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# A STUDY OF QoS METRICS

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***Abstract*- Quality of Service is an area, at present lot of research work is being carried out. The main thirst for QoS is to improve the 'best effort' paradigm. To provide QoS based service in the network is extremely difficult, it is done at the routing layer. The difficulties involved in the QoS routing come in the form of constraints like delay, cost and jitter. These constraints act as one or in multiple constraints, which is known as NP-hard. QoS routing is an important aspect in the entire QoS framework. In this paper, a detailed study is made on metrics which act as single or in dual metrics, which influence the performance of QoS.**

**Various real-time services, like web casting, audio/video conferencing and television, are being deployed over the Internet. For the above listed services we have to provide a guaranteed service, which can be achieved only by scrutinizing the metric constraints like delay, bandwidth, jitter or metric combination like delay and cost, bandwidth and delay, bandwidth and cost. To implement an algorithm to enhance the QoS routing, cost to implement increases, this cost issue gets balanced if the performance of the end service is considerably improved.**

***Keywords:* QoS routing, delay, bandwidth, cost.**

## I. INTRODUCTION

The aim of Quality of Service (QoS) in communication, one way or other related to network performance. To provide a better understanding of QoS systems we adopt the ITU's definition of Quality of Service [17].

Definition:' Quality of Service- the collective effect of service performance which determines the degree of satisfaction of a user of the service'. From [17], it describes QoS, serveability, trafficability performance, and dependability. To implement, the high level concept is required to provide the service can be mapped to serveability; the control of traffic is measured in QoS performance, and important point is to consider the overall performance which reflects dependability.

QoS routing is an important element in the entire QoS framework. The main

Objective is to find suitable path for different services, for effective utilization of network resources. Instead of finding shortest path, selecting several alternate paths for a service will play a vital role in the mentioned constraints delay, jitter, bandwidth, and cost.

To achieve better QoS, we have to direct communication over large network. This reduces the structural complexity of routing i.e., by ordering the routing on prescribed criteria to satisfy. The classification of routing provides a better view of how to classify the routing metrics.

All the novel networks have to understand the essence of QoS routing to propose solution which is acceptable. Finding a multiconstrained path is more complex and requires a suitable algorithm to carry out the solution for the complex problem. The overall effort is to provide better QoS than that was provided earlier.

This paper focuses on the various QoS routing algorithms and protocols, which have been proposed in literature, for unicast in the IPv4 based Internet. It aims to serve as a comprehensive survey of the routing algorithms and protocols proposed for an individual or a combination of metrics being constrained or optimized.

## II. NEED FOR QOS ROUTING

The need for QoS, is to standardize the concept, IETF stopped the work in late 1990. This is because of lack of understanding of conceptual framework and unaware of routing protocols, before standardizing the concept we have to proceed in a broad manner.

The conceptual difficulties start at the definition itself. If we take the view point that routing consists of static and dynamic algorithms, then a proposed QoS routing algorithm will solve the Multi-constrained (Optimal) Path (MC(O)P) routing algorithm. In the MCP problem, each link u-v in a given graph is characterized by a link weight vector $w(u \rightarrow v) = [w_1, w_2, \ldots, w_m]$ with m positive real numbers $w_i(u\text{-}v) \geq 0$ as components. The MCP problem asks for a path P from a source node to a destination node that satisfies Eq. (1) for all $1 \leq i \leq m$ QoS metrics, when $L_i$ are the QoS constraints on the path.

$$W_i = \sum_{(u \rightarrow v) \in p} w_i(u \rightarrow v) \leq L_i \qquad (1)$$

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Only few algorithms provide approximate results, one such as Self-Adaptive Multiple Constraint Routing Algorithm (SAMCRA). The second element in QoS routing is frequent updation of routing table to exchange information. It is a very good area to research in the computer networks and to propose latest algorithms to enhance the performance of QoS routing.

## III. QoS CONSTRAINT

The constraint can be classified broadly in two areas: path constraints and tree constraints. Path constraint needs to be satisfied from the sender to the receiver. Tree constraints need to be satisfied over the entire multicast distribution tree created by the multicast routing protocol from the sender(s) to the receivers. In this paper, the main focus is on path constraint, so it is dealt in detail.

The computation complexity is primarily determined by the composition rules of the metrics. Additive (delays, delay jitter, logarithm of successful transmission hop count and cost.). Multiplicative (1-loss probability =probability of successful transmission). Concave / minmax (bandwidth).

