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INVITED PAPER *Special Section on Networking Technologies for Dependable Networks*

Dependable Networks as a Paradigm for Network Innovation

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SUMMARY In past, dependable networks meant minimizing network outages or the impact of the outages. However, over the decade, major network services have shifted from telephone and data transmission to Internet and to mobile communication, where higher layer services with a variety of contents are provided. Reviewing these backgrounds of network development, the importance of the dependability of higher layer network services are pointed out. Then, the main aspects to realize the dependability are given for lower, middle and higher layer network services. In addition, some particular issues for dependable networks are described.

key words: *dependability, Internet, networking, contents, management*

1. Introduction

Dependability is the word expressing values for systems or services showing their availability and reliability to users or customers because of their integrity, trustfulness, and traits that can encourage someone to depend on them.

In the field of computing systems, dependability is well studied recently, and the attributes of dependability are recognized as the integration of availability, reliability, safety, confidentiality, integrity, maintainability and so on [1]. However, in the field of networks and network services, there is very limited discussion of dependability itself, even though there are some papers using the word "dependability" [2]. So, there is no given definition for the dependability of networks. But, the author considers that the dependability in the field of networks means comprehensive attributes consisting of availability, reliability, functionality, quality, security, survivability, scalability and so on, regarding the network and/or the network service for their users or customers. In a practical sense, dependability means that the network and/or the network service works the way a customer wants it to work, when the customer wants it.

In 1990's, these attributes of dependable network services were mainly demanded by business customers. In general, the business customers subscribe to high-class services, and usually negotiate with telecommunication companies regarding their needs which are not only about service functionality but also availability, reliability, survivability, scalability, and so on. So, telecommunication companies have been making a lot of effort to develop dependable network services for business customers, which have been known as self-healing network services, customer control services, dual-homing services and so on. Thus, in past, dependable networks meant minimizing network outages or the impact of the outages [3], [4].

By the way, over the decade, major network services have shifted from telephone and data transmission services to Internet services like E-mail service, WWW service, SNS (Social Networking Service), IPTV, etc., and to mobile communication services. As a result, the variety of network services have been greatly expanded, but customers are not always satisfied with these advanced network services. That reason may be coming from the fact that the service performance is not well guaranteed in terms of availability, reliability, quality, security, and so on. Concretely speaking, most of the newly developed services are provided using Internet (connection-less packet switching network using TCP/IP and/or UDP/IP protocol), which realize the network performance called "best effort" in terms of availability, reliability and quality. But, another reason is that most of the Internet services are poor in control and management capabilities for application layer networking and processing. As far as lower layer network services, the just-launched NGN (Next Generation Networks) can provide much more dependable network services compared to current network services given by ISP (the Internet Service Provider).

Dependability is a very natural but general demand of customers for network services, since human life are going to depend more and more on network environments in the future. Besides, future network services might shift to higher layers. Therefore, dependable networks must be the core paradigm for future network innovation.

In this paper, the author shows development trend of network services in the future, and points out the importance of the dependability of higher layer network services. Then, the main aspects to realize the dependability are given for lower, middle and higher layer network services. In addition, some particular issues for dependable networks are described.

2. Development of Network Services

Modern communications, starting with the telegraph in mid-19th century, has progressed dramatically and given immeasurable contributions to social development. Real benefits of modern communications are provided by the network services based on communication systems and network operation with the latest technologies in each period. The very brief steps of communication network progress are (I) tele-

