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A NEW QoS ROUTING ARCHITECTURE IN NGI

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Abbreviations

NGN: Next Generation Network
NGI: Next Generation Internet
IETF: Internet Engineering Task Force
ITU: International Telecommunications Union
ITU-T: International Telecommunications Union - Telecommunications standardization sector
OSI: Open System Interconnection (released by International Organization for Standardization)
IEEE: Institute for Electrical and Electronic Engineers
IP: Internet Protocol
QoS: Quality of Service
MPLS: Multiple Protocol Label Switching
IntServ: Integrated Service
RSVP: Resource Reservation Protocol
DiffServ: Differentiated Service
DV: Distance Vector (Routing Protocol)
LS: Link-State (Routing Protocol)
OSPF: Open Shortest Path First
RFC: Request For Comments
TCP: Transmission Control Protocol
UDP: User Datagram Protocol
ATM: Asynchronous Transfer Mode
PNNI: Private Network-Network Interface

Abstract

After a thorough understanding of the relevant research knowledge and the key theory of NGN, I describe the research objectives and the recent development of the QoS routing in this thesis. QoS routing is regarded as the key part in the problem of the next generation of integrated-service network. A new routing algorithm is put forward in this thesis, which is better than OSPF in some aspects. As for the experiment, NS2 is chosen as the simulation environment, and some other experimental results are also included to manifest its strongpoint. The development and requirement of NGN is described in Chapter One; The definition and types of routing and the basic theories of QoS routing are described in Chapter Two; The development and research method of QoS are focused in Chapter Three. The new routing algorithm and simulation is proposed in Chapter Four.

[Key words] NGN, QoS, Unicast, Routing Algorithm, OSPF, Self- organizing

Chapter1

Introduction of NGN

"The traffic in the Internet is exploding as it is doubling every year" [50]. With the rapid increase of the Internet user and the complexity of the Internet application, there is an increasing demand for the multi-functions of Internet, which includes not only the bandwidth and performance of the transmission media and communication equipments, but also some key technologies such as routing algorithm, resource allocation and so on.

1.1 The Background Information

There are more and more applications being transmitted on the Internet, which include the real –time applications, the various audio and video formats interactive applications, and the diverse data traffic. So, though Internet can work effectively now, it will face the future problems such as: the rapid increase of the internet users, the different application types and the heavy overhead. Therefore, with the further development of the Internet, the more and more problems and disadvantages of the current Internet will emerge. The key point is: the traditional IP routing used Best-Effort system to focus on the problem of how to connect effectively, but it could not guarantee the service and function of the intelligent routing. As a result, it will not correspond to the future development of Internet.

To address these problems such as security, address allocation, services differentiation, and Quality of Service, the government of U.S.A has declared the plan about NGI (Next Generation Internet) in October 1996, in order to promote development and implementation of the future Internet [43]. And some other countries have set up their plans and researches to correspond to future development of the Internet.

The " IPv6", regarded as the latest version of IP, was explored to update or replace IPv4. The widely used IPv4 has not changed since 1981. Though as one of the core protocol of the current Internet, IPv4 can either solve the problems or meet the requirements of the development of the Internet, in spite of its strong function. IPv6 offers a huge space of IP addresses with 128 bits, which is the 2^{96} times as much as the IPv4 addresses so that IPv6 can solve the problem of address [8] [24]. Though, IP is not the only protocol of TCP/IP stack, and the problem of address space is not the only requirement of Internet development. IPv6 offers more security and QoS support and so on.

To satisfy the requirements of the users and practical applications, as well as for the effectiveness of the Internet, it is necessary to make QoS routing play an important role in the future Internet. Hence QoS routing is the vital technology used in next generation Internet, which is the focus of my thesis.

1.2 NGN

The next generation network must provide reliable service for more and more audio, video and multimedia data traffic. The NGN research is inevitably developing in spite of controversy [21].

NGN is a concept to define and deploy networks; such networks are divided into different layers and planes as well as open interfaces, which could provide a platform for service providers and network operators. And such a platform could evolve step by step in order to meet demands for establishment, deployment and management of ever increasing new business [13].

In Feb.2004, after heated discussion, ITU-T SG13 conference defined the NGN [22] as: NGN is a Packet Based Network; it can offer multifold services including telecom services, has the ability to use bandwidth effectively and supports QoS, divides a network into service functions and substrate transmission technology. NGN allows users to have random access to the networks of different service providers, allow universal mobility and make sure users that services are coherence and singleness.

The implementation of QoS in IP networks should not only rely on one single technology, but should on the combination of the data plane, control plane, traffic plane, management plane and so on, for it is an integrated technology of multi-plane or multi-layer. With the deep understanding of this point, the relevant researches in standardization will be advanced in various aspects. However, the implementation of these thoughts needs the solutions to the problems of management and technology.

For many service providers, the most important challenge they must face, is how to find an effective and practical way to offer satisfactory guarantee for end-to-end QoS with various services. At the same time, the performance of the whole network must be fully considered. It is the objective of the future development to achieve a new IP network supporting QoS. There are some solutions at various layers and for some corresponding problems: RSVP, IntServ, Diffserv, MPLS, strategy managing and so on, although it is impossible to make an end-to–end QoS solution to problem. The reasons are listed as follows:

1) Equipments made by different manufacturers implement different QoS in their own way.

2) There is no universal criterion and standard for QoS. To standardize it, IETF and ITU-T exert an important influence. IETF works out the definition of the protocol implementation and ITU-T emphasizes whole framework and the formation of IP performance specifications. Internet II and IPCablecom and others offer their solutions with end-to-end QoS in IP networks.

Three IP QoS -centered proposals have bee established.

“1) Y.qosar, described QoS support framework in a Packet Based Network; it was composed of a set of QoS function modules, what cover control plane, data plane and management plane. It has been accepted.

2) Y.123.qos, described a QoS architecture for Ethernet-based IP access network.

3) Y.e2eqos is an end-to-end QoS architecture for IP/MPLS networks. Especially for the core layer of network, MPLS was supported as a key technique and QoS routing and traffic engineering was also supported.” [22]

Chapter 2

QoS Routing

It is more and more popular to make the application with timely delivery over local or wide area network, especially over Internet. Despite the commonness of high-speed and video/audio/data compression, it is urgent to find out a better solution to network technology. The growth in data traffic and a wide range of requirements of emerging applications call for better and new mechanisms for control and management of communication networks [3].

QoS (Quality of Service), just as its name implies, describes how a user is satisfied with a service offered by a provider. There is an example in reference [12] for the notion of QoS with lively description: Because the frequency of eye blinking is one fiftieth of a second, if the video series appear on the monitor (such as CRT) at the rate of 25 to 30 frames per second, the viewer will sense the automation of the picture. But if the some frames are interrupted by the information loss or delay on Internet, the human eye's receiving system will sense the non-continuity of the pictures. The human ear receiving system has the anti-jamming ability against the minor distortion of the signal. . The loss rate of the audio signal less than 5% to 10% is acceptable, according to different coding system. Information loss is due to the no periodic noise or loss of syllable. As for IP telephone, the long end-to-end delay will make the receiver wait a long time to speak. In some audio double-way communication, the high delay causes the communication failure.

2.1 Introduction of QoS routing

In Internet, many contradictory factors compete for the same resources: senders try to send traffic with sometimes very high rates and bursts; receivers expect to receive messages with low delays and high throughput; service providers try to get the maximum profit with the minimum investment in network infrastructure [12]. Traditionally, current Internet (refer to IP mostly), based on best-effort system, provides a best-effort service. Traffic is transported as quickly as possible, but there is no guarantee for it, it is sufficient to process many traditional services such as e-mail and ftp, but the proportion of these services in Internet is decreasing. Integrated services networks are expected to support multiple and diverse applications, with various quality of service (QoS) requirements. The actual QoS metrics of interest are likely to vary from one application to another, but are projected to include such measures as cell loss, delay, delay jitter and bandwidth guarantees. The Table 2.1(1) [9] shows the QoS requirement of some applications, and explains that different traffic flows may have different requirements in terms of quality of service (QoS). For example, the best route through a network for a voice call may not be the best for a file transfer [7]. There are many aspects in QoS studying, including packet scheduling, QoS routing, resource reservation, call admission control, and so on. It is the process of selecting the path to be used by the packets of a flow based on its QoS requirements [13, 14, 15]. QoS routing will be discussed later. Admission control will happen while user and network system are negotiating about QoS requirement: if a QoS requirement is too exigent to be supported, it may possibly be depressed. At the ports of routers and switches in network, to ensure QoS requirement for users, resource reservation must be performed.

