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Research on QoS routing in the Internet

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***Abstract*—With the development of Internet and the constant emergence of all kinds of multimedia business, user's demand on Quality of Service (QoS) becomes higher and higher. However, the current Internet routing protocol could not provide a good solution for QoS. Quality of service route is at present a very important research topic in the routing protocol, but it is hard to give a perfect method for network. Two factors should be considered in order to implement QoS routing in Internet with balance between economical and technical factors. This paper mainly studies on the technical problems of QoS route and provide an algorithm called SAMCRA to improve the Qos and give some analysis about it.**

Keywords-Internet; QoS; Routing protocol; MCOPRP;

I. Introduction

With the rapid development of Internet and the constant emergence of rising businesses with real-time requirements (such as VoIP, video conference, multimedia distance learning, video on demand), user's demand on Quality of Service (QoS) becomes higher and higher. However, the current Internet routing protocol has no idea of QoS. Quality of service need to comprise all the requirements of a connection in mobile and computer network, such as service loss, signal-to-noise ratio, response time, interrupts, frequency response, loudness levels, and so on. Quality of service route is at present a very important research field. Generally speaking, how to provide users with QoS services in the network is a very complex problem, especially the QoS routing technology. In fact, the QoS routing problem under multiple constraints is a problem of NP-complete. However, the design of routing algorithm should follow the following principles: correctness, simplicity, robustness, stability, fairness and optimality[1]. If infinite network resources were available, then all application traffic could be carried at the required bandwidth, with zero latency, zero jitter and zero loss. However, network resources are not infinite[12] . It makes the routing protocol designers fall into a dilemma: if QoS is functioned in the routing protocol, it is contrary to the principle of simplicity algorithm. Certain applications can tolerate some degree of traffic loss while others cannot[12]. The compromise is a sub-optimal solution of the QoS routing problem under multiple constraints obtained by heuristic algorithm, but which makes the routing algorithm lose optimality characteristics. This paper mainly studies the important problems existing in QoS route so far.

II. Multi-constrained optimal path routing problem (MCOPRP)

User's demands on network quality of service in QoS route mainly are constraints, such as delay, jitter, bandwidth, and packet loss rate on the choice of the routing algorithm path. A routing algorithm with the function of QoS must meet multiple constraints and should be the optimal as far as possible.

A. The concept of QoS

Quality of service (QoS) came into being with the appearance of ATM in the late nineteen eighties. Few years ago, QoS was introduced to Internet, some of whose main technologies include Intserv, Diffserv, RSVP and MPLS[2].

Quality of service (QoS) refers to the overall service performance[2] of satisfaction degree of user's service requirements. QoS can be described by the following parameters[3]:

- Business availability: the reliability connecting the user to IP operations.
- Delay: the time interval between two reference points of data packet sending and receiving.
- Jitter: the time difference between data packets in a group of data flow transmitted in the same path.
- Throughput: the rate of sending data packets in the network, indicated by average rate or peak rate.
- Packet loss rate: the highest rate of discarding data packet when transmitted in the network.

B. MCOPRP problem description

The biggest challenge of QoS to Internet is IP connectionless system structure. The services provided by Internet do not specify a particular route. IP packet sequence conducts hop-by-hop between routers, the same packet may be transmitted along different paths. So, how to select an optimal path dynamically to transmit packet under multiple constraints is a very important issue.