The additive and multiplicative metric of a path is the sum and multiplicative of the metric respectively for all the links constituting the path. The concave metric of a path is the maximum or the minimum of the metric overall the links in the path. This metric is usually dealt with a preprocessing step called topology filtering, where on all the links that do not satisfy the constraint are pruned and not considered further in the path selection process. The metrics considered should be orthogonal to each other so that there is no redundant information among the metrics.

Wang and Crow croft [22] proved that the problems of finding a path subject to two or more independent additive and/or multiplicative constraint in any possible combination are NP-complete. The only tractable combination are the concave constraint and the other additive/multiplicative constraints [22].Van mieghem, F.A Kuipers [19] suggest that there may exist class of graphs in which QoS Routing is not NP-complete. A few polynomially solvable cases have been cited in[19]. When all the nodes have degree two it can always be solved in polynomial time irrespective of the link weight structure.

QoS Routing is NP-complete when the QoS metrics are independent and are real numbers or unbounded integers. If all metrics except one take bounded integer values, then the problems are solvable in polynomial time by an extended Djikstra or Bellman Ford algorithm. When both metric are additive [3] suggests that given a weight W (u,v) between nodes u and v, it can be converted to new weight function W'(u,v)= $\lceil (W(u,v) * x / c \rceil$.This reduces the constant $W \leq c$ to $W \leq x$ where c is a real Number or an unbounded integer and x is a bounded integer. It is proved that the solution for the simpler problems is also a solution for the original problem.

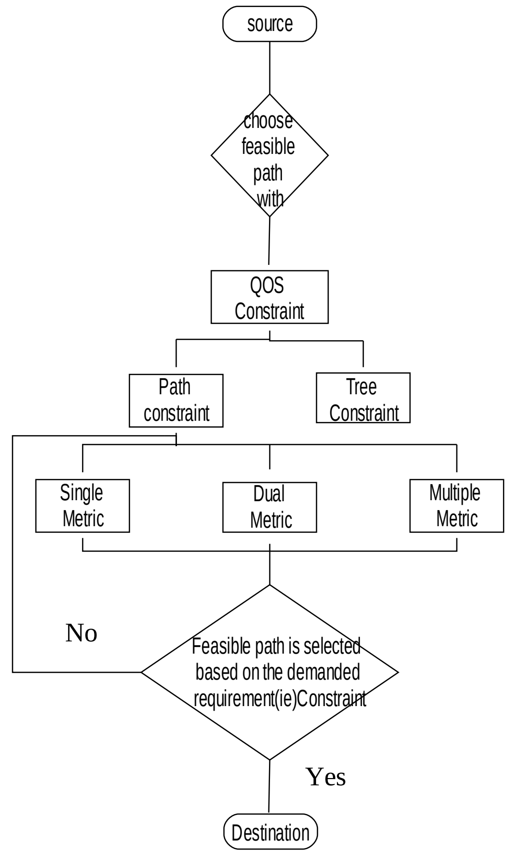


**Figure 1.Indicates the influence of metrics**

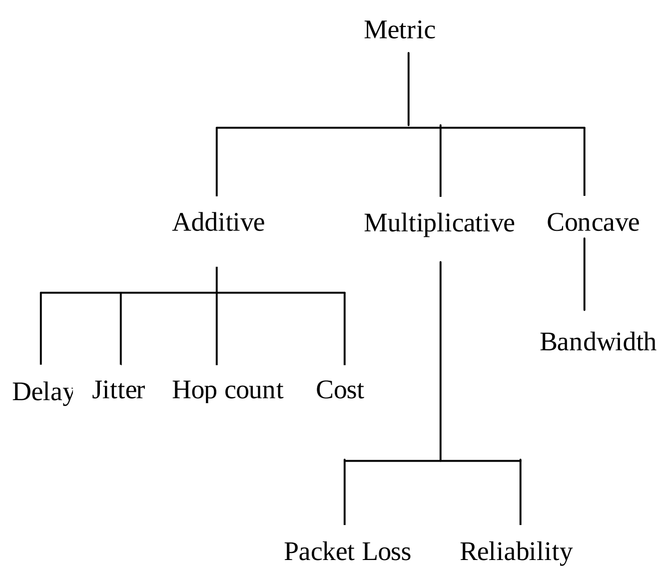

**Figure 2. Taxonomy of Metric**

## IV.METRICS CLASSIFICATION

### *A. Additive Metric*

Additive metric has following metrics delay, jitter, hop count, cost. Delay is a metric that obeys the normal addition operator (+), we call such a metric as an additive QoS metric. Number of hops is another example of additive metrics. Generally delay jitter is also considered to be additive.