Another definition: QoS is a set of quality promise about information transmission between the senders and receivers, or between users and integrated service network. In other words, Quality of Service includes two facets, one is the service that a user asked while using multimedia communication on Internet with the expected performance and quality, and the other is how that is supported by the service provider.

Applications	Metric	Range of requirement
FTP	Bandwidth	0.2~10Mbps
Telnet	Delay	≤800ms
Telephone	Bandwidth	16kbps
	Delay	0~150ms
	Delay jitter	1ms
	Packet loss ratio	$\leq 10^{-2}$

MPEG-1	Bandwidth	≥1.86Mbps
	Delay	250ms
	Delay jitter	1ms
	packet loss ratio	$\leq 10^{-2}$ (not compressed)
		$\leq 10^{-11}$(compressed)
HDTV	Bandwidth	≥1Gbps(not compressed)
		≈500Mbps (lossless compressed)
		20Mbps at least (compressed)
	Delay	250ms
	Delay jitter	1ms
	packet loss ratio	$\leq 10^{-2}$ (not compressed)
		$\leq 10^{-11}$(compressed)

Table 2.1: QoS requirement of some applications [9]

QoS control is considered as the hinge of Internet integrated services. The goal of QoS control is to offer differentiation between services and guarantee of performance. Though, in network, especially in large-scale network such as Internet, to support QoS is very difficult. It needs holistic cooperation from every layer of OSI 7-layers model and every network element.

The further Internet goes ahead, the more various and heavier traffic will be on the network; so researches for Internet QoS will go deeper. IETF has divided QoS control into two parts: integrated services model and QoS implementation. They established a series of definitions and standards from 1997. The design of integrated services was then proposed: RFC2211 [58] defining Internet controlled-load service, RFC2205 [5] defining RSVP, RFC2212 [46] defining Internet guaranteed service, RFC2215 [47] defining Internet IntServ architecture and RFC2216 [48] defining QoS service criterion [9]. Scalability of IntServ was limited, and difficult to implement, then IETF proposed another QoS architecture, DiffServ. To this day, Internet QoS is still a hot issue in Internet research and development.

2.2 Routing and network layer

The network layer in OSI reference model is the same as the Internet layer (IP) in the TCP/IP stack with their functions, and the most important function in both layers are routing. Furthermore, network layer is a very important layer in OSI reference model and actual networks. It is essential to make an improvement in routing algorithm.

2.2.1 Introduction of routing

Routing is a main function of a router, and an important part of whole process of communication. Routing a packet, is also called Path Determination, occurs at network layer, and enables a router to evaluate the available paths to a destination, and to establish the preferred handling of a packet. Routing services use network topology information when evaluating network paths. Routing consists of two basic tasks: the first is to collect the state information and keep it up-to-date, the second is to find a feasible path to destination based on the information collected.

Network routing essentially consists of two identities, the routing protocol and the routing algorithm. The routing protocol supplies each node in the network with a consistent view of that topology and, in some cases, of its resources at some moment in time. The routing protocol deals with the complex dynamic processes such as topology updates, determination of significant changes, and the flooding of topology information to each node in the network. The dual of the routing protocol, the routing algorithm, assumes a temporarily static or frozen view of the network topology provided by the routing protocol. The routing algorithm provides the intelligence to compute a path from source to destination, which is possibly subject to constraints and mostly optimizing a criterion [19]. This thesis use NS2 as the simulator, and put focus on static and session routing. Within static and session routing of NS2, the distinction between routing algorithm and routing protocol was blurred [30], thus this thesis will not differentiate them clearly.

2.2.2 Routing algorithm

Routing protocol accomplishes routing through the implementation of a specific routing algorithm. Examples of routing protocols include RIP and OSPF. Most routing algorithms can be classified as one type of two basic algorithms: Distance Vector (DV) and Link-State (LS). The distance-vector routing approach determines the direction and distance value (vector) to any link in the network. The link-state (also called shortest path first) approach computes and keeps topological information of the whole network through the SPF algorithm, and re-computes the exact topology of the entire network while topology is changed. Another type, the balanced hybrid approach combines aspects of the link-state and distance-vector algorithms, such as EIGRP. The first twos are discussed in this thesis.

DV: Distance-vector-based routing algorithms pass periodic copies of a routing table from router to router (node to node). These regular updates between routers (nodes) communicate topology changes. Each router receives a routing table from its directly neighbor. The algorithm eventually adds up the network distances so that it can maintain a database of network topology information. DV algorithms do not, however, allow a router (node) to know the exact topology of a network.

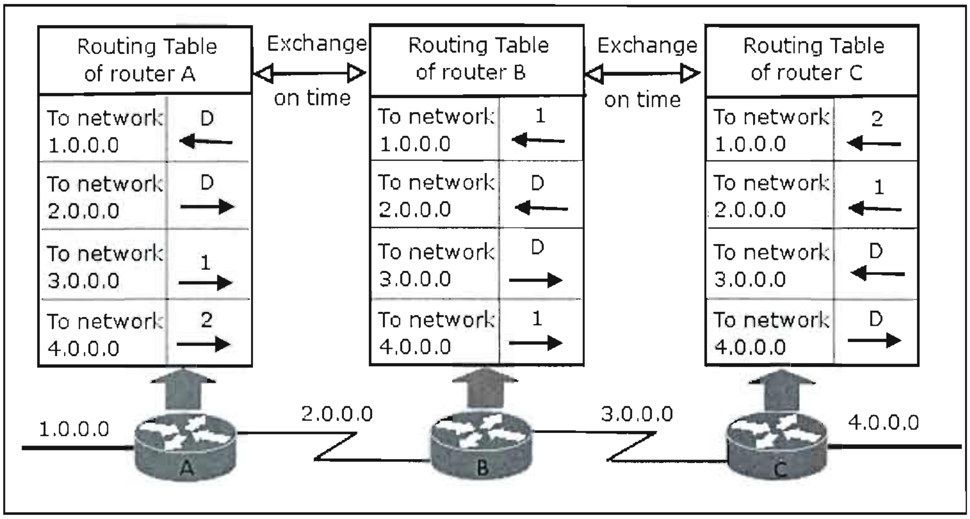

Figure 2.2.2(1) DV

DV call for each router (node) to send its entire routing table to each of its adjacent neighbors at every interval. The routing tables include information about the total path cost (defined by its metric) and the logical address of the first router on the path to each network contained in the table. DV routing is applied in NS2 by Distributed Bellman –Ford routing: the distance of the interval is 30s in RIP, while that is only default 2s NS2 (used for simulation)

In DV routing, there are some problems :such as “routing loop” and “counting to infinity”, thus DV is not suitable for large-scale network. So, this thesis is inclined to choose LS as the reference algorithm.

LS: Link-state based routing algorithms, also known as SPF (shortest path first) algorithms, maintain a complex database of topology information, and a link-state routing algorithm maintains full knowledge of distant routers and how they interconnect. Link-state algorithms rely on using the same link-state updates. Whenever a link-state topology changes, the first router (nodes) which become aware of the changes will send out the information to other routers(nodes) so that all other routers can use it for updates. This process involves the transportation of the common routing information to all routers in the network for the convergence.

Link State (LS) routing algorithms have been fairly successful in best–effort network routing. Routers use flooding to disseminate LS information. Each router initiates the flooding of LS information for the links it is attached to [64].

Within static and session routing of NS2, Dijkstra's all-pairs SPF algorithm is used to compute route, it is the essential of LS.