The routing problem of multi-constrained optimal path, as a NP-complete problem, is to find an optimal path satisfying multiple constraints in the network. As shown in Figure 1, if each link of network link set E has m weights, where wk(i,j) is the value of k weights in the link [i, j]. For

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any QoS request R=(S，D，C_1，C_2，⋯，C_{m-1})，where S is the source node, D destination node, and Ci restrictive conditions of the i weights on transmission path, i=1，2⋯m-1, the mathematical model of transmission path which meets the transmission requirements and optimizes the m parameter is:

$$\text{Min} \sum_{[i,j]\in E} w_m(i,j) * x_{ij} \qquad (x_{ij} \in \{0,\ 1\}) \qquad (1)$$

$$\text{For all edge[i,j]:} \begin{cases} x_{ij} \in \{0,\ 1\} \\ F_1(x_{ij}*w_1(i,j) \mid [i,j] \in E) \le C_1 \\ F_2(x_{ij}*w_2(i,j) \mid [i,j] \in E) \le C_2 \\ \ldots\ldots \\ F_{m-1}(x_{ij}*w_{m-1}(i,j) \mid [i,j] \in E) \le C_{m-1} \end{cases}$$

For the most cases, the function Fi is cumulative, like delay:

$$F_i(x_{ij}*w_i(i,j) \mid [i,j] \in E) = \sum_{[i,j]\in E} w_i(i,j) * x_{ij} \qquad (2)$$

Or with extreme property, like constraint bandwidth of transmission path:

$$F_i(x_{ij}*w_i(i,j) \mid [i,j] \in E) = \min\{x_{ij}*w_i(i,j) \mid [i,j] \in E\} \qquad (3)$$

Or multiplicative, such as packet loss rate:

$$Fi(xij*wi(i,j) \mid [i,j] \in E) = 1 - \prod_{[i,j]\in E} (1 - w_i(i,j) * x_{ij}) \qquad (4)$$

When function Fi is cumulative or multiplicative, the whole problem is a linear programming problem. In general, when m>2, it is a NP-complete problem. So MCOPRP is a tough one, which shows that the purpose of some heuristic algorithms proposed is the suboptimal solution of the problem in polynomial time. Some scholars have come up with QoS route algorithm[4] based on genetic strategy, because genetic algorithm is an effective tool for the NP problem. But due to multiple-peak of genetic algorithm, it may not be able to obtain the optimal solution of MCOPRP. There are only a few exact QoS routing algorithms at present, among which SAMCRA is a typical one.

C. SAMCRA algorithm[5]

If Network topology is denoted as G (N, E), where N denotes the set of network nodes, E represents the set of nodes link. We can also use N and E to denote the number of nodes and links separately. The link weights vector supporting QoS network is composed by m nonnegative QoS measure（$w_i(e)$,i=1,...,m e∈E). A QoS measure can be cumulative (such as delay, jitter and cost), or with extremum property (such as available bandwidth), or multiplicative (such as packet loss rate). The QoS measure of extremum property can be disposed by deleting all links which can not meet QoS constraints. But it is more difficult to deal with cumulative or multiplicative measure. As section B says, when measure is cumulative or multiplicative, the problem MCOPRP is a NP-complete problem, so the problem is a very difficult problem in large networks.

1) The idea of SAMCRA algorithm

SAMCRA is the development of TAMCRA. SAMCRA, unlike TAMCRA, is guaranteed to find a path meeting all constraints, as long as there is such a path. SAMCRA assigns the queue space only when needed, while TAMCRA assigns queue space in advance. Similar to TAMCRA, SAMCRA is based on the following three basic concepts:

- **The nonlinear path length measure.**
  The length of path P is defined as follows:

$$l(P)=\max\left(\frac{w_i(P)}{L_i}\right) \qquad 1 \leqslant i \leqslant m \qquad (5)$$

  Here, $w_i(P) = \sum_{e\in P} w_i(e)$ and Li is the constraint of the i measure.
  The definition of the path length must be nonlinear in order that the path obtained satisfies the constraint l(P) ⩽1. A solution of MCOPRP is such a path that its link weight satisfies all constraints, wi(P) ⩽Li (i=1,...,m)， and wm(P) in minimum. For more restricted path optimization, SAMCRA can employ different length function. By means of equation (5), all QoS measures are treated equally. For instance, an important inference of nonlinear path length of equation (5) is that the subpath of the shortest multidimensional path is not necessarily the shortest, which asks us to consider more paths instead of a shortest one, that is, the shortest path K.