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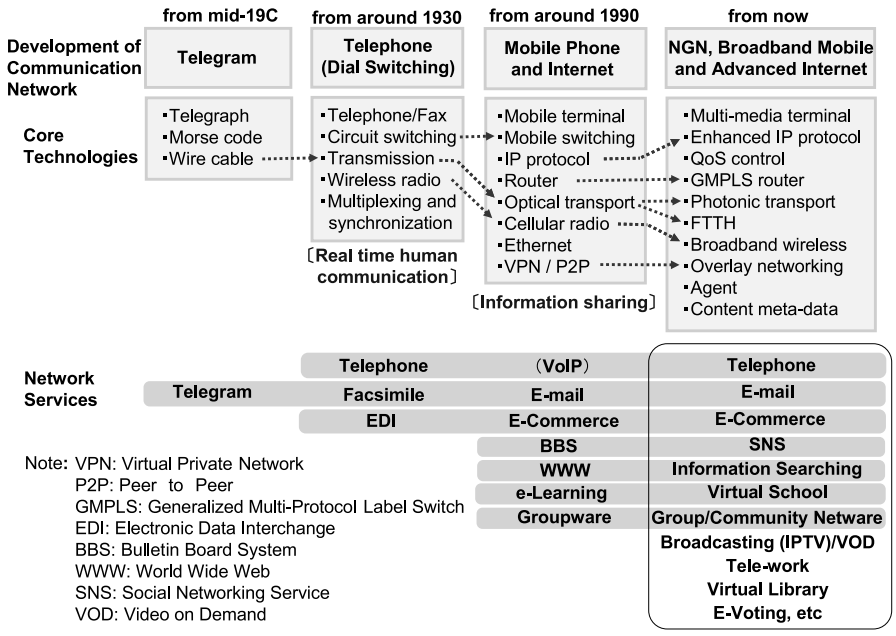

Fig. 1 Past and predicted future networks.

graph using Morse code telegraph and wires from mid-19th century, and together with using wireless radio popularized from around 1910, (II) dial telephone networks using transmission and switching systems from around 1930, (III) cellular mobile-phone networks rapidly grew in the 1990's and Internet using packet switching router and IP protocols popularized in the same period, and (IV) NGN (Next Generation Network), broadband mobile and advanced Internet might be popularized in the near future. These network progress steps can be summarized in Fig. 1 in conjunction with their core technologies and services. The core technologies mean main technologies with key roles leading to each step. On the one hand truly new technologies made a breakthrough to a new step, and on the other hand basic technologies evolved toward a new step. The latter ones are indicated with the dotted arrows in Fig. 1.

For the first step of modern communication, the telegram overcome long distance to permit exchange of messages and provided un-measurable effect, even though available place was limited and skillful telegraph operation works were required. Especially for ships, the radio telegram from around 1910 is only way to communicate with base stations or other ships during their voyage. It was indispensable for safe shipping. Hence, the telegram might have been a really dependable service for customers at that time.

The telephone is one of the most important social services in every country in the world. The dial telephone enabled natural conversations in real time without waiting. This is a quite attractive and useful communication means compared to telegram. It has penetrated households and business offices, like air on the earth. So during some period in past, the telephone might have been highly evaluated as a dependable network service.

The customer increase for mobile phones and the Internet was quite rapid in 1990's. These two new network services have enabled personal and multi-media communications. Furthermore, the Internet has enabled sending and receiving extremely large volume of information. Internet clients (PC terminals) and severs can work long hours without break, so that extremely large number of mailing like SPAM is possible. Such a large number of calls are impossible by telephone. This is a completely different situation from the telephone era. As a result, customers can easily share information or contents via the networks. Today, many application services are developed and provided over the mobile networks and/or Internet. However, these services have presently a lot of problems from the view point of the dependability of network services. In particular, the crucial problems are related to such security incidents as personal information leakage, computer virus, DoS (Denial of Service) attack, Web page altering, copyright infringement, and so on [5]. As for the personal information leakage, 993 incidents in Japan were reported via news media and Internet news services during fiscal 2006, according to the survey by NPO Japan Network Security Association [6]. The survey revealed also that the total number of victims of personal information leakage during same year was around 22 million, an increase of 2.5 times compared to 2005.

Today's network environment is evolving into the NGN (Next Generation Network) and advanced Internet. In these evolutional networks, major problems of the conventional Internet are going to be resolved, these are QoS (Quality of Service) guarantee, reliability and security assurance, and so on, and providing open API (Application Interface) for ASPs (Application Service Providers) as a network service enhancement. Over these evolutional networks, various application networks so-called overlay networks are ex-

pected to be developed and deeply penetrated. These networks could provide more dedicated or customized services to each customer group or community. In this way, the network environment is going into new era, where each network would be a kind of "cooperative platform" or "creative environment" for a project team, a hobby group, a voluntary community, and so on [7].

