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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS AND NEXT-GENERATION NETWORKS

ITU-T Y.2600-series – Scenario and requirements of reconfigurable networking based on minimum network functions and network polymorphism in future packet based networks

ITU-T Y-series Recommendations – Supplement 26

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Supplement 26 to ITU-T Y-series Recommendations

ITU-T Y.2600-series – Scenario and requirements of reconfigurable networking based on minimum network functions and network polymorphism in future packet based networks

Summary

Supplement 26 to the ITU-T Y.2600-series Recommendations aims to provide reconfigurable networking scenarios, to focus on the mechanisms for minimum network functions and network polymorphism and to define the basic requirements of reconfigurable networking based on minimum network functions and network polymorphism in future packet based networks (FPBN) as described in Recommendation ITU-T Y.2601.

History

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Future packet based networks (FPBN), minimum network functions, network polymorphism, reconfigurable networking.

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ITU-T Y.2600-series – Scenario and requirements of reconfigurable networking based on minimum network functions and network polymorphism in future packet based networks

1 Scope

This Supplement provides scenarios and the basic requirements of reconfigurable networking based on mechanisms for minimum network functions and network polymorphism and demonstrates a possible candidate solution to meet these requirements.

2 References

[ITU-T Y.2011] Recommendation ITU-T Y.2011 (2004*), General principles and general reference model for Next Generation Networks*.

[ITU-T Y.2601] Recommendation ITU-T Y.2601 (2006), *Fundamental characteristics and requirements of future packet based networks*.

[ITU-T Y.2611] Recommendation ITU-T Y.2611 (2006), *High-level architecture of future packet-based networks*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 control plane [ITU-T Y.2011]: The set of functions that controls the operation of entities in the stratum or layer under consideration, plus the functions required to support this control.

3.1.2 data plane [ITU-T Y.2011]: The set of functions used to transfer data in the stratum or layer under consideration.

3.1.3 management plane [ITU-T Y.2011]: The set of functions used to manage entities in the stratum or layer under consideration, plus the functions required to support this management.

3.2 Terms defined in this Supplement

This Supplement defines the following terms:

3.2.1 future packet based network (FPBN): A network architecture providing the topmost layer(s) of the transport stratum as defined in [ITU-T Y.2011].

NOTE 1 – This definition is based on the description of FPBN in [ITU-T Y.2601].

NOTE 2 – Fundamental characteristics and requirements of future packet based networks are defined in [ITU-T Y.2601].

3.2.2 independent scalable control plane (iSCP): An architectural approach to future packet based networks (FPBNs) which consists in separating the control plane from the data plane.

NOTE – Fundamental characteristics and requirements of future packet based networks are defined in [ITU-T Y.2601].

3.2.3 minimum network functions: A set of network functions which can support the most basic and important network functions including network addressing, routing and forwarding. Network addressing, routing and forwarding cannot be achieved without any one minimum network function in the set of network functions.

3.2.4 network polymorphism: A network can show different network morphologies, such as different network addressing and routing mechanisms or different packet transmission modes.

3.2.5 reconfigurable networking: A networking mechanism which can flexibly support changes to the network structure, network protocols and the network functions of network elements, to meet frequently changing application requirements.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

ANC	Atomic Network Capability
AS	Atomic Service
BGP	Border Gateway Protocol
CC	Combination Chain
CID	Content Identifier
FPBN	Future Packet Based Network
HID	Host Identifier
IDC	Internet Data Centre
IP	Internet Protocol
LID	Location Identifier
NGN	Next Generation Network
NICE	Network Intelligence Capability Enhancement
ONF	Open Network Forum
OSI	Open Systems Interconnection
OSPF	Open Shortest Path First
RIP	Routing Information Protocol
RPN	Reconfigurable Polymorphic Network
SDN	Software Defined Networking
SID	Service Identifier
SP	Service Path
TCP	Transmission Control Protocol
UDP	User Datagram Protocol

5 Conventions

In this Supplement:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this document is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus this requirement need not be present to claim conformance.

The keywords "can optionally" and "may" indicate an optional requirement which is permissible, without implying any sense of being recommended. These terms are not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with this document.