- **The shortest path K:**
  The nature of the shortest path K algorithm is Dijkstra algorithm. The algorithm does not stop when reaching the target node, but until it reaches the destination node K or all possible paths are calculated. The shortest path K is used in the intermediate node i from the source node s to the destination node d in order to save multiple sub-paths in the node i from s to i. Not all sub paths have been saved, but only non-dominated paths.

- **The principle of non-dominated path :**
  For the path of Q and P, if wi(P)⩽wi(Q) i=1，...,m, and at least a link weight vector component equation

is false, the path Q is controlled by the path P. SAMCRA only takes non-dominated paths into account. The principle of non-dominated path not only reduces the search space of algorithm effectively, but also guarantees the optimal solution.

2) The complexity of SAMCRA algorithm

In the network G (N, E), the number of paths in SAMCRA queue will not exceed kN, among which k shows the number of non-dominated path stored in the node queue. Because SAMCRA adaptively assigns its size at each node queue, K may be different for different nodes. When using the Fibonacci heap to construct queue, at most O(log(kN) calculations are needed if a minimal path is chosen from kN different paths. The time complexity[5] of SAMCRA in the worst case（$k=k_{max}$）is:

$$TC_{SAMCRA} = O(kN*\log(kN)+k^2mE) \tag{6}$$

The space complexity of SAMCRA is:

$$SC_{SAMCRA} = O(kN) \tag{7}$$

k_{max} is an upper bound of non-dominated path number in G (N, E). It is hard to find a precise formula for K, but two upper bounds can be determined. The first upper bound of K:

$$k_{max} = \lfloor e(N-2)! \rfloor \tag{8}$$

is the upper bound of total paths from the source node to the destination node in network G (N, E).

If the granularity of each constraint is limited, the second upper bound for k:

$$k_{max} = \frac{\prod_{i=1}^{m} L_i}{\max(L_j)} \tag{9}$$

As known from the above analysis, the complexity of SAMCRA under multiple constraints in the worst case is NP complete. Mieghem and Kuipers show through the experiment in [5] that the average time complexity of SAMCRA is polynomial in most cases, especially when each component $w_i(e)$ of link weight vector is independent random variable. But in theory the time complexity of SAMCRA is still NP complete, and we are not sure each component $w_i(e)$ of link weight vector is independent random variable in the practical network. So we can only believe that SAMCRA is still NP complete problem.

D. The problem to solve

Several pertinent QoS routing algorithm have been described in [6] and [7] and evaluated through simulation experiments. The results show that SAMCRA has the best performance. But SAMCRA is NP-hard theoretically. If we can improve or propose a new SAMCRA algorithm to have the acceptable complexity, or make it feasible in practice, it will become a milestone in this field.

If we want to carry out the routing function of QoS in Internet, then the following problems are worth considering:

- Whether or no SAMCRA algorithm can be improved and make its complexity acceptable? If yes, how to improve?
- Whether there is a more effective data structure for SAMCRA algorithm to replace the Fibonacci heap structure?
- For Internet, which path length function is more appropriate for SAMCRA?
- How to expend SAMCRA to the QoS multicast routing?

III. QOS ROUTING PROTOCOL

QoS routing protocol is the most difficult problem for current realization of QoS in Internet. the QoS network protocol based on state must be implemented in order to enforce QoS routing in Internet. The link-state routing protocol [1] is used in the Internet currently. In this protocol, each node finds its neighbors first and measure its link state connected with each neighbor, then the link state information is transmitted to other nodes in the network through flooding, in the end, each node can obtain the a complete network topology and the global image of the state. State information on each link shows the numeric representation, that is link weight. Although flooding is simple and reliable, the unnecessary communication it contains leads to the resources waste, especially in the QoS routing in need of switching multiple dynamic parameters frequently. It is not possible to monitor all changes in the Internet, even not necessary, because not all the changes are important. But there are two possible changes needed to consider[8]:

a) Non-frequent changes caused by nodes joining or leaving the network. This is the only topology change currently considered in the Internet.

b) The changes associated with resource consumption or network traffic. QoS routing needs to consider this kind of change.