If m $(n_1,n_2)$ is the metric of the link connecting the two nodes $n_1$, $n_2$ then,
For any path P= $(n_1,n_2,\ldots,n_{i)},$ metrics could be classified in to three types

Additive, if $m(p)=m(n_1,n_2)+m(n_2,n_3)+\ldots+m(n_{i-1},n_i)$, such as, delay, delay jitter and cost.

#### *1) Delay*

There are several types of delay which packets suffer from when they travel from one node to another node along a path in networks. The most important of these delays are: processing delay $(d_{proc})$, queuing delay $(d_{queue})$, transmission delay $(d_{trans})$ and propagation delay $(d_{prop})$. Processing delay is the time required to process the arrived packets in a node. Queuing delay is the time a packet experience at a queue as it waits to be transmitted onto the link. It can vary from zero to very long depending on how many packets in the queue are waiting to be transmitted. Transmission delay is the time required to transmit all of the packet bits into the link. Propagation delay is the time required to propagate a bit from the beginning to the end of a link. It is the distance between two nodes divided by the propagation speed which is a little less than the speed of light. Therefore, the total delay is the sum of processing delay, queuing delay, transmission delay and propagation delay, namely:

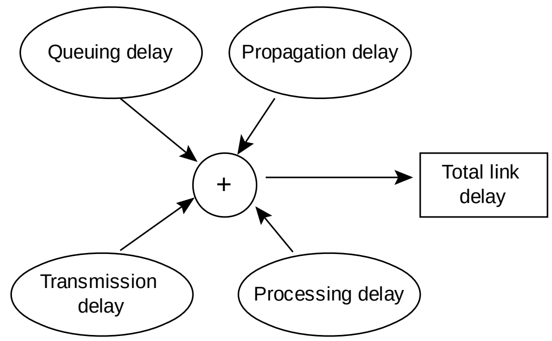


Figure 3. Depicts the total link delay

$$d_{total} = (d_{proc})+(d_{queue})+(d_{trans})+(d_{prop}) \quad (2)$$

According to Guerin-Orda Algorithm [2, 7], they considered the imprecision in the network, to determine the delay-constrained path. The aim of the algorithm is to find a path from source to destination, with highest probability, which satisfies the proposed metric delay as base requirement; a NP-Hard problem. What the algorithm implies is distribution of end-to-end delay in a equal probability among all the links from source to destination. Given a probability function $f_1$ $(d_1)$, [11] defines a cost function $c_1$ $(d_1)$ =-log $f_1$ $(d_1)$ so that the cost associated with each link is positive and it decreases as the associated delay increases. Shin-Chou algorithm [2] uses probing to overcome the high communication overhead.

#### *2) Hop Count*

It can be used as the path cost of networks. A path with minimal hop-count is preferred because it conserves network resource as well as the most convenient indicator of path delay. Average length of routes is defined as:

$$ALR = \sum_{i \in ACP} hopcount(i) / ACP \quad (3)$$

Where *ACP* is the set of accepted sessions, and hop count (i) is the number of hops traveled by the accepted sessions.

#### *3) Cost*

The Network cost is cost of transceiver required at the node as well as the number of wavelengths For end-end measurements, extracting router level path between pair of host is often useful for topology, but for such a measurements we need to trace full N (N-1).so making full O $(N^2)$ becomes costly normally it takes minutes to trace.

***Example***

In the following Fig. 4, it is required to find a path between node S and node T, meeting the following constraints: 2/6/15, where the constraints represent bandwidth, delay, and cost respectively.

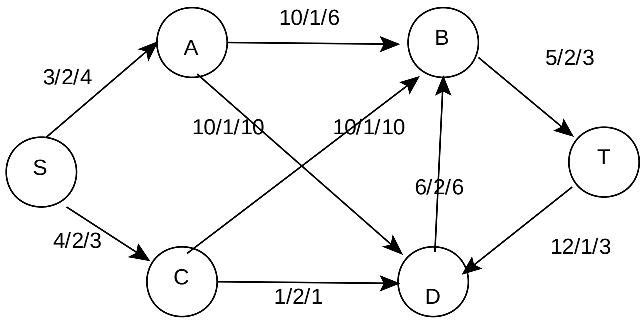


**Figure 4.Example to find a path with the constraints**

It is clear from the Fig. That the only path from S to T, which meets the constraints is: S → A → B → T.

