message on receipt of the third NTFY message. What happened is just time sequence cooperation. Besides, $RADIUS \overset{ind}{\sim} H.323$. If the tightest relationship between each pair of protocols is emphasized, Figure 8 can be produced. It is notable that there is a big inconsistency between Figure 6 and Figure 8 and it will be further discussed in section III.

2.6 On protocol conversion

Since among the four types of protocol relationships the protocol conversion relationship is the most complex, it is discussed exclusively in this subsection. The IFTs [46, 47] of C4-SS and C5-SS are illustrated in Figure 9 and Figure 10 respectively. Those ellipses drawn with dashed line denote interfaces between entities and those arrows denote bi-directional signalling IFTs. The IFT can

only exist within a single protocol or within two protocols with protocol conversion relationship. It is notable that the information interaction on IFT C4-SS↔TG can only be initiated by C4-SS.

The IFTs which traverse C4-SS or C5-SS in Figure 9 or Figure 10 are protocol conversion related. The following protocol conversions are involved: $\mathrm{ISUP} \overset{con}{\sim} \mathrm{BICC}$, $\mathrm{ISUP} \overset{con}{\sim} \mathrm{SIP\text{-}T}$, $\mathrm{ISUP} \overset{con}{\sim} \mathrm{H.323}$, $\mathrm{ISUP} \overset{con}{\sim} \mathrm{SIP}$, $\mathrm{BICC} \overset{con}{\sim} \mathrm{H.323}$, $\mathrm{BICC} \overset{con}{\sim} \mathrm{SIP}$, $\mathrm{SIP\text{-}T} \overset{con}{\sim} \mathrm{H.323}$ $\mathrm{SIP\text{-}T} \overset{con}{\sim} \mathrm{SIP}$ and $\mathrm{H.323} \overset{con}{\sim} \mathrm{SIP}$. However, there is no $\mathrm{BICC} \overset{con}{\sim} \mathrm{SIP\text{-}T}$. Within these protocol conversion relationships, five call control protocols are included. The softswitches are turned from black boxes to white ones with the help of these IFTs. For example, the C4-SS in Figure 4 is a black box and it turns to be a white one in Figure 9, where more details are presented. Such effect just embodies the function of IFT. Here the softswitch acts as a gateway and a control point at the same time, not like the case in the IIN model[46], where the service control gateway function (SCGF) and the service control function (SCF) are apart apparently, so the situation to be faced within the softswitch will be more complex than that in the SCGF. As we know, the protocol conversion can be realized in two modes, that is, by direct conversion or by indirect conversion. The indirect conversion works in such a mode that a protocol is converted into a generic protocol first, and then the generic protocol is further converted into another protocol. On protocol conversion mode, we propose the following rule.

Decision rule for protocol conversion mode: suppose there are n ($n \geq 2$) protocols have the requirements of conversion between each other, if direct conversion is taken, the number of

Fig.8 Relationships between three protocols

protocol converters need to be constructed is $C_n^2 = n(n-1)/2$; if indirect conversion is taken, the number of protocol converters needed is n . Thus, when $n < n(n-1)/2$, i.e. $n > 3$, indirect conversion is more suitable than direct conversion since the number of converters to be constructed is less; when $n = 3$, there are the same numbers of converters to be constructed under both protocol conversion modes.

Besides, if we consider the scalability of softswitch system, the advantage of indirect conversion against direct conversion will be more and more evident along with the number of new protocols added to softswitch increases. Taking it under consideration that $n = 5$ in C4-SS or C5-SS and there is no protocol conversion between BICC and SIP-T, we decide to adopt indirect conversion in C4-SS and C5-SS.

Fig.9 IFTs between interfaces of C4-SS

Fig.10 IFTs between interfaces of C5-SS
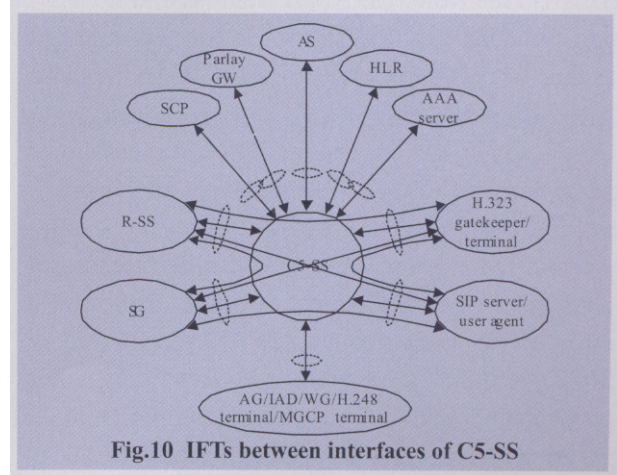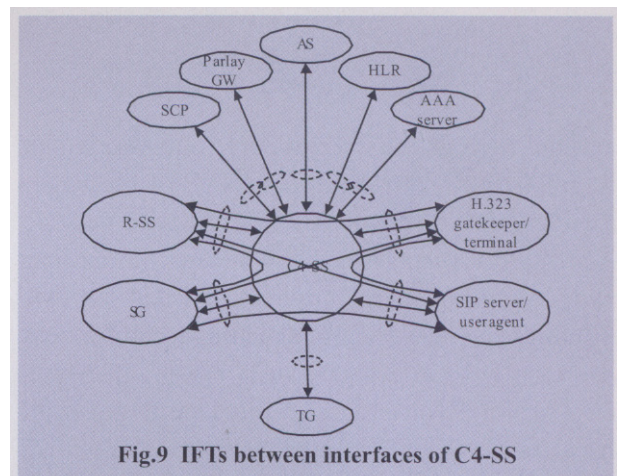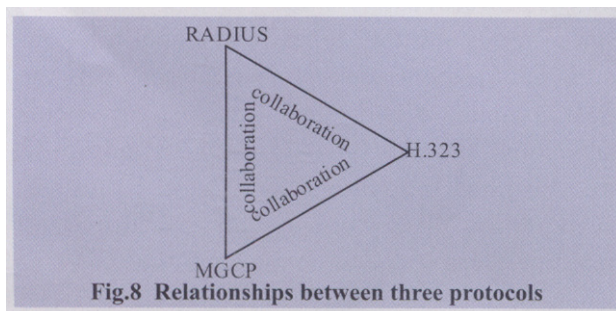
III. PROPERTY OF PROTOCOL RELATIONSHIPS IN SOFTSWITCH