QoS includes the following parameters: bandwidth, delay, jitter, packet loss rate and cost. The imperative consideration is which parameters should be chosen in the routing strategy, which determines the network service quality to a large extent, and the complexity of routing algorithm. So, In order to realize QoS, the following questions need answers: How many parameters are appropriate? which parameters should be chosen? How to weight these parameters to reflect their importance?

In order to calculate an optimal path satisfying multi-constrains, the router must obtain the link state information of the network. But the link state information in Internet is highly dynamic, so in order to realize the QoS routing functions in Internet, it is necessary to select the link state information updating strategy for optimization. The following key questions must be considered for the updating strategy: when should each router exchange state information? timing exchange or triggered exchange? If timing exchange, how long does it exchange? The last question is a dilemma: if the time interval of two information exchanges is too short, a large amount of network resources are used up for the treatment of frequent information exchange. The result is that the effective availability is reduced and the scalability of the network cab be seriously affected; if the time interval of two information exchanges is too long, the network state information kept by the router will be lagged seriously, thus, the optimal path satisfying multi-constrains calculated by QoS routing algorithm maybe not the optimal, even can not meet the requirements of QoS.

Because the update cycle of router link state information can't be unlimited short and the necessary transmission delay for link state information exchange between routers, it is inevitable that the link state information in router is imprecise. But the QoS routing algorithm (such as SAMCRA) is static, it assumes that the link state information on which it depends is accurate, then, there is a new problem: how to ensure the path calculated by QoS routing algorithm is trustworthy if the link state is not accurate? Guerin and Orda proposed a probabilistic algorithm in [9] to the inaccuracy of the link state information: whether to select the link is determined by the probability how the link meets the constraints. But how to ensure the relevance between the probability of link state information accuracy and the probability of link chosen? A problem is put forward in [10] that the inaccuracy of link state can be solved by a multi-path QoS routing algorithm: to ensure the correctness of the path by calculating multiple paths. But what path selection strategy can be used to choose an optimal path from multiple paths calculated?

IV. THE EXPANDABILITY OF QOS ROUTER

Internet is a huge interconnected network. The expandability of QoS router must be taken account in order to realize the routing function of QoS in Internet. King-Shan Lui points out in [11] that in order to deal with the expandability in large network, the network are usually organized into a hierarchical structure, and routing protocol in the network is also hierarchical routing protocol. In Internet, the whole network is divided into many autonomous systems (AS), and an autonomous system is divided into many areas. The inter-domain routing protocol is used in a internal AS, the routing protocol recommended is open shortest path first interior gateway protocol (OSPF); the inter-domain routing protocol is used between ASs, usually border gateway protocol BGP[1]. It is the best for QoS router to follow the existing Internet hierarchical structure in order to change the system structure of the original Internet as less as possible.

A. Intra-domain routing

The most widely used intra-domain routing protocol in Internet network is OSPF protocol because the OSPF protocol is relatively simple and has good expandability. But the OSPF protocol does not have a QoS routing capability. So, is there a QoS routing protocol to replace the OSPF protocol?

Although QoS routing can provide the service quality meeting the requirements of users, it brings extra burdens to the network: a. the cost of the routing path calculation. The complete NP complexity of exact routing algorithm (such as SAMCRA) means the index unit time is consumed in order to find a optimal path meeting QoS constraints. b. extra storage space. SAMCRA algorithm needs to compute K shortest paths, and store these paths with Fibonacci heap. In section 2, we have illustrated a upper bound of k_{max} = $\lfloor e(N-2)! \rfloor$ in the worst case, which means the index unit space needed to save these k paths in the future. c. communication cost. In order to find a optimal path meeting multiple QoS constraints, the link state information must be frequently exchanged between routers to ensure the timeliness of network status view in a router. And the information exchanged is multidimensional. Compared with the one-dimensional information exchanged by traditional routing protocols, the multidimensional exchanging information takes more cyber source.

