Dynamic Adaptive Routing

Nikolaos Nikou
Laboratory of Telecommunications Technology
Helsinki University of Technology
http://keskus.hut.fi/opetus/s38130/

Abstract

This paper presents briefly dynamic and adaptive routing. Dynamic routing is the dominant alternative to static routing.

Dynamic routing can support mobile networks that change dynamically by definition but also networks that, due to the parameters implied by Quality of Service need to direct user traffic to alternative routes others than those implied by the static route definitions.

Keywords: Dynamic Routing, Adaptive Routing Quality of Service

The purpose of this document is to present the Dynamic Adaptive Routing. No new ideas are introduced here and all sources used are found in the reference section

1 Introduction

Information networks continue to increase in size, complexity and importance.

More and more devices are connected to computer networks, from desktop computers to cellular telephones, Web servers to pagers, television set-top boxes to smoke detectors. As connections proliferate, network topologies necessarily become more and more dynamic. Devices may move from place to place, or maintain intermittent connections, or change their relationships to the network and their peers on the fly.

Networks must be flexible enough to allow these devices to communicate with each other in a variety of ways and across a variety of substrates. For example, physical links currently in widespread use include Ethernet, cellular radio, short-range infrared, and analog modem (to name a few).

It is very difficult to design a conventional network that adjusts well to either changing usage patterns over short time scales or to evolving needs and circumstances over the long haul. Dynamic routing can provide support on the fly, in response to new situations or demands, and without human intervention.

The goal of routing in a communications network is to direct user traffic from a source to the correct destination in accordance with the connections Quality of Service requirements. The requirements are the parameters for the guarantees the network is providing. These can be maximizing network performance (e.g., delay and throughput) and minimizing costs (e.g., equipment and facilities).

The underlying technology of the network imposes constraints on the network objectives. Constraints arise from the limitations of the network technology, the volume of user and network traffic, and the Quality of Service requested by the connection.

It is the multi-objective, multi-constraint nature of routing that makes it such a complex problem in communications networks. A problem that usually has two or more additive or multiplicative Quality of Service parameters, some of which are often conflicting.

That is why there have been several proposals to use Fuzzy logic as a heuristic approach to the problem. The Fuzzy logic is going to be described in the last section. For specific implementations of the Fuzzy logic look at [3] and [4].

The network though in order to satisfy the above conditions must adapt itself to the present conditions. Alternative routes are evaluated on a real-time basis and are very computation intensive at the switches.

1.1 Outline

Section 2 presents the Dynamic routing. Section 3 presents the Adaptive routing, on Section 4 a small presentation of Fuzzy Logic.

2 Dynamic Routing

Originally the networks were build hierarchical. This is still the case for most PSTN networks and we see also this on the IP networks and recently adopted by Internet community. The hierarchical model allows the extensive use of static routing. During static routing the routing remains fixed independent of the current state of the users and the networks. Static routing is based on expected rather than actual network state. Static routing involves virtually no real-time activities other than traffic forwarding and thus requires almost no computational resources within the network itself. This was primary the reason for the establishment of the fixed hierarchical networks on the PSTN networks.

The rate and unpredictability of changes in modern communications networks makes it a necessity to use dynamic routing within the network to improve performance.

Dynamic routing selects routes based on the current state information for the network. The state information can be predicted or measured but the route will change depending on the available state information at the time of the traffic request. The evolution of the networks components switches, routers, controllers, gateways, etc., allowed the introduction of additional logic on these components. The network can cope now with the dynamics of traffic and react to real-time network traffic accordingly, by introducing real-time behavior and state dependency in order to avoid congestion and to achieve optimal performance.

Dynamic routing is distinguished by two factors:

- The computational model that the routing service is using
- The state information nature

There are two computational models used in Dynamic Adaptive Routing the centralized and the distributive.

Traditionally we could see that the location of the computational engine in the routing system was centralized. With the introduction of the IP networks new possibilities arise and new requirements. There is a strong desire for decentralization and a higher level of dynamism. With the decentralized routing system, multiple peer entities perform routing functions. Most of the proposals are speaking for a distributive routing system, where routing nodes share state information to cooperatively provide routing functionality.

Distribution replicates functionality at multiple entities and increases the reliability of the system. It also makes the network responsive to local state changes that a centralized controller may not have detected. Since the computational load is spread over the entire network the routing functionality will be less affected by overloading the network. A distributed implementation is more scalable because adding routers also adds computational units to the network.