6 Introduction

With the rapid development of Internet services and next generation network (NGN) services, application layer requests need a more flexible and efficient transport stratum as defined in [ITU-T Y.2011]. In addition, network requirements will be increasingly polymorphic and subject to frequent changes in the future, so it is very difficult to accurately predict the requirements of future networks and it is even more difficult to design new candidates for future packet based networks (FPBNs) based on these currently predicted requirements.

Today, as a consequence, academic and industrial communities have begun to study future network architecture solutions which can "flexibly change the network structure to adopt the frequently changing application requirements". This means that the future network must be polymorphic and so able to easily change the network structure, network protocols and network functions of network elements, to meet frequently changing application requirements. This task is ongoing and promising progress has been made. Reconfigurable networking is becoming one of the basic characteristics of future packet based networks (FPBNs). Figure 1 shows the change from transport control protocol/Internet protocol (TCP/IP) to reconfigurable networking.

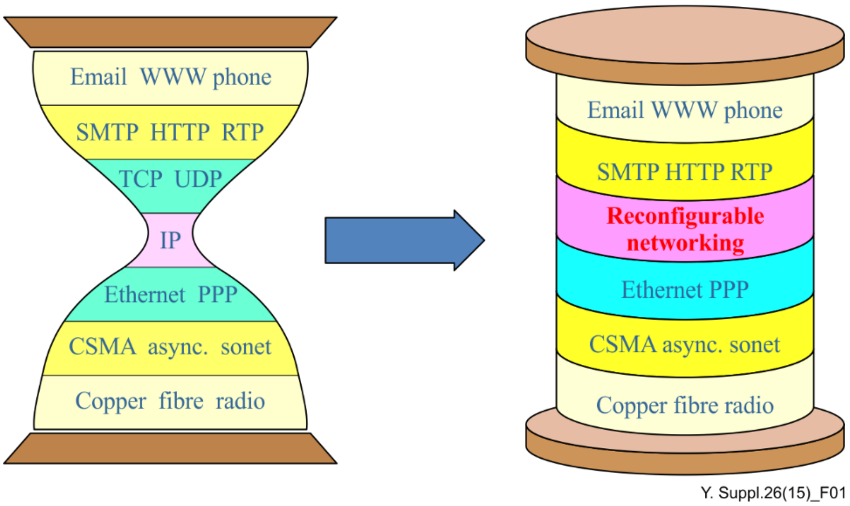

Figure 1 – From TCP/IP to reconfigurable networking

7 Reconfigurable networking mechanisms

There are many different approaches and methods that can be employed to realize reconfigurable networking. One method under research is to abstract the network functions and encapsulate them as network middlewares. These network middlewares can be used to assemble a specific network which can meet all of the needs of that specific network.

Another method makes full use of the "micro kernel" concept of a computer operating system and designs a "micro kernel" of network functions. This micro kernel can support the most basic network functions and includes the minimum network instruction set. Other network functions are in the form of plug-ins and are spliced to the network micro kernel in a plug-and-play manner to compose a relatively simple and efficient network layer.

Figure 2 shows a simplified reference functional framework of this mechanism.

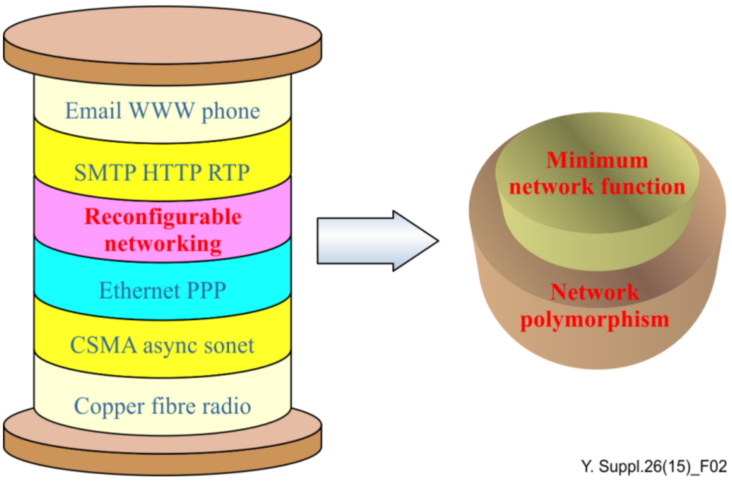

Figure 2 − Reference functional framework of minimum network functions and network polymorphism

This framework adopts the concept of a "mico kernel" and network polymorphism which abstracts the most basic and most important network functions as stable minimum network functions. Other network functions can be derived based on the minimum network functions. The process of creating new network functions based on these most basic network functions is called network polymorphism.