The additional burdens of QoS routing impose restrictions on its expandability, while in large networks like the Internet the expandability is the basic characteristics of routing protocols. Therefore, in order to realize the routing function of QoS in Internet, the following problems must be solved: (1) how to find a compromise so that it can not only meet the QoS requirements from users, but also accept the time complexity (which can be applied to the Internet)? That an eclectic method has been proposed is a heuristic routing algorithm. (2) how to reduce the storage space required by QoS routing algorithm? (3) what kind of information exchange strategy should be used to keep the timeliness of state information at the same time to reduce the consumption of cyber source?

B. The inter-domain routing

The border gateway protocol (BGP) is the standard of inter-domain routing protocol in the Internet. The current version is BGP-4. Because of the scalability, stability and flexibility of BGP, it is a very popular inter-domain routing protocol. But the current version of BGP does not have the ability of QoS. Many researchers and equipment manufacturers are working to improve the BGP to possess the ability of QoS. However, it's worth noting that BGP itself without the capability of QoS is a very complex routing protocol, if coupled with the QoS function, the complexity of BGP will be even hard to be accepted so that the performance of BGP protocol enhanced in realistic environments may be worse than the original BGP. Therefore, whether it is possible to improve BGP so as to perform QoS is still a problem to be solved.

Another option for the QoS inter-domain routing is to use overlay method, whose main idea is to separate the strategy control processed by router from BGP device, and form an independent layer [8]. Its main problem is how to combine the covering layer and BGP routing layer together effectively.

The expandability of the BGP also remains to be further research.

V. CONCLUSION

With the higher demand for quality of service users ask from the Internet, The implementation of QoS routing function in the Internet becomes much more important. Unfortunately, the QoS routing has not been applied to the Internet so far. In addition to the economic reason, the technical problem is another important one. Some basic problems are point out in this paper which are existed in QoS routing, such as: a) the complexity of QoS routing algorithm. b) the imprecision of network state information. c) the expandability of QoS routing protocol. These problems of QoS router must be solved properly to make it implemented by Internet in the near future. In the future work, we should evaluate the proposed solution and the effectiveness of the solution.

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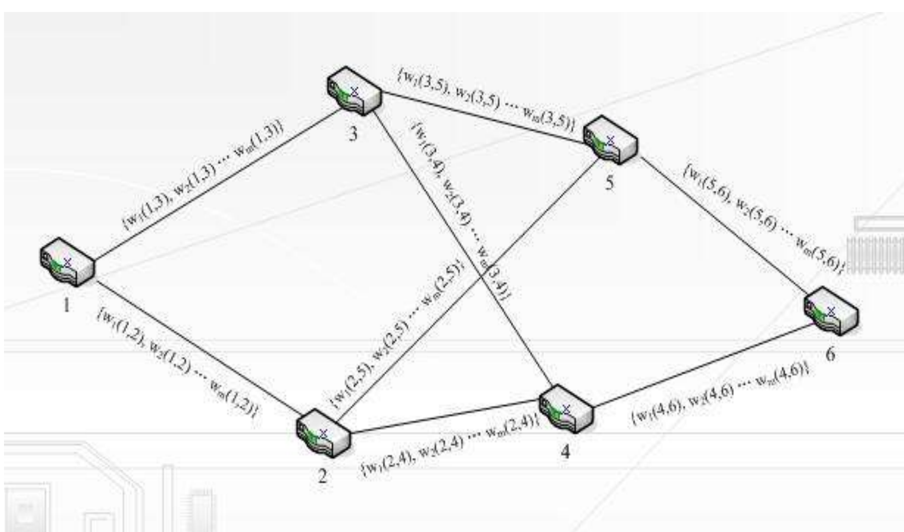

Figure 1. QoS network model