The Dynamic Adaptive Routing is relying on real-time information. Alternative routes are found based on the actual state of the network. The estimation of the current status of the network requires computational resources. Alternative approaches have been introduced with the use of Fuzzy logic where heuristic algorithms can produce almost ideal paths.

3 Adaptive Routing

According to [1] Dynamic Adaptive Routing is the <<Automatic rerouting of traffic based on a sensing and analysis of current actual network conditions. NOTE: this does not include cases of routing decisions taken on predefined information. >>

Adaptive routing is driven purely by the current state information available for the network. The term adaptive refers to the network's ability to adapt to conditions and find a route optimal to the present conditions. Unlike time-dependent routing, alternative routes are evaluated on a real-time basis and as such have no dependence on the time of day. Adaptive routing is computation intensive at the switches since the state information must be examined frequently but it is also more responsive to local network conditions.

The nature of the state information used to make routing decisions is an important distinction in dynamic routing systems. In time-dependent routing implementations, the choice of routes taken is a factor of the time of day when the request for traffic takes place. This approach relies on accurate predictions of network traffic as a function of time to avoid congested links or switches in a network. Time-dependent routing is not considered adaptive because routing alternatives remain fixed during a constant time period, such as one hour.

4 Examples

Three algorithms that belong to Dynamic Adaptive Routing are presented bellow, the Efrouter [4], the Dynamic Alternative routing (DAR) [18] [21] and the Real-Time Network routing (RTNR) [19] [21]. Both have been used on switched networks.

Efrouter [4] is a complete routing system that is enhanced by computational intelligence algorithms based on fuzzy-et theory and generic algorithms. A subset-interactive autoregressive model is used to predict link utilization levels, based on experience from the static traffic observations as well as dynamic knowledge acquired during the network's operation. Eftouter is able to foresee which path is the best to carry a specific connection, by calculating the shadow cost of allowing this connection through each feasible path.

Dynamic Alternative Routing is a simple but effective form of dynamic routing which is decentralized and which uses only a small amount of local information. DAR is an adaptive call-routing strategy that stochastically selects an alternative route using local information about the loading of outgoing trunks to determine the feasibility of selected routes.

Real-Time Network Routing is an adaptive routing method. It has been designed to be adaptive over multiple classes of service, which makes it easily extendible to carry B-ISDN traffic. RTNR also provided ingress/egress routing service to facilitate integration of Dynamic Routing into global networks.

DAR has been implemented in the British Telecom PSTN while RTNR replaced DNHR in the AT&T network starting in 1991.

4.1 Efrouter

Efrouter is a complete routing system, which decides upon routing paths according to the flow diagram in the

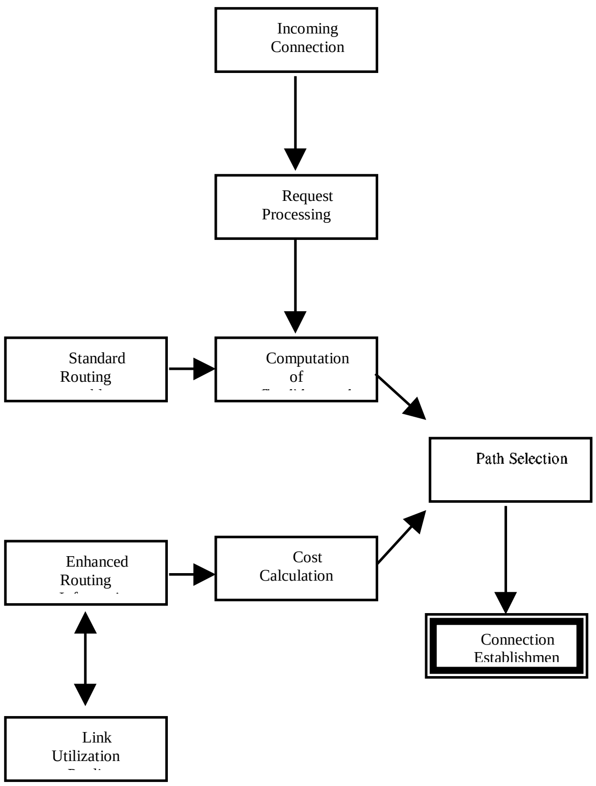

figure bellow.