8 Reconfigurable networking scenarios

8.1 Internet service providers can build customized data networks with high efficiency and minimum functions

Large Internet companies are experiencing an increasing need to build their own IP backbone networks which can replace the backbone networks currently provided by network operators. These Internet companies believe that the communication requirements of their own networks are very specific and that the functions of traditional routers provided by the network operators are too complex. Indeed nearly 80% of the functions and characteristics of traditional routers are not needed and are never used. However said large Internet companies still have to pay for these unused functions when purchasing traditional routers. Consequently a clear and strong requirement exists to design simple and efficient routers that can adopt new architecture and that have specific network functions. This was one of the original intentions of these big companies when they initiated the establishment of the Open Network Forum (ONF) to develop software defined networking (SDN) standards.

A similar situation was encountered in the field of application servers. When these large Internet companies build their own Internet data centres (IDCs), most of them adopt customized application servers which have had surplus functions removed and which have a relatively low price. Today the number of application servers in IDCs can be counted in the thousands or even tens of thousands. The success experienced by these Internet companies with customized application servers within IDCs has led to positive expectations for the success of customized network routers.

When these large Internet companies design their own routers using different design methods, the design costs are increased to a certain extent. Consequently, in order to simplify the router design process a demand exists for these companies to design a "micro kernel" router function model. The micro kernel includes only the minimum functions to realize the addressing, routing and forwarding functions. Other functions can be plugged in dynamically. Based on this idea, the basic functions based on the minimum set of network functions and the specific function needs of companies can be met. This will reduce to some extent the design costs of routers and shorten the design cycle, but it can also greatly reduce the production costs.

8.2 Future Internet researchers can build a future Internet testbed with routers so that functions can be conveniently expanded

Future Internet researchers are currently actively researching new Internet architectures and key technologies in order to solve the problems of insufficient network address space, difficulties in guarantying quality of service and a lack of security and trusted mechanisms in IP networks. There are numerous research directions and a lot of candidate solutions.

Given this situation, it is necessary for future Internet researchers to establish a large future Internet testbed so that this testbed can provide a flexible testing environment for a variety of future Internet research programs.

In the process of testbed construction designers hope that network functions of network nodes in the future Internet testbed can change control and routing protocols flexibly to achieve efficient forwarding. As it is very convenient to change the functions of a future Internet testbed these "micro kernel" functions can be any one of the candidate solutions.

8.3 Flexible network architecture supported by reconfigurable networking can improve network security and robustness

Currently, with the popularization of Internet applications and the depth of integration of Internet with other industries, Internet based on traditional Internet protocol (IP) is being faced with more and more serious threats to network and information security. Some experts believe it is impossible for network systems to realize complete network security through the design of "zero-bug" networks. Network attackers can always find vulnerabilities in the network and equipment. Networks in the long term are not safe. Reconfigurable networking provides another way to improve the security of the network. The network structure and equipment status within a certain range can be adjusted dynamically and so it becomes difficult for network attackers to keep up with a rapidly and frequently changing network. At the same time, reconfigurable networking can also improve the robustness of the network, when the network fails, the reconfigurable network can exhibit fast finding, locating, and good self-healing.

8.4 Traditional network operators can adopt reconfigurable networking to build smart pipe or network intelligence capability enhancement (NICE)

Internet and mobile Internet have greatly expanded the Internet application types. Different Internet applications have different network requirements such as for example different quality of service (QoS) guarantee mechanisms. Current IP based Internet has great difficulty both in meeting these varied types of requirement and in providing differentiated services. One of the most important development directions for traditional network operators has been to build smart pipes, or in other words, to provide for network intelligence capability enhancement (NICE). Reconfigurable networks can provide a technically feasible approach to providing NICE. Reconfigurable networks can dynamically be aware of network status or application requirements and can dynamically and flexibly recombine the network functions according to these requirements. In this way IP networks can provide value-added services based on the abilities provided by reconfigurable networking.