In such a situation, the customer might pay attention much more on smooth networking and processing of contents, not just QoS for information data transfer. Hence, the dependability of networks is going to increase necessarily in importance as a measure evaluating the customer satisfaction of network services. For example, QoE (Quality of Experience) is now studied instead of conventional study of QoS, which is now mainly focused on the network services of VoIP (Voice over IP) and IPTV.

3. Required Functions for Dependable Networks

Future networks will deliver many more customer-oriented services than today's ones. Network services would include high-level of information data networking as well as contents networking and processing, which are focused on each customer individual, customer group or customer community. Examples of these services are a virtual school using e-learning and video conference, a tele-work project team connecting members and related databases. They would require special service capabilities customized for their particular activities.

The macroscopic model of network is shown in Fig. 2 together with OSI (Open System Interface) 7-layer model. Macroscopic network model consists of three layers, which are "Network Infrastructure," "Information Data Networking" and "Content Networking and Processing." This macroscopic three layer model is too rough to design and implement actual networks, but is practically useful to explain the conceptual networking structure and functions.

The lower layer of "Network Infrastructure" is well known as the network resource for basic data transmission, which is equivalent to the layer 1 through layer 4 of OSI 7-layer model.

The middle layer of "Information Data Networking" includes today's VPN (Virtual Private Network) and P2P (Peer to Peer) networking, which is called Overlay Network in general. This layer's networking is realized usually over the network infrastructure provided by more than one ISP.

The upper layer of "Content Networking and Processing" is the content-oriented application which are given as a particular application service with networking and processing of contents, for example an agent service for E-mail handling, a secure document management service, a copyright processing service, an intelligent information searching service, and so on.

The main functions to realize dependable network service for each macroscopic layer are listed in Fig. 2. In order to realize higher layer network services with high performance and sufficient dependability, the lower macroscopic layer of network services is also required to be high performance and sufficient dependability. At the same time, it is needed that the macroscopic layered functionalities and their interfaces must be standardized to enable inter-layer cooperation.

In reference to the macroscopic layered networks, one of recent hot topics is overlay networking, which is mainly focused on the information data networking layer. In order to realize dependable overlay networking, well-designed management systems are required not only for networking security in conjunction with membership attributes, but also for effective data transfer control among members, depending on the traffic in the network infrastructure.

As for the content networking and processing layer, it seems there is a small number of approaches from the networking viewpoint. But, there are a lot of research activities regarding how to handle and/or process content through networks. In order to provide dependable network services, the functions for the content networking and processing layer

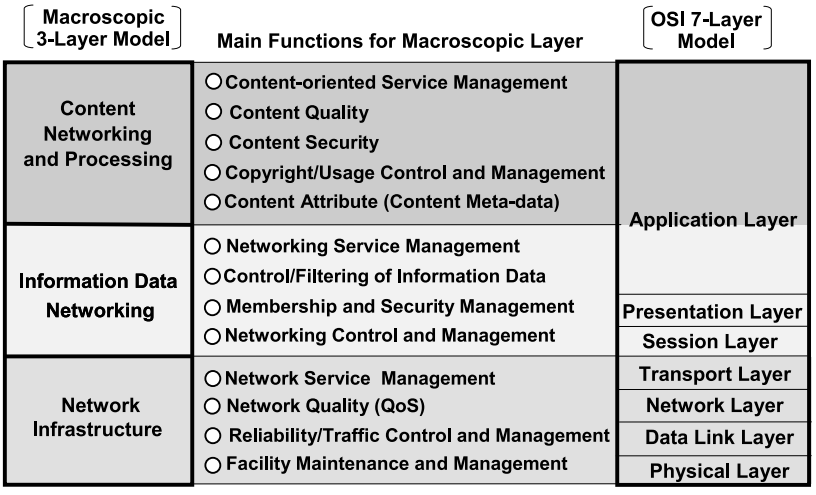

Fig. 2 Macroscopic 3-layer network model and main functions for each layer.