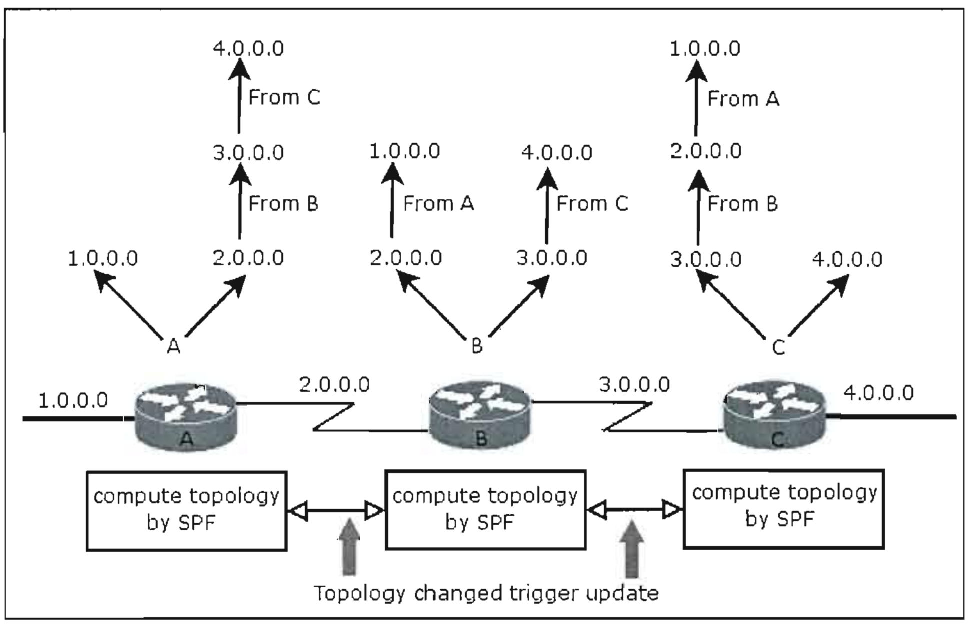

Figure 2.2.2(2) LS

2.2.3 Convergence

Generally, the routing algorithm is fundamental to dynamic routing (session routing in NS2). Whenever the topology of a network changed, every node needs new knowledge. The knowledge needs to reflect an accurate, consistent view of the current topology. This view is called convergence. When all nodes in a network operate with the same information, the network is said to have converged. In other words, convergence occurs when all nodes use a consistent perspective of network topology. After topology changed, routers must recomputed routes.

The process and the time required for re-convergence vary from routing protocols. Fast convergence is a desirable network feature because it reduces the period of time in which routers would continue to make incorrect routing decisions.

2.2.4 Exterior Gateway Protocols and the Interior Gateway Protocols

As for the autonomous system, there are two types of routing protocols: the Exterior Gateway Protocols (EGPs) and the Interior Gateway Protocols (IGPs). "Exterior Gateway Protocols route data between autonomous systems. An example of an EGP is BGP (Border Gateway Protocol), the primary exterior routing protocol of the Internet."[10]

BGP is the Exterior Gateway Protocols designed for the TCP/IP Internet. BGP is not the algorithm completely based on LS or on DV. Its main function is to exchange the information with other autonomous system. Each autonomous system can run different Interior Gateway protocols. BGP are being developed to meet the demands of rapid development of the Internet.

2.3 Theory of QoS Routing

Routing algorithm that make use of the information related to the network status, as well as to QoS requirements of the traffic being routed, are generally known as QoS routing or constraint–based routing (QoS based routing).

Although there are high bandwidth links in the Internet, they can not solve all problems. The best-effort service supported by traditional IP can only provide one treatment for all types of flows, which is not good enough for many applications such as real-time applications, and IP does not support applications with QoS constraints. It degrades the efficiency of actual network resources utilization, and is inefficient to integrate service applications [25].

QoS routing has been receiving considerable attention in recent years. It is considered a very promising method for enhancing integrated services networks performance and possibly one of the available techniques for the deployment of the future Internet [17, 32].

2.3.1 Unicast and Multicast

Most routing problems can be divided into two classes: Unicast routing and multicast routing. The definition of them is shown by [49]. The difference between unicast and multicast at QoS routing is whether to find a network path between two end users or a network tree rooted at the sender and covering all receivers, which can meet the requirements of QoS. In this thesis, we discuss unicast mainly. In short, we consider the situation of a sender and only one receiver (called "point to point" in the part of unicast in reference [1]).

2.3.2 QoS Metrics

Network layer has a critical role to play in the QoS support process. It provides the desired QoS by considering the metrics in the path selection process [39]. And QoS metrics play a very important role in providing better QoS. When a routing algorithm updates a routing table, its primary objective is to determine the best information to include in the table. Every routing algorithm interprets what is best in its own way. The metrics is the actual tool to compare different routing algorithm(s). Typically, the smaller the metric value, the better the path.

Many metrics base on single parameters of a path or link in network. Some complex metrics are calculated by combining several parameters.

The value of a metric over the entire path can be one of the following types [1]:

[1] Additive metrics:

It can be represented mathematically as follows

$$f(p) = \sum_{i=1}^{LK} f(lk_i)$$

Where *f(p)* is the total of metric *f* of path *(p)*, is lk_i a link in the path *(p)*, *LK* is the number of links in path *(p) and i*=1 ,.... , *LK*.

Delay, delay jitter, and cost are examples of this type of composition. Delay is the time taken from point-to-point in a network [36]. Delay jitter is one kind of jitter referred to in RTSP. It is the fluctuation/variation of end-to-end delay from one packet to the next packet within the same packet stream/connection/flow.

[2] Multiplicative metrics:

It can be represented mathematically as follows

$$f(p) = \prod_{i=1}^{LK} f(lk_i)$$

Packet loss ratio, indirectly, is an example of this type of composition. The reason for the word of "indirectly", is that loss probability metric can be easily transformed into an equivalent metric that follows the multiplicative rule.

[3] Concave metrics:

It can be represented mathematically as follows

$$f(p) = \min(f(lk_i))$$

Bandwidth is an example of this type of composition. The bandwidth we are interested in here is the residual bandwidth that is available for new traffic. It can be defined as the minimum of the residual bandwidth of all links on the path or the bottleneck bandwidth.

2.3.3 The objective of QoS routing

Obviously, the various and complex services in current Internet make the service requirements more complicated due to the multi-metrics. QoS routing was considered one of the key issues. A constraint-based routing protocol can generate paths that satisfy certain specified constraints, such as routing policy constraints or quality of service (QoS) constraints. Routing with QoS constraints is also known as QoS routing, and is a longstanding research topic [17].

The QoS routing is different from traditional best-effort routing. It is connection-oriented like TCP rather than the connectionless UDP or IP in the best-effort routing, which can provide guaranteed service by resource reservation. The goal of QoS routing solutions is two-fold: (1) satisfying the QoS requirements for every admitted connection and (2) achieving the global efficiency in resource utilization.

The task of QoS routing is to search for a feasible path to satisfy the QoS requirement with collecting and keeping the up-to-date information. A feasible path (path in unicast and tree in multicast) is defined as the one which has sufficient residual resources to satisfy the QoS constraints of a connection. The process of searching for a feasible path greatly depends on if the information collected or kept is accurate and timely. That is just what QoS routing algorithm (routing protocol) are required. Certainly, concision is another point, for the reason of reducing load.

2.3.4 Routing problem

Within unicast, there are 4 basic routing problem, link-optimization routing, link-constrained routing, path-optimization routing and path-constrained routing. These basic routing problems can be solved by Dijkstra's algorithm or Bellman-Ford algorithm directly or indirectly. Many composite routing problems can be derived from the above four basic problems. The figure2.3.4 which is cited from reference [49] describes each of them. Among which, there are two NP-complete problems, and there are two important assumptions as follows: (1) the QoS metrics are independent, and (2) they are allowed to be real numbers or unbounded integer numbers. If all metrics except one take bounded integer values, then the problems are solvable in polynomial time by running an extended Dijkstra's (or Bellman-Ford) algorithm [45]. If all metrics are dependent on a common metric, then the problems may also be solvable in polynomial time.