8.5 Flexible network architecture supported by reconfigurable networking can facilitate the business mode of network virtual operation

Currently network virtual operation provides a relatively new business model of network operation, especially for mobile networks. Virtual operation of mobile networks is developing rapidly which is allowing mobile Internet services to become more personalized. In this way network virtual operation is significantly promoting the development of mobile networks and services. Virtual operation is gradually becoming the new development direction of mobile Internet services. With regard to packet based networks, virtual network operators hope to be able to re-optimize or re-define network resources and network services in order to achieve some specific network functions and so better support personalized network requirements. Reconfigurable networking can support virtual network operators in redefining the network resources, gives the virtual network operators maximum network control rights and helps to promote the network services innovation of virtual network operators.

9 Function requirements

9.1 Routing mechanisms requirements

There are at least four kinds of entity identifiers in future Internet, namely location identifier, host identifier, content identifier and service identifier. Correspondingly there are at least four kinds of routing mechanisms in future Internet, namely location-based routing, host-based routing, content-based routing and service-based routing.

Reconfigurable networking should support the characteristics of "network routing polymorphism", and should at least support the four kinds of routing mechanisms, namely location-based routing, host-based routing, content-based routing and service-based routing. In addition reconfigurable networking can support emerging routing mechanisms conveniently.

9.2 Network functions requirements

Reconfigurable networking should provide reinforced capabilities of the network layer and transport layer which are defined in TCP/IP protocol. Traditional TCP/IP networks experienced bottleneck problems in the IP network layer, including difficulty in guarantying quality of service, poor security and credibility, lack of manageability, controllability and scalability and weakness in supporting ubiquitous mobility. In reconfigurable networking, the functions of the network layer and transport layer should be harmonically integrated, this means that the connect oriented transmission mode and the connectionless transmission mode should be supported in the "micro kernel" of network functions at the same time. This reinforces the capability of fundamental network transmissions and supports the polymorphic routing mechanisms. Therefore, the network capability of fundamental transmission can be reinforced dynamically and polymorphic networks can be supported.

9.3 Service provision requirements

Reconfigurable networking should provide extensible, application-adaptive, customizable and diverse network services for different applications. In reconfigurable networking, a particular application can be divided into basic service function elements (atomic services) and network functions can be divided into basic network function elements (atomic network capability). Reconfigurable networking should combine several atomic network capabilities to meet and support the requirements of a particular application. Therefore, in reconfigurable networking, two kinds of function models should be defined: the atomic service model and the atomic network capability model. The atomic service model can be built by clustering and classifying the fundamental network service (atomic service) required by various applications; the atomic network capability model can be built with the fundamental network function elements (atomic network capability) required by various atomic services.

Based on these concepts of "atomic service" and "atomic network capability", the aim to "flexibly change the network structure to adopt frequent and rapidly changing applications" can be achieved by matching between "atomic service" and "atomic network capability".

Reconfigurable networking should support the characteristics of the combination of "atomic service" and "atomic network capability".

9.4 Context awareness requirements

Reconfigurable networking should realize reconfiguration of the network structure, self-configuration of network resources and self-adjustment of network capabilities. Reconfigurable networking should provide network awareness capability. Reconfigurable networking should realize network capabilities adaptive to applications with a flexible combination of network resources and node capabilities. In this way the mechanism and structure of infrastructure reconfiguration can be built based on self-configuration of resources and self-adjustment of capabilities at the network level.

9.5 Resource virtualization requirements

Reconfigurable networking should support virtual networks based on a physical network. Among these virtual networks, network resources should be isolated from each other. In each virtual network, network resources should be guaranteed; a network resource management function (system) should be provided and should work independently.

9.6 Network manageability requirements

Reconfigurable networking should provide manageability and controllability of network infrastructure and these capabilities can achieve network security which is embedded in network infrastructure. Reconfigurable networking should support network isolation and application isolation and provide traffic trace-back capability.

9.7 Open operation interfaces and protocols requirements

Reconfigurable networking is recommended to provide unified operation interfaces and protocols of network resources, to support virtual network operators, network operators and even end users to redefine or re-optimize the underlying network behaviours to meet specific network requirements.