#### *4) Cost and Delay as Metric*

The delay metric measures the time to send and receive a unicast packet from one node to another. Delay can be subdivided into six different phases. The overall delay is composed from queuing delays ($Q_S$ and $Q_R$), processing delays ($P_S$ and $P_R$), transmission delay T and propagation delay P. Given a bandwidth p, the transmission delay of b bits equals b/p. Thus, the overall delay D follows the equation

$$D=P_S+Q_S+P+b/p+Q_R+P_R \qquad (4)$$

The Network cost is cost of transceiver required at the node as well as the number of wavelengths For end-end measurements, extracting router level path between pair of host is often useful for topology, but for such a measurements we need to trace full N (N-1).so making full O ($N^2$) becomes costly normally it takes minutes to trace.

The metrics cost and delay are additive, [4] suggest that given a weight w(u,v) between nodes u and v, it can be converted to a new weight function w'(u,v)=$\lceil (w(u,v)*x)/c \rceil$ thereby changing the constraint $w \le c$ to $w \le x$, where c is a real number or an unbounded integer and x is a bounded integer. If L is the length of path p, and w (p)$\le 1\left[(L-1)*c\right]$/x, then p is also a solution for the simpler problem. The cost-delay constrained QoS routing is reduced to two problems where the link weights are

Original cost and new-delay (u, v)

$$=\lceil (d(u,v)*x)/\Delta d \rceil$$

Original delay and new-cost (u, v)

$$=\lceil (c(u,v)*x)/\Delta c \rceil$$

Where x= coefficient * distance(source, destination).coefficient is a given positive number, d(u,v) is the delay of the path from u to v, c(u,v) is the cost of the path from u to v, $\Delta_d$ is the delay constraint and $\Delta_c$ is the cost constraint.

The Delay Constrained Unicast Routing (DCUR) algorithm proposed by Salama [10, 2] decides to go with least cost and least delay. Control message is used to direct the packet in the constrained path. It provides the user with two paths one with least path and other with least delay, loops may exists if the control message visits the same twice. Sun-Landgendorfer improves on Salama by avoiding loops [2].

The Delay-Cost Constrained Routing (DCCR) [7], Chong et.al uses k-shortest path algorithm. Using non-linear weight function, it efficiently searches a path subject to delay as constraint at first, and then it searches against cost. If the path found with less delay is much less than path found with cost, then path with less delay is chosen.

#### *5) Bandwidth and Delay as metric*

The metric delay is considered along with concave metric, because delay is considered more important than the other metric cost, jitter. Cost and jitter metrics come in to play only when any one of the metrics bandwidth and delay takes the upper hand. Bandwidth and related routing metrics indicate the capacity of data which can be sent over a link within a given time. From the perspective of a node, this is equal to the transfer rate of a link. Many factors other than theoretical physical bandwidth have a significant effect on this metrics, e.g. packet loss ratio [8]. Bandwidth metrics are very popular when the performance comes into play for QoS routing.

Wang-Crowcroft algorithm [2, 18] uses source routing to remove the link which has got less bandwidth than the required bandwidth. The shortest path is found from source to destination using Dijkstra's algorithm. Next, hop-by-hop algorithm is used to find the best path with respect to bandwidth and delay. The bottleneck bandwidth is given higher priority over propagation delay which is dealt more in quantization of QoS metrics by Orda [23].

#### *6) Bandwidth and Cost*

The Ticket Based Probing (TBP) algorithm proposed for delay constrained least cost routing in the section on cost and delay metric can be applied to bandwidth constrained least cost routing [5]. Probes are sent from the source, limited in number, towards the destination. Receipt of a probe by the destination ensures availability of a path satisfying the desired resource requirements.

### B. Multiplicative Metrics

We call a metric as multiplicative QoS metric if it has the operator (*) defined as: $m_1+m_2=m_1*m_2$

Multiplicative, if $m(p)=m(n_1,n_2)*m(n_2,n_3)*\ldots*m(n_{i-1},n_i)$

The reliability r as r=1-loss rate. Then r is a multiplicative metric Where, $[1- m(n_1,n_2)]$ represents the success ratio over the link $n_1,n_2$. The loss probability of path is given by $m(p)=1-[(1- m(n_1,n_2))*(1- m(n_2,n_3))*\ldots*(1-(m(n_{i-1},n_i))]$. So, $\{1-[(1- m(n_1,n_2))*(1- m(n_2,n_3))*\ldots*(1-(m(n_{i-1},n_i))]\}$ will represent the loss probability over the whole path.