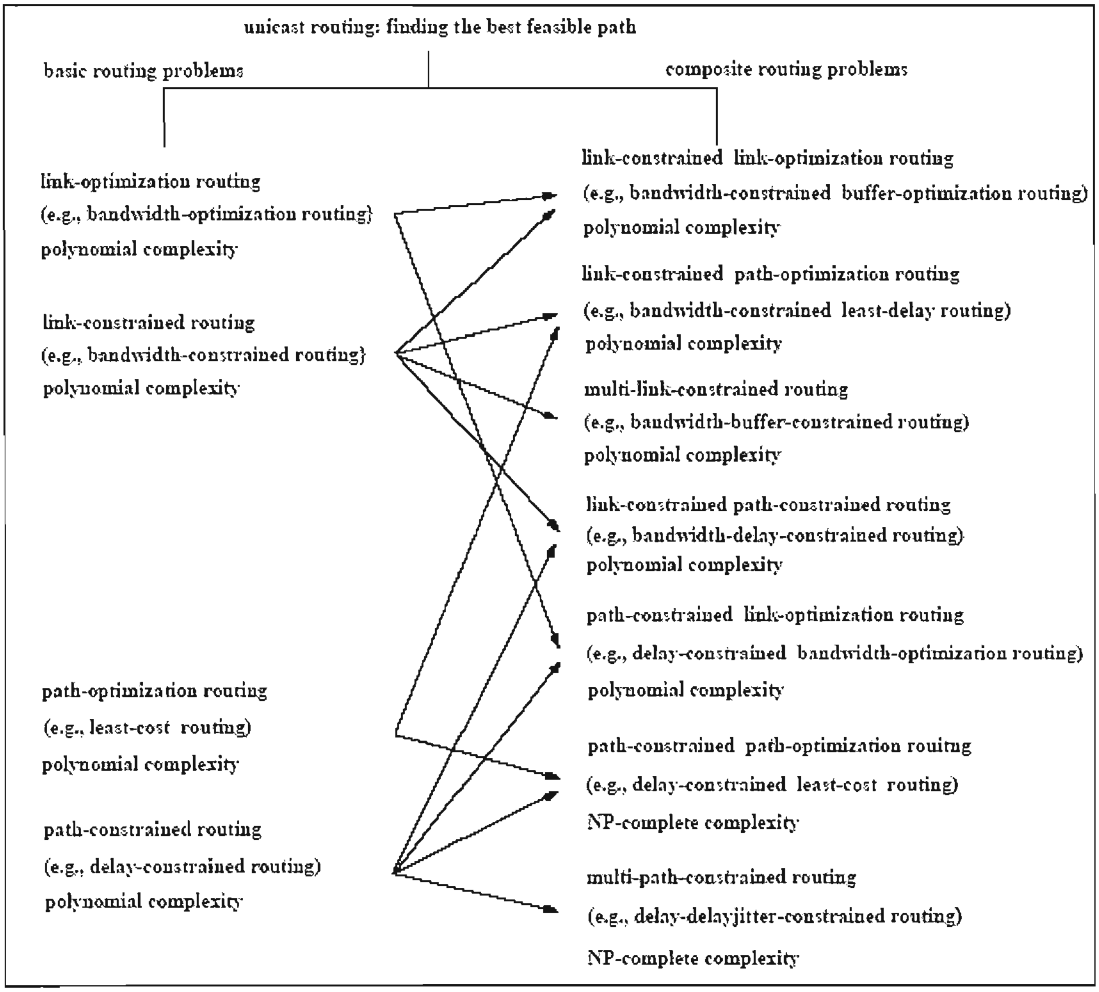

Figure2.3.4 Routing Problem in Unicast [49]

2.3.5 Routing Strategies

According to the way how to maintain the state information and how to search for a feasible path, several routing strategies are classified as: source routing, distributed routing, centralized routing and hierarchical routing. And we discuss mainly the first and the second following.

Source routing is simpler than distributed routing, and can search for a feasible path more effectively [9]. The source node calculates the entire path locally, and maintains a complete global state. It avoids dealing with the distributed computing problems such as distributed state snapshot, deadlock detection and distributed termination problem. Many source algorithms are conceptually simple and easy to implement and evaluate. In addition, it is easier to design heuristics for some NP-complete routing problems than to design distributed one.

The weaknesses of source routing are obvious. Every node maintains the global network state, so it has to be updated frequently to get the network parameters such as unused bandwidth and delay in time. The update overhead is high. The link-state algorithm only provides approximate global state in a large-scale network because of the aim to reduce update overhead, then the failure to use an "existing" feasible path may occur and this will cause an increase in network overhead. The computational task at every node is a high overhead too. In summary, source routing has higher overhead, and shortage of scalability.

Distributed routing uses distributed computation to compute a feasible path. Most distributed routing algorithms need a distance-vector protocol or a link-state protocol to maintain a global state in the form of distance vectors at every node. Based on the distance vectors, the routing is done on a hop-by-hop basis. The distributed routing distributes the computation task among the intermediate nodes between the source node and the destination node. Apparently, it is possible to search multiple paths for a feasible path. Hence, the chance of successful routing increase and network overhead relatively reduces. In addition, distributed routing has better scalability than centralized routing.

Some distributed routing algorithms that depend on global state have the same weakness as a source routing. Other distributed routing algorithms which do not need global state tend to send more messages, and routing loop may occur like the situation described in DV routing. It is very difficult to design an efficient distributed routing algorithm for the NP-complete problems.

Centralized routing all routing decisions are made by some designated node, such as a network control centre.

Hierarchical routinghas been used to cope with the scalability problem of source routing in large-scale networks.

2.3.6 The problems in QoS routing

There are mainly three advantages of QoS routing: it enables creation of virtual-circuit-like services over IP networks, improves user satisfaction by increasing chances of finding a path to meets the QoS constraints, and improves network utilization by finding alternate paths around congestion spots [17].

However, providing different quality-of-services (QoS) support for different applications in the Internet is a challenging issue [66]. Decision with multiple objectives is very different from decision with only one objective. The multiple objectives problem do not have uniform measured standard and perhaps make some contradiction. In general QoS routing has further objectives: minimum end-to-end delay, packet loss ratio and cost, maximum bandwidth, and least consumption of network resources. Among these above-mentioned objectives, the measurement unit is different. Moreover, cost is not fixed measurement which is determined according to resource management policy. Thus, it is impossible to actualize multiple objectives in a physical sense. On the other hand, the contradiction among these objectives makes it impossible to optimize all objectives. Perhaps, a particular objective is emphasized while another one may get worse.

On the other hand, network routings in general rely heavily on network's state information on resource availability at network nodes and links. In order to keep network state information accurate, many parameters associated with QoS requirements must update in time. Unfortunately, this is practically impossible when the network is highly dynamic and changes are frequent, because it brings out high computational cost and protocol overhead. Thus, network routing algorithms must deal with the situations in which network state information is inaccurate [15, 49].

These two intractable problems must be faced to for QoS routing. QoS routing algorithms try to find out an optimal path not only to satisfy a single application but also to avoid the whole network performance degradation, so a trade-off between accuracy of network state information and network overhead must be made [12, 40]. In general, network information update timing can use two methods: continuous or periodic. It can also be dictated by a major load change or a topology change; these are the two mechanisms applied presently.

Chapter 3

Related Research Background

Since 1990's many algorithms were put forward from the researches on QoS.

The requirement of QoS mainly refers to constraints and optimization of metrics of network link or path. These metrics include: delay, delay jitter, bandwidth, packet loss ratio, load, cost and so on. Hence in reference to [49], the routing problems are classified as four basic types: link-constrained routing, link-optimization routing, path-optimization routing and path-constrained routing, and It is thought that other composite problems are derived from these four basic ones.

3.1 Research of QoS routing

QoS control was considered as the key question to support integrated service in Internet. Lots of QoS supporting works, which are developed for the switches and protocols of ATM networks, laid the solid foundation for IP network. [9]

Some QoS-related researches focused on hardware level, such as reference [29] in which writers proposed their design of QoS-capable IP router. Though it is a good idea to let hardware work according to the different demands of the applications, it will rely heavily on the hardware manufacturers. Therefore more research works will be dedicated to the invention of new algorithms or the improvement of the existing algorithms.