10 Security considerations

As described in clause 8.3, in reconfigurable networking, flexible network architecture can improve the network security and robustness. On the one hand, it is difficult for network attackers to keep up with the rapidly and frequently changing network and on the other hand, when the network fails, reconfigurable networking can also improve the robustness of the network and the network can exhibit fast finding, locating and good self-healing.

Appendix I

A candidate solution of reconfigurable networking based on minimum network functions and network polymorphism

The content of this Supplement mainly focuses on scenarios and function requirements. Based on these requirements, there may exist several solutions for reconfigurable networking. The content described here is informational and helps provide a better understanding of the main content of this Supplement.

I.1 Network function reference model

One solution for reconfigurable networking adopts a network function reference model as shown in Figure I.1. On the data plane, there is a reinforced Internet interconnection transport layer, i.e., a reconfigurable polymorphic network (RPN) layer. On the management plane, one new "cognition" function has been introduced in addition to the legacy four management functions, which are "failure management", "performance management", "security management" and "configuration management".

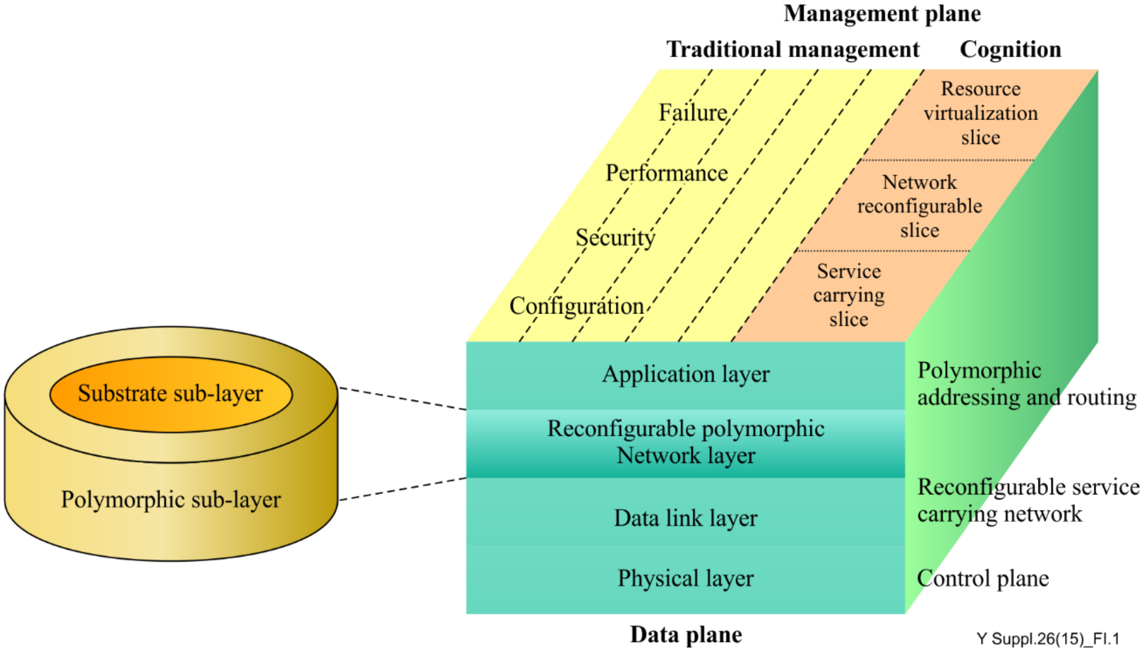

Figure I.1 – Network function reference model of the reconfigurable network architecture

The RPN layer is a reinforced Internet interconnection transport layer which includes functions of both the network layer and the transport layer in the ISO open systems interconnection (OSI) network reference model. The RPN layer is composed of two sub-layers: the substrate sub-layer and the polymorphic sub-layer. The substrate sub-layer is an Internet interconnection transport layer supporting the minimum network functions with both connection-oriented and connectionless packet transmission mode capabilities. The polymorphic sub-layer can add additional functions based on the substrate sub-layer, such as the polymorphic characteristics of performance-specific, security-specific, or multicast-specific applications.