Multiple metrics (e.g., delay, bandwidth and loss probability) can certainly model the characteristics of a network more accurately. However, it may not be feasible to have many parameters as metrics since the problem of finding a path subject to multiple constraints is inherently difficult.

A problem with two simple additive constraints called "shortest weight-constrained path" was listed in [21] as NP-complete although the proof has never been published. Jaffe investigated this particular problem further and proposed two approximation algorithms that solve the problem in pseudopolynomial-time or polynomial-time if the lengths and weights have a small range of values. The problem is much more complicated in routing as the resource requirements specified by the applications are often diverse and application-dependent. The following sets of parameters, though by no means exhaustive, are among the most important and natural ones that may be chosen as metrics: delay, delay jitter, cost, loss probability and bandwidth. Among them, delay, delay jitter and cost are additive while loss probability and bandwidth are not.

The above routing constraint can be solved with several techniques. We categorize the solution as

*Single Metric representation of the individual metrics:* The single metrics can be useful to find lot of feasible alternate paths; it is linear combination of link weight

*Fallback Routing approach:* This approach checks all constraints one by one with respect to single metrics, the one that satisfies the single metrics will also satisfies other metrics.

*Dependent QoS Metrics:* The dependent metrics are split up to one and solved in polynomial time.

According to Yuan [23], the node which has less constraint can be solved in polynomial time. He transferred additive constraint to multiple constraint which has got more than three constraint cannot be solved in polynomial time.

Path vector protocol called QoSFinder [21] has been proposed that considers throughput (t, function of bandwidth and load), delay (d) and loss rate (e). The cost to reach the neighboring node is updated in the router; the path is selected based on the demand that satisfies the constrained requirement. The path is selected based on availability (A), defined as $A_t= (t/t_d)$, $A_d= (d_d/d)$, $A_e= (e_d/e)$.

Ma-Steenkiste algorithm [12, 2] states that when WFQ-like scheduling algorithms are used, queuing delays, delay-variation, and loss are not independent metrics; they are a function of bandwidth. This simplifies the problem and makes it solvable in polynomial time.

Tunable Accuracy Multiple Constraints Routing Algorithm (TAMCRA) [20, 6] is based on three concepts non-linear path, k-shortest path, principle of non-dominated path. With these concepts the search space reduction is done efficiently. Some of the advantages of TAMCRA are

Calculation time of TAMCRA increases linearly with the value of k, until it reaches a threshold, the calculation time depends on the size of the graph. The value of k with multiple constraints has to solve in polynomial time. The shortest path is limited to a certain threshold, the chance of finding a shortest path decreases as the value of k increases exponentially.

### C. Concave Metric

We call a metric a transitive QoS metric if it has operator (+) defined as:

$t_1+t_2 =\min [t_1,t_2]$

Or,

$t_1+t_2=\max [t_1,t_2]$

For a better understanding we consider only transitive metric, which is termed as concave metric, e.g., Bandwidth.

Concave, if $m(p)=\min[m(n_1,n_2),m(n_2,n_3),\ldots,m(n_{i-1},n_i)]$, such as, bandwidth.

#### 1) Bandwidth

Bandwidth is a concave metric which is handled by topology filtering. The link which has got bandwidth less the required bandwidth then the link, which has got lowest bandwidth, is removed before selecting any feasible path from source to destination. But Guerin-Orda Algorithm [2, 7] considers imprecision in the network while selecting path. The network doesn't consider enough information to select the path; the path is selected based on the best multiplicative probability. The multiplicative problem is transformed to an additive problem by assigning weight $w_1$ to the link 1 as log $P_1$, where $P_1=P_1(w)$ is the probability of success in the link having the w units of bandwidth.

The term bottleneck bandwidth, i.e., in (bandwidth) the smallest link capacity along the path, which is given in kbps. The smaller the bottleneck bandwidth is, the more it contributes to the overall path metric sum. As a consequence, it is less likely that a path with a small bottleneck bandwidth is selected for routing

The "available bandwidth" has been previously given various interpretations (such as fair share or bulk TCP throughput), there is growing consensus in the literature for a definition that is equivalent to [9], [13], [15]. A longer discussion of the capacity and available bandwidth metrics, including clarifications for paths with rate limiters, traffic shapers, or time-varying capacity, can be found in [14].