Here is the commonly-used research method: a network is modeled as a graph <V,E>. Nodes (V) of the graph represent switches, routers and hosts. Edges (E) represent communication links (because of different analysis method and objectives, the models of the graphs may vary from each other). The research method is: to make the NP-complete problem to a simpler one, therefore which can be solved in polynomial time and then used to solve the new problem by either an extended Dijkstra's algorithm or an extended Bellman-Ford algorithm. In general, time complexity and communication complexity of an algorithm, described with V and E, will be an important measurement.

In addition, there is another important concern on whether it is worthwhile to do the research work with QoS routing. In order to obtain the benefits by QoS, costs must be paid to invent new routing protocols or to improve the existing ones. At the same time it may cause the problems of potentially higher communication, processing and storage overhead. And the solution must be found from the practice application of QoS routing algorithm so as to prove the value of QoS routing. During the process of finding the solution, much research has been done to evaluate or compare algorithms deployed. As for the relevant researches, besides the simulator experimentation, some quantitative analysis and evolution standard play an important role in study and development process.

There are some measurements proposed in some recent articles [18, 48, 49].

3.2 Recent algorithm

Many researchers and groups propose their QoS routing algorithms. A majority of them give heuristic for multiple QoS optimization and constrained routing.

As to the type of unicast source routing, Wang-Crowcroft algorithm finds a bandwidth-delay-constrained path by Dijkstra's shortest-path algorithm. First the links in a network topology which cannot meet the requirements of bandwidth are cut off. Then SPF algorithm computed with delay as the key metric. Thus, bandwidth-constrained and shortest-delay path is found. Guerin and Orda studied the bandwidth-constrained routing problem and the delay constrained routing problem with imprecise network states. Chen and Nahrstedt [45] proposed a heuristic algorithm for the NP-complete multi-path constrained routing problem. The main idea of this algorithm is to map the QoS metric field to a finite set, which ensure the polynomial solvable. There is an estimate and a comparison between them at reference [49].

The others, which belong to unicast distributed routing, include: Wang and Crowcroft proposed a hop-by-hop distributed routing. Every node pre-computes a forwarding entry for every possible destinations, it is an important theory [69]. Salama et al. proposed a distributed heuristic algorithm for the NP-complete delay-constrained least-cost routing problem. A cost vector and a delay vector are maintained at every node by a distance-vector protocol [14]. Sun and Langendorfer improved the worst-case performance of Salama et al. algorithm by avoiding loops instead of detecting and removing loops [42]. The distributed multi-path routing algorithm proposed by Cidon et al. combines the process of routing and resource reservation. Every node maintains the topology of the network and the cost of every link. When a node wishes to establish a connection with certain QoS constraints, it finds a subgraph of the network which contains links that lead to the destination with a "reasonable" cost [23]. Shin and Chou proposed a distributed routing scheme for establishing delay-constrained connections. Global state is not required to be maintained at any node. This algorithm floods routing messages from the source toward the destination [31]. PNNI is an important hierarchical link-state routing protocol in ATM networks. These algorithms are described and compared in reference [49] [53]. In that article, important routing algorithms proposed before 1998 are summarized. In addition, OSPF, a typical LS protocol and a very important routing protocol used by Internet has release its version 2 [38] in 1998. Reference [51] compares the performance of Widest Shortest Path (WSP), Minimum Interference Routing (MIRA), Profile-based routing (PBR), and per-packet dynamic routing for bandwidth acceptance ratio, and maximum link utilization in 2002. In [56], writers established a new mathematical programming model to solve QoS routing problem, presented a modified Lagrangean relaxation algorithm, and introduced its advantage.

Some multicast routing protocols are proposed to solve multiple QoS constraints routing problems. such as MRPMQ, SAMCR, A*prune, DQMRP [57, 58, 59, 60].

Aimed at reducing delay, Pre-computation was introduced in [53, 54], the major idea of these papers is: every node calculates the feasible paths and maintains a QoS routing table. Algorithms such as MEFPA [11] constructs a number of linear energy function distributed uniformly in the multi-dimensional QoS metric space, and then converts different QoS weights to a single energy, at last, use Dijkstra's algorithm to create the least energy trees based on QoS routing table. And the performance and scalability of some Pre-computation methods were analyzed. P. Van Mieghem and F. A. Kuipers discussed the exact QoS routing algorithms and gave explanation in their article [41] in 2003.

After 2004, new researches include: Off-Piste QoS-aware Routing Protocol proposed by Tal Anker, Danny Dolev and Yigal Eliaspur. OPsAR, a QoS aware routing protocol which achieves better performance results with reasonable cost was based on the Multi-path routing approach, but constrains the number of paths used and leverages on previous resource reservation attempts. The reference [40] proposes the properties of a new dynamic resource allocation scheme that utilizes online measurements to achieve the required QoS. Xiaojun Lin and Ness B. Shroff proposed an optimization based approach for Quality of Service routing in high-bandwidth networks [60]. LI La-Yuan, LI Chun-Lin proposed A Multicast Routing Protocol with Multiple QoS Constraints [34]. Mirjana Stojanovi´c and Vladanka A´cimovi´c-Raspopovi´c proposed A Novel Approach for Providing Quality of Service in Multiservice IP Networks. And some algorithms concern Wireless (mobile) routing. Most of routing algorithms in this class concentrate on finding a new route for an existing connection during the handover process between cells (rerouting).

Since there are more and more QoS researches focused on ant colony algorithm, in the reference to [67], Zhang and Liu proposed hierarchical QoS routing solution Based on Ant Colony Algorithm. The main idea is: first to divide the routers into different levels (layers), then the ant algorithm was used to search for a feasible path in the same layer, while the SPF was applied between the different layers. In reference to [68], Zhou used ant colony algorithm to solve the problem of bandwidth, delay and minimum cost constraint multicast routing therefore proposed the QoS multicast routing algorithm Based on Ant Colony Algorithm, QMRA. Xu Li and Li La-yuan proposed the global optimized multicast routing algorithm OQMRA, on the basis of analysis of multi constraint QoS multicast routing [62].

Through these papers, the common process of QoS design and implementation was inferred as figure3.2 in [37].

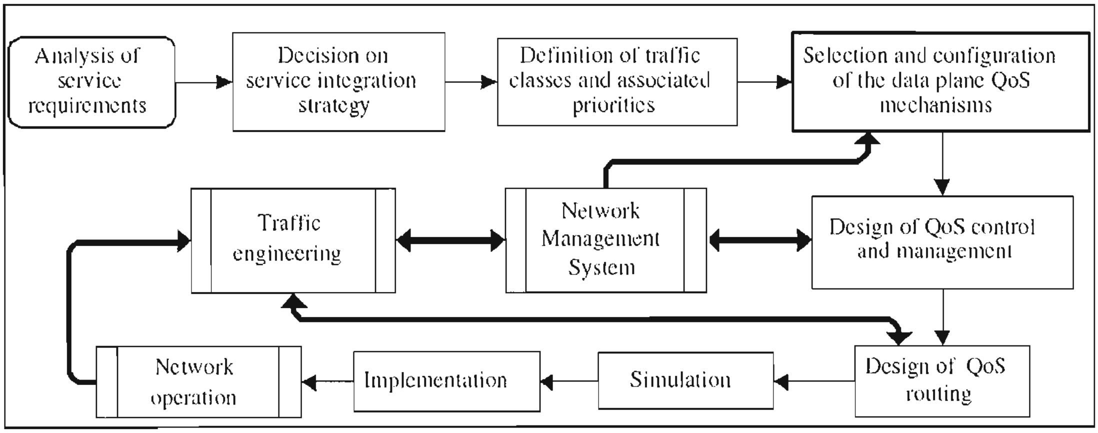

Figure 3.2 The process of QoS design and implementation. [37]

Chapter 4

A New QoS Routing Algorithm Based On End-users

The two important Routing Protocols used in current Internet are Link-state protocol and vector distance protocol (chapter 2, 3), which are all dynamic routing protocol, but their ability was found very limited, while the Internet developed rapidly with its complexity. According to the hypothesis of their algorithms , the traditional routing algorithms depended on the accurate computation of routing information of the network. As the scale of network continues to increase, it becomes very difficult, and even impossible under actual environment. Though, in this chapter, an Internet routing solution is proposed.