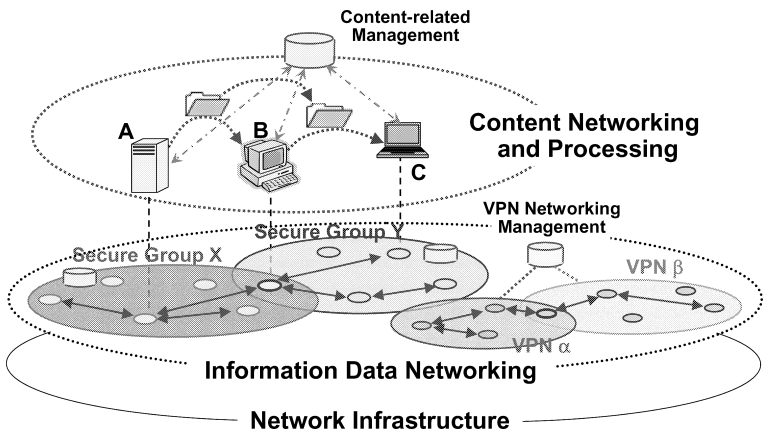

Fig. 3 Image of overlay structure of networks.

are extremely important. Because, content through networks are actual entities directly connected to customers. There are a lot of facts to loose security, reliability, lawful or regulated restriction, privacy, public order and standard of decency, and so on, due to the deficiency or the weakness of functionalities related to the contents networking and processing.

Overlay networks are definitely important in order to provide a dedicated "cooperative platform" or "creative environment" specialized to each customer group or each community. The issue is how to realize an effective network architecture to provide dependable network services as well as ubiquitous network services to customers. Figure 3 shows the image of overlay structure of networks reflected macroscopic 3-layer network model in Fig. 2. In the content networking and processing layer, the crucial issue is how to control and manage the content properly at the user terminal where content from different secure networks meet together. For example, in the case that the received content from the user A by the user B who are both members of secure network X are sent to the user C who is a member of different secure network Y, the network management system needs to check the content attributes like copyright, authority of user B and C, before user B sends out the content from the user A to the user C. As for content attribute, the content meta-data is the essential element to ensure dependability. As for content networking, the content-related management system must refer to the membership information which is controlled and managed in the information data networking layer. In some cases, several information data networking layer's networks may be related to the particular contents networking and processing layer application like a tele-work project. Because, project members are usually from different companies who belong to each company's secure network (information data networking layer). Thus, the inter-layer cooperation of management systems is also essential.

4. Research Issues toward Dependable Networks

4.1 Various Aspects for Dependable Networks

Since there is neither a complete definition nor reasonable criteria for the dependability of network services, it is very tough work to settle clear research objectives for dependable networks. At this stage, on the one hand, various research challenges from the dependability viewpoint should be encouraged. On the other hand, systematic study approaches should be accelerated to realize effectively and early dependable networks as a real network environment. For these purposes, various aspects to be studied are listed below.

(1) Network Infrastructure

- The convergence of conventional network services with NGN should be accelerated.
- The API (Application Interface) of NGN should be improved effectively to provide required functions to control the network resources from the overlay networks.
- New network architectures with new protocols starting from scratch should be studied (e.g. the New Generation Network (NwGN) project in Japan, the Future Internet Design (FIND) project by NSF in US, the future network projects in FP7 (7th Framework Programme in EU, etc.).
- Transfer capability with the least time delay should be provided for real time control through networks (e.g. network robotics, emergency system).