TABLE I

CONSTRAINT BASED QoS ALGORITHMS

The link with the minimum transmission rate determines the capacity, while the link with the minimum spare bandwidth determines the available bandwidth. To avoid the term bottleneck link, which has been widely used for both metrics, we refer to the capacity limiting link as narrow link and to the available bandwidth limiting link as tight link. Note that these two links may be different.

The packet pair method (sometimes called Packet Inter-Arrival Time method) was designed to measure the queuing delays at intermediate nodes and the destination node of a packet. However, it also is possible to infer from the queuing delay to the bandwidth of a link, if packets of different sizes are examined.

Putting all of the pieces together, we present a capacity-estimation methodology that has been implemented in a tool called pathrate. Pathrate sends many packet pairs to uncover the local modes of the underlying bandwidth distribution and then selects the local mode that corresponds to the capacity.

The following things to ignore while computing bandwidth

- Ignoring the variability of the available bandwidth process.
- Evaluating the accuracy of available bandwidth estimation through comparisons with bulk TCP throughput.
- Ignoring the relation between probing stream duration and averaging time scale.
- Estimating the tight link capacity with end-to-end capacity estimation tools.
- Ignoring the effects of cross traffic burstiness.
- Ignoring the effects of multiple bottlenecks.

## IV. SUMMARY

In this paper, we overviewed many problems in QoS routing which cannot be solved without considerable measure. The problem with QoS routing is a dynamic aspects, due to its complexity. New algorithms have to be proposed for an equal weight between the computation time and connection-success ratio, this enhances the throughput and responsiveness of QoS routing. Instead of proposing an algorithm for every new problem a generic algorithm is needed to solve the problem of QoS routing. Besides the overview of current researches in QoS routing, we believe that this paper will contribute to resolve lot of problems imposed due to QoS metrics.

| Routing Algorithm | Metrics | Time complexity |
|---|---|---|
| Guerin-Orda Algorithm | Delay | $O(Kx^3e)$ |
| Guerin-Orda Algorithm | Bandwidth and delay | $O(d^2 n^2e)$ |
| Shin Chou Algorithm | Delay | O(e) |
| Extended Dijkstra's Algorithm | Delay and Cost | $O(x^2n^2)$ |
| Extended Bellman Ford Algorithm | Delay and Cost | O(xne) |
| Delay constrained Unicast Routing(DCUR) Salama | Delay and Cost | $O(n^3)$ |
| Sun-Landgendorfer Algorithm | Delay and Cost | O(n) |
| Delay Scaling Algorithm(DSA) | Delay and Cost | O(( e+n log n) D/ε) |
| Lagrange Relaxation based Aggregate Cost(LARAC) | Delay and Cost | $O(e^2log^4e)$ |
| Ticket Based Probing(TBP) | Delay & cost, Bandwidth and Cost | O(me) |
| Wand Crowcroft | Bandwidth and Delay | O(n log n+e) |
| Jaffe's Distributed Algorithm | Any two additive metric | $O(n^5b \log nb)$ |
| Heuristics Algorithm for Multi-constrained Optimal Path (H-MCOP) | Multiple additive metrics | $O(n \log n+Kx \log kn+(x^2+1)x)$ |
| Tunable Accuracy Multiple Constraints Routing Algorithm (TAMCRA) | Multiple additive metrics | $O(Kx \log Kn+K^3x)$ |
| Self-Adaptive Multiple Constraints Routing Algorithm (SAMCRA) | Multiple additive metrics | $O(Kn \log(Kn)+K^2xe)$ |
| Chen-Nahrstedt | Bandwidth and cost | O(xve) |
| Salama | Delay and Cost | $O(v^3)$ |

## REFERENCES

[1] G. Apostolopoulos, D. Williams, S. Kamat, R. Guérin, A. Orda, T. Przygienda, "QoS Routing Mechanisms and OSPF Extensions", IETF, RFC 2676, August 1999.

[2] Shigang Chen, Klara Nahrstedt, "An Overview of Quality-of-Service Routing for the Next Generation High-Speed Networks: Problems and Solutions", in IEEE Network, Special Issue on Transmission and Distribution of Digital Video, November/December 1998, pp. 64-79.