In this chapter, the difference between network router and the term "node" is blurred.

4.1 The problem and algorithm feature

As to the routing protocols, such as RIP, OSPF, BGP, routing tables are established by exchanging the network information among the routers. And those protocols are referred to as the routing protocols based on routers. If there are only a few routers, especially if the routers are maintained by a single management entity, the advantages of these routing protocols are distinct. While the scale of network increases, there are more and more management entities, these protocols do not satisfy the requirement. The main problem may be concluded as follow:

The complexity of the routing protocol is an important bottleneck of technology to the develop routers in future networks.

- The difficulty to test and validate a routing protocol is evident, especially, in the practical evolutions with multiple equipments from difference vendors.
- Dynamic of the routing protocol to "path determination" is not good. Nowadays the path determination operated in routing protocols is independent from forwarding the actual data, It causes the difficulty to combine the process of "path determination" with the adjustability of variation network status.
- Within several views such as the methods of processing data packets, the structures or length of packets, the rate of processing, and capability requirement for memories and processors, the requirement of a routing protocol is quite different from that of forward data in practice.

In general, the process of "path determination" in Internet has substantively got rid of the central control from traditional telecom network. Along with the continuous extending of network's scale, the diversity of networks composing, and the increase of transmission rate, to predigest components of nodes and management is a very important point for improving the reliability, enhancing utilization and decreasing costs of the whole network. This chapter describes a self-organizing network routing within user level as an efficient solution.

The routing architecture based on end-user proposed in this paper, the process of "path determination" is implemented by the end-user. Routers only exchange network information and combine all end-users' determinations and decide which one is the best, so that a great lot of complex works of calculation is allocated to each user node in the network. Then, to implement a same size task with this distributed mode, it will reduce the cost more obviously than the traditional mode, and more overhead will be released. The residual process capability of users in the future networks will be utilized more adequately to form a larger, stronger, and holistic network calculation entity. On the other hand, what the users find is the network service performance of point-to-point, which is more close to actual state. Therefore, implementing the process of "path determination" by the user nodes will combine the routing and QoS more efficiently to satisfy users' requirements better.

About self-organizing network routing on user level, the earliest application happens in some research in the field of bionics. The bionics is the science to study how to mimic the animals' functions and structures, and its aim is to make the biological phenomena useful for technical applications. According to some research productions, many solutions to complex problems are proposed, such as genetics algorithm [70, 71] and evolutionary strategy. An algorithm was proposed by Italia scholars: M. Dorigo , V. Maniezzo , A. Colorni, they named the algorithm as "ant colony system" [35], and using it to find the solutions for TSP problem, assignment problem [16] and job-shop problem [15] and so on, and these solutions brought better performance. Hence, the "ant colony system" became a very attractive method to solve various optimization problems. Though there is not much research on applying it in network routing, some researches have showed more advantage of ant algorithm, in this field. It is considered that ant algorithm have a great future in routing application.

With the researches in biochemistry, we understood that how ants could find the shortest path to their food rapidly. There is a brief description as following: we put forward an assumption that a group of ants are looking for food. Once an ant finds something but cannot bring it back, it will go back home along the way which it came by, and leave a kind of ectohormone along the way, that is pheromone. Then the other ants know how to get to that food.

If there are more ways leading to the target, then how is the process of "path determination"? The pheromone will volatilize as its diffusing. At different points of the paths, and at different directions of one point, the degree of concentration differs.

Usually, ants go along with the direction with higher concentration. So, more and more ants will choose the shortest path to target.

Most correlative researches which have been found in this field combined certain algorithm with actual routing problems, in order to seek optimization solutions. There were some researches which attempted to apply ant algorithm to modify RIP, and to achieve better performance. In these algorithms, every node notified itself existing in reverse direction, and a signal eigenvalue is generated and will attenuate at every node it passed. For every node, the direction with maximum signal eigenvalue will be chosen to approach to the target for data. However, these algorithms require the network which is symmetric to actualize its advantage, and implement the "path determination" process by routers. When it determines the routing dynamically, there is lots of notifying information and complex local calculation will occur.

In order to resolve these problems, in this paper, a unicast end-user routing architecture is proposed, which comply with minimum hops criteria, its validity is proved by simulation. Because of unicast and minimum hops criteria, the proposed algorithm is easier to compare with existing routing protocols such as RIP or OSPF. According to simulation result, it has a better performance than routing protocols implemented by routers. There are several strong points of this algorithm as follows:

i) End-user has the ability of self-determination, and the routing architecture proposed is a sort of end-user control system.

ii) Routers do not need the knowledge of whole network topology. In this architecture, to determine route depends on the information of various port (direction), the information (pheromone) is left behind by tinting packet (a type of packet in this architecture, which will be defined later.).

iii) In a network using this algorithm, "path determination" is independent of router calculation. Similar to non-routable protocol, it is non-routing protocol. Hence, its simpleness is obvious.

iv) The packet structure in the architecture is very simple. There are three types of packet, that is, probe packet, tinting packet and data. Probe packet and tinting packet are not actual data, the former one helps in looking for feasible path, whereas the latter one marks the found paths. Different packets are transmitted in different ways.

v) Probe packets released by end-users seek for the best path in the network, and router table will be updated by tinting packets. Though the whole network topology is unknowable for any "ants", dynamic distributed computation ensures to achieve the best feasible path at a certain term.

vi) Holistic optimization and quicker convergence are coming true because of cooperation between end-users in the architecture.

The shortcomings of the architecture include:

i) Longer time is needed at algorithm starting.

ii) The routing architecture cannot resolve some essential problem of QoS yet, for example, to evaluate QoS metrics accurately in an actual network environment.

4.2 The distributed, scalable, users-based routing architecture

4.2.1 The rationale of the proposed routing architecture

The proposed method was enlightened by Ant Algorithm. In this architecture, “ant” packet is introduced. There are three types of “ant”. An explorer ant, who seek feasible path to destination node, in fact, is a probe packet. It remembers the path it passing by and collects information of these nodes. Every end-user sends a number of them to certain target. In the process of transmission, information of nodes which ant collects, include node character such as IP address, and QoS metric such as delay and available bandwidth. The information will be added to the head of packet to help “path determination” process for destination node. When those test ants from a source reaches destination through different paths, destination node compare them with information in their head, seek out feasible paths which can satisfy QoS requirements, and make choice. After the path have been chosen from source to destination, another type of ant is sent out, i.e. the tinting ant. The tinting ant, that is, the tinting packet, returns along with the chosen path, and leave pheromone behind, inform these nodes. Perhaps a router on the chosen path finds some pheromone at its different interfaces (direction).

To harmonize the various possible decisions made by end-users, a router establish a pheromone vector for its each interface which connect with another subnet. Tinting packet updates routing tables of routers which it passes by. According to this process, after some time, the best routing will be explored and ascertained.

A pheromone vector corresponds to a router interface one by one. The value of specified vector expresses the pheromone of the interface to corresponding subnet. In a router, the tinting packet received from a specified direction only has the right to update the value of pheromone vector with the same direction in routing table. In common operation process of forwarding data, router chooses its output interface to send data packets which has the maximum value of pheromone vector. The network needs not to be symmetric in this architecture, but it must be ensured that tinting packet can reach every node on the chosen path. And the routing architecture will be much easier to implement in a symmetric network.

4.2.2 The process of routing

There is four routing courses in this routing architecture, and their occurrences are simultaneous or intersectant , which are described as follow:

i) Routing Discovery Course: There are three types of packets in the proposed routing architecture, data packet, probe packet and tinting packet. When the end-user sends data, it sends a number of probe packets to the destination from its interfaces. In order to find better path, these probe packets choose their way randomly, and data packet determine which interface it chooses for the base pheromone.

ii) "Path Determination" course: As probe ants arrive, the destination node compare the information included in the head of those probe ants received in a special term. One or more will be chosen if they can satisfy a set of given QoS requirements. Once a probe ant is chosen, it means that the path it passes is chosen indeed. Then, tinting packet is generated, and return along the chosen path(s).

iii) Updating Routing Table course: Suppose the initial situation, the value of pheromone of every path are the same and fixed. Where tinting packet return, in those nodes which it passes, routing table will be updated. In a network with M routers, if a router has N output interface, then its routing table will maintain a table with M rows and N columns, the values in the table express the probability to choose this interface to destination. If a pheromone value at some interface of a router has not been updated after a fixed interval, volatilization will take place, so the value ought to reduce.

iv) Forwarding Data course: The interface of router with the maximum pheromone value will be chosen, data packet will be forwarded along the chosen path.