(2) Information Data Networking

- Distributed control and management of routing and connections is a key issue.
- Membership management is required to have strong security, privacy control, and customization capabilities.
- Flow control and filtering control for information data should be established.
- Address and routing, which is fundamental issue for networking, should be studied freely in the overly networks independent from the architecture of network infrastructures, so that new network architecture studies

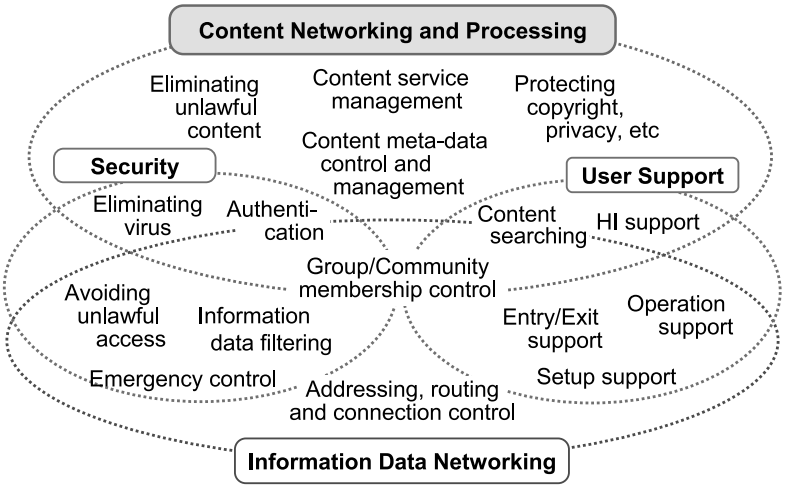

Fig. 4 Main study issues for dependable network services.

could be accelerated.

(3) Content Networking and Processing

- The main issues for content networking and processing are dealing with copyright, protecting security and privacy, and eliminating unlawful content.
- An appropriate content meta-data system is absolutely essential to control and manage content properly as they are delivery, copy, modification, etc.
- For the security of content use, a basic issue is to develop authentication systems related to target services.
- User support issues are very important, because customers' perception of the dependability of services may depend much on good or bad user support.

Dependable content networking and processing may not be realized without dependable information data networking as well as dependable network infrastructure. Specially, many functions in the information data networking layer would be tightly interdependent to develop actual dependable services. These relations are shown schematically in Fig. 4.

4.2 Control and Management of Contents through Networks

In dedicated networks as "cooperative platform" or "creative environment," customers request collection and/or exchange effectively various content such as data, document, videos, multimedia content and so on, as the need arises. In order to provide dependable services to these customers, the proper control and management of content to be collected and/or exchanged is an indispensable service function.

In this case that a dedicated network has no interaction with outside networks like an intranet, the content services to inside customers is organized by consistent control and management of content according to internal rules. In an intranet, the secure content management is attained by access control to the database according to the customer right to process the database contents.

However, in the open network environment for today and the future, dedicated networks have mutual interaction with each other in terms of content to be collected and/or exchanged. Even though each dedicated network is strictly isolated from outside networks, a customer belonging to a number of different dedicated networks have a problem as he/she has to control and manage content under his/her right to process them. In either case, a powerful processing system will be needed to control and manage the collection and/or exchange of content through networks in order to provide dependable content services in the future. For this, there are following two types of processing scheme.

(a) Centralized control and management: Content to be collected and/or exchanged is processed by the centralized content management system, together with CA (Certification Authority) center.
(b) Distributed control and management: Content to be collected and/or exchanged is processed at the customer's terminal based on the meta-data linking to content using each content identifier. The meta-data is located in a distributed database which records attributes, IPR (Intellectual Property Right) and other tag information regarding content itself.

Taking into account the processing speed and flexibility for various categories of contents, the distributed system (b) will be preferred. As for content meta-data system, DOI (Digital Object Identifiers) and CrossRef system, "Content-ID" system and "Handle System" are typical examples. DOI and CrossRef system is popular in the electronic book and scientific journal area [8]. "Content-ID" system is mainly used for video stream contents, which includes a unique code embedded into the stream by watermark technology and complete meta-data set required to manage contents [9]. "Handle System" is useful for content collection from Web servers or repositories by an HDL (Handle) identifier and location resolution servers [10].