In Figure 8, $\mathrm{MGCP} \overset{col}{\sim} \mathrm{RADIUS}$ while in Figure 6 $\mathrm{H.248} \overset{ind}{\sim} \mathrm{CAP}$ and $\mathrm{H.248} \overset{ind}{\sim} \mathrm{GSM\ MAP}$. It seems that an inconsistency about relationships between vertical and downward protocols and vertical and upward protocols exists. In fact, when an MGCP terminal connected to a C5-SS initiates a call, the MGCP protocol plays a role which is not merely a call bearer control protocol. It also does some jobs of call control protocol, such as reporting the calling party number, collecting and reporting the called party number. However, these jobs are not carried out by H.248 between C4-SS and TG. Therefore, $\mathrm{MGCP} \overset{col}{\sim} \mathrm{RADIUS}$ in Figure 8 is essentially a relationship between call control protocol and AAA protocol. Based on Figure 6, Figure 8 and the analysis results of MSC charts of other service scenarios, a property is induced, as follows.

Property of protocol relationships in softswitch: set S_h= {horizontal call control protocols}, $S_{v\text{-}d}$= {vertical and downward call bearer control protocols}, $S_{v\text{-}u\text{-}1}$= {vertical and upward service control protocols}, $S_{v\text{-}u\text{-}2}$= {vertical and upward mobility management protocols}, $S_{v\text{-}u\text{-}3}$= {vertical and upward AAA protocols}, $S_{v\text{-}u}=S_{v\text{-}u\text{-}1} \bigcup S_{v\text{-}u\text{-}2} \bigcup S_{v\text{-}u\text{-}3}$.

Within each protocol group:

If $P_1, P_2 \in S_h$, then $P_1 \overset{con}{\sim} P_2$;

If $P_1, P_2 \in S_{v-d}$, then $P_1 \overset{col}{\sim} P_2$;

If $P_1, P_2 \in S_{v-u-i}, i=1,2,3$, then $P_1 \overset{ind}{\sim} P_2$.

Between protocol groups:

If $P_1 \in S_h$, $P_2 \in S_{v-u}$, then $P_1 \overset{col}{\sim} P_2$;

If $P_1 \in S_h$, $P_2 \in S_{v-d}$, then $P_1 \overset{col}{\sim} P_2$;

If $P_1 \in S_{v-u}$, $P_2 \in S_{v-d}$, then $P_1 \overset{ind}{\sim} P_2$;

If $P_1 \in S_{v-u-i}, P_2 \in S_{v-u-j}, 1 \le i, j \le 3, i \ne j$ then $P_1 \overset{col}{\sim} P_2$

The property is shown as Table 2.

Table 2　Protocol relationships in softswitch

		$S_{v\text{-}d}$	S_h	$S_{v\text{-}u}$		
				$S_{v\text{-}u\text{-}1}$	$S_{v\text{-}u\text{-}2}$	$S_{v\text{-}u\text{-}3}$
$S_{v\text{-}d}$		col ~	col ~	ind ~		
S_h		col ~	con ~	col ~		
$S_{v\text{-}u}$	$S_{v\text{-}u\text{-}1}$	ind ~	col ~	ind ~	col ~	col ~
	$S_{v\text{-}u\text{-}2}$			col ~	ind ~	col ~
	$S_{v\text{-}u\text{-}3}$			col ~	col ~	ind ~

IV. SUMMARY AND FUTURE WORKS

An obvious merit of protocol grouping together with classification of protocol relationship is: if multiple protocols are assigned to different groups and protocol conversion is allowed only between protocols from the same group and the relationship between two protocols from different groups is treated as protocol relationships other than protocol conversion, lots of the hard mismatch[48] situation of protocol conversion can be avoided. If protocol conversion is forcibly carried out between two protocols from different groups, failure is often caused for the number of atomic protocol functions[48] shared by the two protocols is too small and protocol complementing[48] is too difficult to fulfill.

Among the four types of protocol relationships, the protocol collaboration relationship and the protocol cooperation relationship are the most similar. The protocol collaboration relationship means explicit information is transferred indirectly between two protocols via a coupling point such as softswitch and the protocol cooperation relationship means implicit information such as time sequence cooperation is transferred.

The research work in this paper makes clear the complicated protocol relationships in softswitch. It is a guide line of the subsequent system development and appropriate decisions can be made according to different protocol relationships. From a more general point of view, although the research work is carried out based on the specific area of

softswitch, its conclusion can be applied to other entities of communications network, such as Parlay GW and call session control function (CSCF) in IP multimedia subsystem (IMS). From a methodology's point of view, it pushes forward the development of protocol engineering.

Now we are developing the softswitch system. Petri nets are to be used to formally model IFTs and protocol conversions[49]. Bugs can be eliminated by the analysis techniques of Petri nets and the robustness of softswitch system can be improved. Till now, the experiences got from the practice have sufficiently verified the correctness and effectiveness of the property of protocol relationships in softswitch and other research results. The two notions of protocol grouping and protocol relationship are scheduled to apply to the course of development of Parlay GW and CSCF as well.

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