The cognition function of the network function reference model is a function of network management within the management plane, providing application cognition and network cognition capabilities. The cognition function contains a resource virtualization function slice, a network reconfiguration function slice and a service carrying function slice:

− The resource virtualization function slice of the cognition function perceives node resources within networks as well as the characteristics and dynamic behaviours of network resources. It virtualizes the tangible and concrete resources of nodes and networks as globally visible and available abstract resources with consistent formal description and network semantics, so as to provide fundamental reconfigurable components for the network reconfiguration slice.
− The network reconfiguration function slice is the sum of network reconfiguration capabilities over the entire network, which cognitively aggregates and allocates the mutually independent abstract resources over the network.
− The service carrying function slice is the network function which provides direct carrying for diverse applications, which is intuitively shown as various service carrying networks with specific network capabilities.

The cognition function, on the one hand, directly provides the fundamental cognition function component for application carrying and on the other hand, abstracts and aggregates node resources and network resources. Thus, polymorphic services are realized with the cognition of characteristics, requirements and behaviours, so as to meet the requirements of various services.

I.2 Functions and concepts

I.2.1 Atomic network capability and atomic service

The atomic network capability (ANC) is the minimum kernel network functions that realize the fundamental transport capability of the network and supports the extension of network kernel functions. The atomic network capabilities are within the RPN layer and they are a collection of the most basic network functions derived from function decomposition and granularity refining of the network layer and the transport layer, including functions of, for example, forwarding, congestion control, traffic control, slicing and security. The atomic network capabilities are classified as basic atomic network capabilities and extended atomic network capabilities. The former is a collection of atomic capabilities that nodes must have, while the latter is a collection of atomic network capabilities extended for achieving specific functions.

The function entities between applications and atomic network capabilities are called atomic services (AS). These atomic services are the fundamental network service functions that support end-to-end data communication semantics, including customizable packet channel, transmission control protocol (TCP) traffic channel and user datagram protocol (UDP) messaging channel.

I.2.2 Combination between service chain and service path

For a particular network application, the atomic network capabilities need various combinations to 'adapt to' the application requirements. When an application requests its service requirements, the network reconfigures from nodes to network so as to adapt to the service requirements. The adaptation is classified into two types, node-level reconfiguration and network-level reconfiguration.

Concerning the node-level, the atomic network capabilities within the node combine dynamically into a sequence of atomic network capabilities with a certain order, forming the service stack, which is called the combination chain (CC). The combination chain is the logic structure with which the nodes transport packets. After data transport completes, the combination chain would exist for a period, which is called the idle period. During the idle period, if other applications send the same requests, then the idle combination chain is activated; otherwise, the combination chain would be deleted. Similar to atomic network capability, the combination chain is classified into public sub-chain and private sub-chain. The former is composed of the basic atomic network capabilities required by common applications, while the latter is composed of the atomic network capabilities for specific needs of certain applications.

As for the network-level, the network selects an optimal path from source to destination and the network nodes and links along the path shall meet the corresponding application requirements. Thus the 'node-link' sequence in the network-level that meets the transport requirements of applications is called the service path (SP). Essentially, the service path is a complex of the routing and the combination chain.

I.2.3 Polymorphic addressing and routing

In order to meet diverse application requirements polymorphic addressing and routing is used to solve the problem of supporting network addressing and routing when multiple network routing systems coexist.

The between/within domain routing protocols for reconfigurable networking are different from the open shortest path first (OSPF), routing information protocol (RIP) and border gateway protocol (BGP) routing protocols which are applied by legacy networks. Instead, routing protocols driven by diverse application requirements are adopted, so as to meet the restrictions of different quality of service and different security requirements.

The addressing of the reconfigurable networking supports separation of identity and location. Four kinds of identities can be derived including location, host, service and content, which replace the legacy IP address regarding addressing:

- The location identifier (LID), corresponding to the legacy IP address, is used for addressing in the IP architecture.
- The host identifier (HID), is used for host-centric addressing. The host performs as the main body in network communications. Interaction with the host and acquisition of content or a service are both achieved with HID, but the ultimate purpose of acquiring a content or a service is delivered to the upper level application process.
- The service identifier (SID), used for service-centric addressing, is a means of expressing communication purposes more directly, which eliminates the redundancy of converting a service name to a network layer address, directly making the service identity as the clue for addressing. In this way, SID performs as the basic communication main body.
- The content identifier (CID), used for content-centric addressing, applies mainly in content acquisition. The communication purpose is achieved with CID, which meets addressing is oriented to data content.