[3] Shiang Chen, Klara Nahrstedt, "On finding Multi-constrained path (MCP) in International Journal of computational Geometry and Application ,1998 ,pp 874-879.

[4] Shigang Chen, Klara Nahrstedt, "On Finding Multi-constrained Paths (MCP)",in International Journal of Computational Geometry and Applications, 1998, pp. 874-879.

[5] Shigang Chen, Klara Nahrstedt, "Distributed QoS Routing with Imprecise State Information",in Proceedings of 7th IEEE International Conference on Computer, Communications and Networks, Lafayette, LA, October 1998, pp. 614-621.

[6] Hans De Neve, Piet Van Mieghem, "TAMCRA: A Tunable Accuracy Multiple Constraints Routing Algorithm", In Computer Communications, Vol. 23, pp. 667-679

[7] Liang Guo, Ibrahim Matta, "Search Space Reduction in QoS Routing", College of Computer Science, Northeastern University, USA, October 1998, Technical Report NU-CCS-98-09.

[8] Luis Henrique M. K. Costa, Serge Fdida (LIP6/UPMC), Otto Carlos M. B. Duarte, "Hop-by-Hop Multicast Routing Protocol", In ACM SIGCOMM, August 2001, pp. 249-259

[9] M. Jain and C. Dovrolis, "End-to-end available bandwidth: measurement methodology, dynamics, and relation with TCP throughput," IEEE/ACM Trans. Networking, vol. 11, pp. 537–549, Aug. 2003.

[10] Alpar Juttner, Balazs Szviatovszki, Ildiko Mecs, Zsolt Rajko, "Lagrange Relaxation Based Method for the QoS Routing Problem", in IEEE INFOCOM 2001, pp. 782-791.

[11] D. H. Lorenz, A. Orda, "QoS Routing in Networks with Uncertain Parameters",Department of Electrical Engineering, Technion, Haifa, Israel, June 97, Research Report EE Pub. No. 1094.

[12] Qingming Ma, Peter Steenkiste, "Quality of Service Routing for Traffic with Performance Guarantees",in IFIP Fifth International Workshop on Quality of Service, NY, May 1997, pp. 115-126.

[13] B. Melander, M. Bjorkman, and P. Gunningberg, "A new end-to-end probing and analysis method for estimating bandwidth bottlenecks," in Proc. IEEE Global Internet Symp., 2000.

[14] R. S. Prasad, M. Murray, C. Dovrolis, and K. Claffy, "Bandwidth estimation: metrics, measurement techniques, and tools," IEEE Network, vol. 17, pp. 27–35, Nov. 2003.

[15] V. Ribeiro, R. Riedi, R. Baraniuk, J. Navratil, and L. Cottrell, "PathChirp: efficient available bandwidth estimation for network paths," in Proc. Passive and Active Measurements (PAM) Workshop, Apr. 2003.

[16] J. L. Sobrinho, "Algebra and algorithms for QoS path computation and hop-by-hop routing in the Internet", IEEE Transactions on Networking, August 2002.

[17] Telecommunication Standardization Sector of ITU. ITU-T Recommendation E.800: Terms and Definition related to Quality of Service and Network Performance including Dependability, 1994.

[18] Turgay Korkmaz, Marwan Krunz, "Multi-Constrained Optimal Path Selection",in Proceedings of the IEEE INFOCOM 2001 Conference, Vol 2, Anchorage, Alaska, April 2001, pp. 834-843.

[19] P.Van Miegham, F.A.Kuipers,"On the Complexity of QoS Routing", Computer Communication, http://www.tvs.et.tudeltt.nl.2001.

[20] Piet Van Mieghem, Hans De Neve, "Aspects of Quality of Service Routing",in SPIE'98, Nov. 1-6, Boston (USA), 3529A-05.

[21] Ronny Vogel, Ralf G. Herrtwich, Winfried Kalfa, Hartmut Wittig, Lars C. Wolf, "QoS Based Routing of Multimedia Streams in Computer Networks", in IEEE JSAC, Vol. 14, No. 7, 1996, pp. 1235-1244

[22] Zheng Wang and J.Crowcroft, "Quality-of-service routing for supporting Areas in Communication,14(7):1228-1234,1996.

[23] Xin Yuan, Xingming Liu, "Heuristic Algorithms for Multi-Constrained
Quality of Service Routing",in IEEE INFOCOM 2001, pp. 355-364.