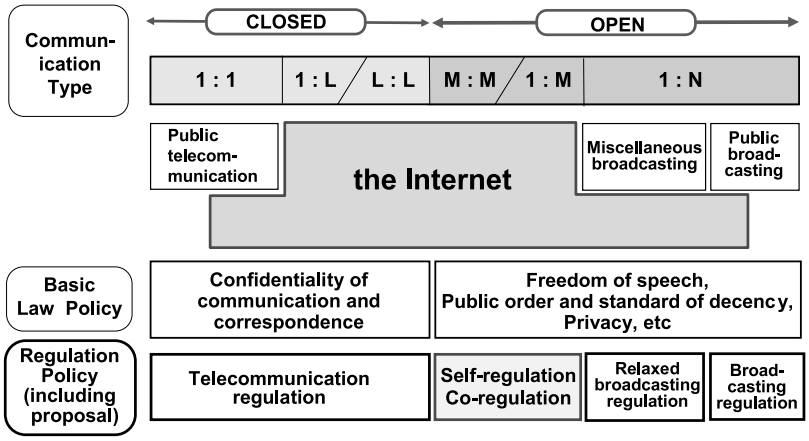

Fig. 5 Regulation model for communication services.

In order to realize dependable content control and management, these kinds of meta-data systems must be applicable to all types of content. So, the content meta-data systems for every content type and their standardization must be developed extensively.

4.3 Relationship between Network Systems and Legal Systems

Dependable networks can not be realized by only the development of technologies. The illegal use and/or provision of network services has become the threat against the dependability. Proper law and regulation are indispensable to guarantee the dependability of network services.

The penetration of the Internet services has changed completely the situation of regulation. Traditional law systems of public telecommunication and public broadcasting were historically developed separately and almost independently. In past, they were completely different areas from the viewpoint of service and also technology. Thus, the basic law and policy for these two areas is also completely different. By the way, the Internet covers not only these classical two areas but also a third area. The third area works as an expanded telecommunication, and same time it works as an expanded broadcasting. Many new services provided over Internet may belong to this third area, for example ML (Mailing List), Web, SNS (Social Networking Service), on-demand video and so on. This situation is illustrated in Fig. 5. In this figure, the third area is divided into 1:L, L:L, M:M, and 1:M. L means a rather small number of persons and they are doing private telecommunication like a conference phone or a simultaneous mailing. M means a rather large number of persons and they are a user of Web, on-demand video, and so on. ML is belong to not only 1:L but also 1:M for example ad mails.

What are reasonable regulations? Answering this question is big challenge. An important point is the segregation between closed and open communication. As far as closed communication, the network services over Internet should be regulated by traditional telecommunication regulation basis. The open part of communication should be carefully discussed and prepare practical regulation rules and laws if necessary. In any case, the area of 1:M and M:M is needs new regulation policy. The idea of self-regulation or co-regulation would be suitable for the regulation of service providers in this area. Anyway, these new regulations should be harmonized with the control and management of network services.

4.4 Definition and Evaluation of Network Dependability

The definition of dependability for network services should be discussed more. For this discussion, the field of computing systems may help us. For computing systems, dependability is three characteristics into following: attributes (availability, reliability, safety, and so on), means (fault prevention, fault tolerance, fault removal, fault forecasting) and threats (faults, errors, failures). As for the dependability of network services, additional viewpoints must be investigated especially for the human factors of customers as well as the behavior of service providers.

The evaluation of the dependability of network services is quite a new research topic. And, it is very important to study together with the definition of dependability for network services.

5. Conclusion

Dependability is a very natural and basic demand of every customer of networks. Networks and network services are going to increase in importance in the future advanced information society, where our activities are expected to heavily depend on the network environment. Hence, “Dependable Networks” must be the core paradigm for network innovation.

Future network environment will provide more intelligent and more customized services compared to today’s ones, which allow customers in each group or community to work collaboratively and creatively while avoiding the excesses of openness. It means the future network services are

going to include increasingly higher layer functions. As a result, the study of dependable networks should be weighted on the macroscopic layer of content networking and processing. At the same time, the dependability of network services should be pursued towards overall solutions with technical and legal harmonization.

In order to accelerate the innovative study on dependable networks, the definition of "dependability" must be discussed intensively and established in the field of networks. In addition, a practical methodology to evaluate the dependability must be developed and popularized.

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