Polymorphic addressing is an addressing approach with multiple modes under the four addressing identities. Physical network nodes should at least support four kinds of addressing identities.

A polymorphic routing procedure can be described as follows: A reconfigurable router cognizes and acquires a network topological connection relationship and the application transport requirements according to the network status and resources. With the constraints of the topology and requirements, it runs polymorphic routing algorithms, building forwarding tables at the reconfigurable router nodes. Note that the four identities (LID, HID, SID and CID) correspond to four kinds of forwarding information, respectively.

I.2.4 Multi-dimensional cognition

Cognition means the intrinsic capabilities of self-learning, self-adaption, self-management and self-development with which the network comprehensively and multi-dimensionally extracts, analyses and integrates its real-time running status, resource distribution and application status, providing fundamental information for upper-level operations of the network reconfiguration.

Network multi-dimensional cognition can be classified into network status cognition and network resource cognition. Network status cognition acquires the transport requirements of all applications over the network with analysis of the network application traffic and forms a view of the network traffic distribution, providing requirement information for network reconfiguration. Network resource cognition analyses and abstracts the capability and running status of network devices and expresses network resources and status in the form of atomic network capabilities.

I.2.5 Dynamic self-adaptive reconfiguration

Based on the cognition of network status and network resources, network reconfiguration dynamically adjusts network capabilities so as to match the operations for application requirement variation. Network reconfiguration aims to achieve the adaption between network service capabilities and application requirements (including function requirements and capability requirements). The patterns of network reconfiguration can be classified into node-level reconfiguration and network-level reconfiguration, where the node-level reconfiguration is a combination chain (CC) reconfiguration, while the network-level reconfiguration is a service path (SP) reconfiguration.

I.2.6 Virtual reconfigurable service carrying network

A reconfigurable service carrying network is a dedicated virtual network according to network capabilities as well as the requirements and the characteristics of applications, which has highly flexible service capabilities and can dynamically make adjustments for specific types of applications.

In reconfigurable networking, network services are mainly provided as a way of building reconfigurable service carrying networks for users and applications. After network operators build reconfigurable service carrying networks for service providers according to their requirements, service providers can provide services for end users as virtual network operators. For example, after building a reconfigurable service carrying network that supports video applications, service providers can provide for end users' applications including high quality video-on-demand, IPTV, video conference and video telephone applications and can adjust the resource allocation according to networking status so as to ensure the network service quality. Figure I.2 shows an instance of the reconfigurable service carrying network.

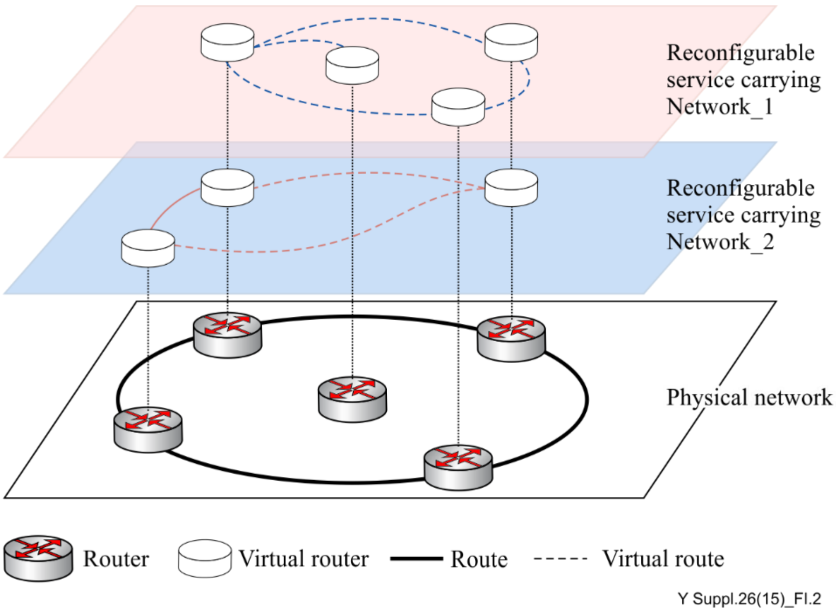

Figure I.2 − An instance of the reconfigurable service carrying network

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