4.3 Pseudocode of the algorithm

```
InputPacket( );
if (pkt_type == DATA)    \\ for data type
{
      if (pkt_Destination == my_ID)
    {
            Destination(pkt);  \\ the packet reach destination node
       return;
      }
      else
    {
            Forward(pkt).   \\ forward the packet
       return;
      }
}
else
{
      if (pkt_type == ROUTING)    \\ for probe type
    {
          if (pkt_Destination == my_AttachedNode)
       {
                if (NodeBufferNumber[RoutingPktSource] == NodeBufferLength)
          {
                      Comparehead(pkt) .   \\ path determination
              GenerateTinting(pkt) .   \\ generate tinting packet
                }
          else
          {
                      AddPacket To ChainTail( ) .
              NodeBufferNumber[RoutingPktSource]++ ;
                }
       }
       else
       {
                LogPktHead( ) ;  \\ such as Delay,bandwidth available,IP Address of PassedNode
          }
    }
    else
    {
          ForwardTinting(pkt) ;    \\ for tinting type
        UpdateRoutingTable( );
    }
}
```

Figure 4.3 Pseudocode of the algorithm

4.4 Simulation and evaluation

Through a series of simulation, practicability and feasibility of the algorithm will be proved. Simulation results indicate that the proposed routing architecture of ERGATE is better than current OSPF at multiple facets.

4.4.1 Simulating environment

The simulator chosen: NS was chosen as the simulator platform [30] to implement this comparison. The same "network" state and traffic are maintained to ensure that the comparison is as impartial as possible.

The assumptions: In order to focus attention on finding a solution to the problem, and to predigest the network model, there are several hypotheses as follow: 1) every nodes in the network can implement any of the four courses independence, can deal with all three types of packet in this architecture; 2) the connectivity of the network is ensured, at least in theory; 3) like some Distance Vector protocols, the maximum hops are defined to avoid routing loop.

According to these hypotheses, the network model is regarded as simpler abstract Internet. Although the situation in actual Internet will be more complex, I think this model can represent Internet approximately.

The QoS metric chosen: I believe, among various QoS metrics, delay, bandwidth and packet loss ratio are the most important three ones (table2.1). Although it is difficult to measure accurate bandwidth available at a certain moment, we think that bandwidth will be sufficient for most applications in future Internet. Then, we should consider more about the other two. That is the main reason for choosing them here.

The network topology chosen: the graph of network topology chosen by this simulating is representative and practicable. It has been used by many articles concerned, because it is similar to the backbone of British public SDH (figure4.4.1). There are thirty nodes and 110 links.

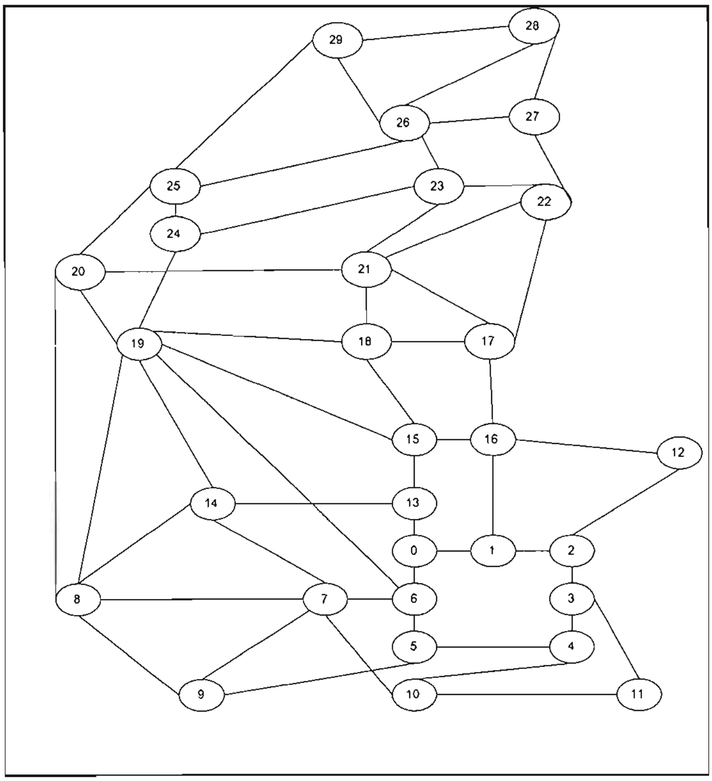

Figure 4.4.1 network topology used by simulation

Preferences： Default simulation time is forty seconds. The maximum interval of sending packets is 1 millisecond. For every source, the buffer length is defined as 10 packets. Like RIP, the maximum hop is set to be fifteen too. The most data was collected at eight seconds after simulation start.

According to practice situations, average interval of sending packets and average size of packet is define as 1000 milliseconds and 800 bytes. For the ERGATE, we fixed the length of probe packets and tinting packets at 100 bytes and the interval of sending probe packet is 10000 milliseconds.

4.4.2 Simulation result

Lots of simulating experiments are done to compare the ERGATE proposed in this paper with OSPF. The QoS metrics chosen by this simulating, delay and packet loss ratio are emphasized in the comparison of the simulation result.

The expressions of the metrics as follow:

Delay = packetsize/bandwidth + TrDelay

Packet loss ratio= $\sum_{i\in T} D_i \Big/ \sum_{i\in T} Pct_i$

$D_i = Pct_i - R_i$

In the expressions of Delay, the TrDelay express the transmission time caused by the distance, it should be considered with the environment of WAN or Internet. In other expressions, D_t express the amount of loss packets at the moment $t\in[0,T]$, Pct_t express the gross amount of packets at the moment $t\in[0,T]$, R_t express the amount of received packet at the moment $t\in[0,T]$.

The explanation of the situation where the input speed of packets is on the increase:

As the increase of packet input speed, average delay of these two algorithms and packet loss ratio of them were increasing. The increase of packet input speed, brings about increase of network load, then packets which need to be dealt will increase, at last delay increase. And in the figure 4.4.2(2), it is showed that ERGATE has less delay than OSPF. As figure 4.4.2(1) showed, packet loss ratio of ERGATE is less than that of OSPF.

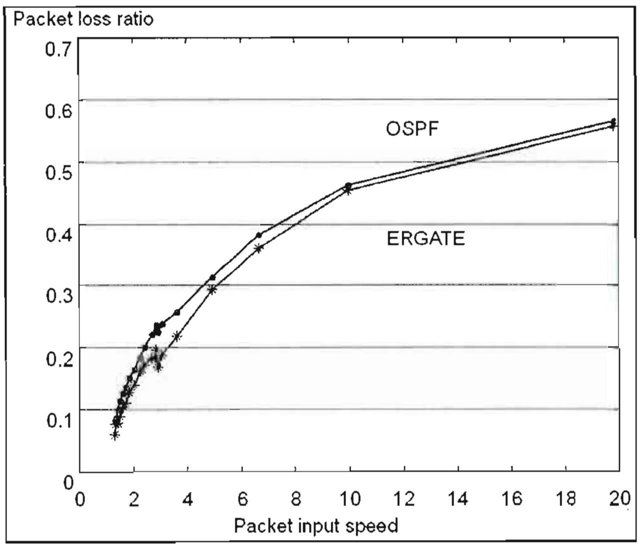

Figure 4.4.2(1) Comparing between OSPF and ERGATE

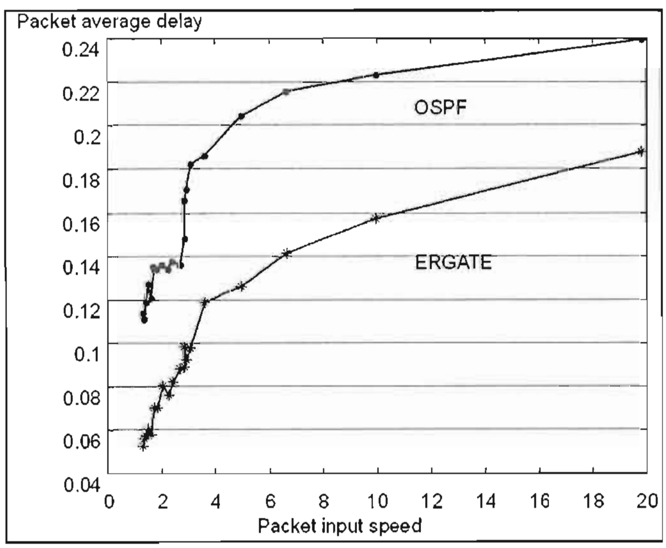

Figure 4.4.2(2) Comparing between OSPF and ERGATE

Here is my analysis to explain this result. When the network or parts of the network become congested, OSPF needs a period of time to get to convergence again and this course depends heavily on performance of hardware. Based on the end-user determination, ERGATE finds and uses the new and better feasible path more rapidly. If the topology of network has not changed, OSPF will keep his routing knowledge usually, but ERGATE may renew its best path with the network status varying.

The explanation of the less traffic situation:

As to the part of simulation, the performance of ERGATE was verified in the case of less network traffic. In this case, along with increasing of the traffic in the network, packet loss ratio and delay of OSPF and EAGATE were increasing. Compared with OSFP, ERGATE has lower amplitude. While the packet input speed changing form 0 to 800kbps, packet loss ratio of OSPF heighten much more, and packet loss ratio of ERGATE keeps lower than 4%. I will try to explain it : OSPF use Dijkstra's all-pairs SPF algorithm to compute routing, after determining the shortest path, all packets will be sent along the path. Although the network changes continually, usual updating routing is only triggered by topology change. Once traffic increased, the load of the chosen path may become too heavy, if so, the fact is that this path is not "the best", and packet loss ratio and delay become higher. With EAGATE, the determination of the best path is more dynamic. According to the timely state, path determination is made. The new best path is updated in time, packet loss ratio and delay will be effectively reduced.

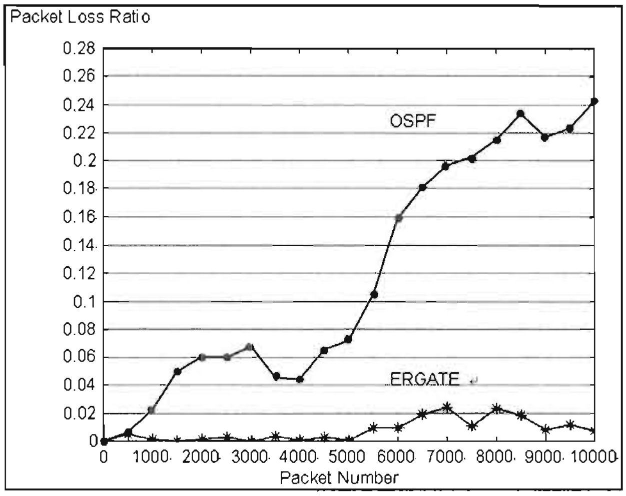

Figure 4.4.2(3) Comparing between OSPF and ERGATE

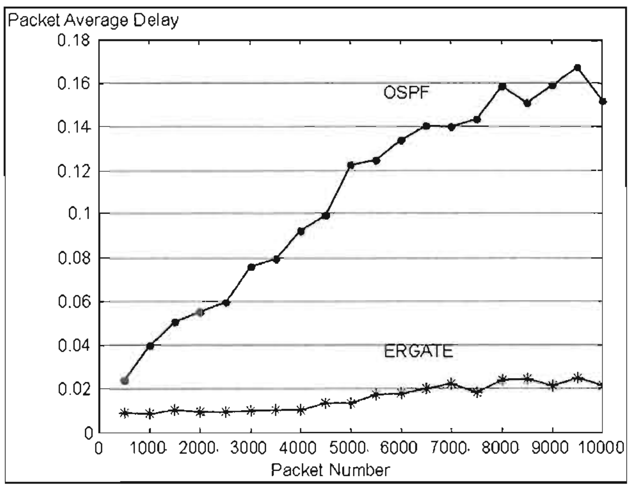

Figure 4.4.2(4) Comparing between OSPF and ERGATE

The explanation of the heavy traffic situation:

In the case of heavy traffic, simulation result showed the advantage of ERGATE too. While there is much traffic in the network (packet input speed was in the range of 800kbps-8mbps), ERGATE is better than OSPF with delay and packet loss ratio too. Using ERGATE, delay and packet loss ratio have no visible difference from the case of less traffic, there is obvious difference in using OSPF.

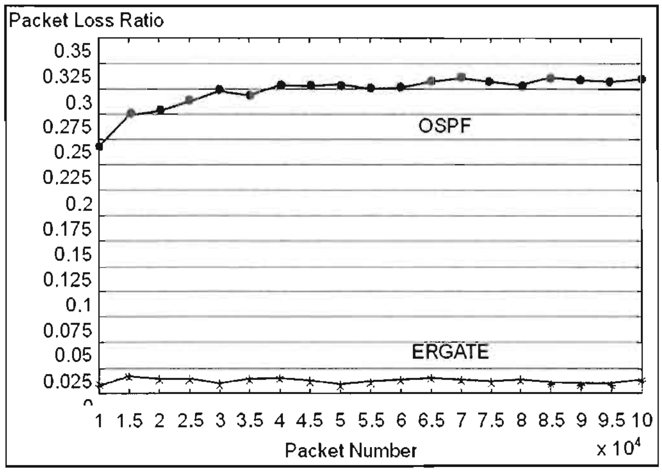

Figure 4.4.2(5) Comparing between OSPF and ERGATE

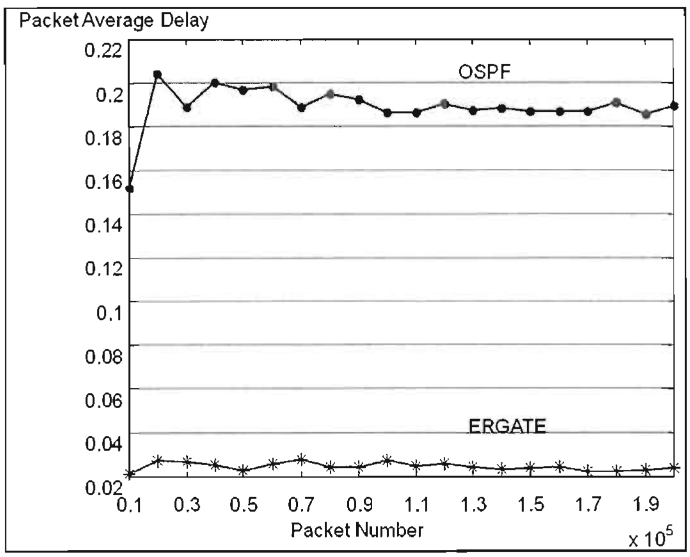

Figure 4.4.2(6) Comparing between OSPF and ERGATE

Conclusion

In this paper, a new routing architecture named as "ERGATE" is proposed and the routing algorithm used by it is also presented. The theory and the simulation show that performance of the routing algorithm is better than the widely-used OSPF under certain circumstances. Moreover it has good scalability and dynamic adaptability. Different from traditional routing algorithm, this algorithm do not have to know the exact network topology completely. The implementation of the architecture is formed by end-user's cooperation and distributed process, and is actualized by self-organizing behaving of all nodes, which function independently. The distributed computing, within this routing architecture, possesses smaller time granularity and faster response than that of Distance Vector and or Link-State routing. In addition, to implement the routing architecture does not depend on high-performance routers.

Being extensible and dynamic are its advantages, but it is more important for the end-users to own the right to determine routing in order to satisfy the requirement of next generation Internet.

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