The incoming connection request is first preprocessed, in order to bring the connection in suitable form and enable parsing of the routing tables according to the connection's preferences in terms of policy requirements as well as underlying network technology. After preprocessing, a set of feasible paths (that are most likely to accept the connection) are found from the routing information tables. This reduced set of routes is then fed to the path selection process, which selects the most appropriate route (i.e. route with the least shadow cost). Finally the appropriate management functions are called for setting up the path and communication lower, intra-domain layer trail connection requests. The shadow cost is the summary metric reflecting the impact of admitting a connection with specific Quality of Service requirements. To calculate the shadow cost one must predict the utilization level of the link. This is done using a fuzzy predictor.

The Efrouter algorithm utilizes time-series statistical data on traffic patterns to predict traffic load on individual links. This is the information that is used to calculate the shadow cost of selecting a path, reflecting the probability of having to refuse a future connection request as a direct consequence of accepting this connection. Based on this metric, the algorithm selects one of the candidate paths, that is expected to have the least impact on the ability of the network to meet demand.

4.2 The DAR algorithm

The DAR algorithm for a fully connected N-node network is as follows. Each link (i, j) has a capacity Cij and assigns a trunk reservation parameter r based on a percentage of its total capacity. Every source-destination pair (i, j) in the network maintains a tandem node k, which is the node in common to the two links of that pair's first alternative path. The tandem node is selected at random from all nodes providing a two-link path from the source to the destination.

Fresh-offered traffic between nodes i and j is first offered to the direct link and is always accepted by this link if a circuit is available. Otherwise, the call attempts the two-link alternative specified by it's tandem node k. If the call can not be routed via node k without violating the TR parameters that call is lost and the pair (i,j) selects a new tandem node at random from those available. If the call is successfully delivered through the direct link or through the tandem node that pair retains k as the tandem node.

One of the desirable properties of DAR is its speed of response. The reselection of a tandem node occurs only after a call fails, so per-call processing is low. Since only one alternate path is retained for each link, the routing decision is fast and predictable.

DAR locks on to a good alternate route, and once a route fails, another route is immediate sought. This can be thought of as a learning scheme wherein the probabilities of choosing a particular overflow path are 1 if the path was just successful, 0 if the path just failed, and 1/(N-2) for all other alternate paths.

Over a sufficiently long period, each DAR alternative path will have been selected an equal number of times, since the tandem nodes are selected at random. Since one call is lost each time a new tandem is selected an equal number of calls will be lost on each overflow path. Thus, if pt denotes the proportion of calls offered to tandem t and bt denotes the probability that a call is blocked through t, then the blocking rate ptbt is equal for all tandems t. Hence,

$$p_t \propto \frac{1}{b_t}$$

Which says that the proportion of overflowing calls routed through any given tandem t is inversely related to the blocking probability on the route. This is the essence by which DAR spreads traffic evenly throughout the network.

DAR can be easily modeled and several variations of DAR have been proposed based on the results of these simulations. In general, the variations of DAR use a method other than pure random to select new tandems from those available. These variations have been shown to yield better performance than classic DAR but they reduce the simplicity of the algorithm.

4.3 The RTNR algorithm

RTNR first tries the direct route and the call is accepted on that route if a circuit is available. If the direct trunk is not available, the originating switch communicates with the terminating switch through the central facilities and the CCS network. The terminating switch sends the busy-idle status of all links terminating at that switch which the sending switch then compares with the status of it's own links to find the Least-Loaded Route (LLR) to the destination.

An alternate path through two links, A and B, with TR parameters (Trunk Reservation parameter is the number of circuits that must be free on a link if that link is to be used as an alternative path) rA and rB, is considered least-loaded if it has the lowest value loadA, B where

$$load_{A,B} = \min\{(r_A - load_A), (r_B - load_B)\}$$

This quantity is often referred to as the TR permissibility of a path since it is a reflection of the bandwidth available in addition to the reservation parameters. A negative TR permissibility would indicate that an alternate route is not available while a large TR permissibility indicates an underutilized path. This is a computationally intensive routing decision to find the <<best>> route when any available route can carry the call but LLR has been shown to have better performance than either Dynamic Non-Hierarchical Routing or DAR. The DAR algorithm may not prove extensible to multiple classes of service while AT&T's RTNR network is currently operating in this mode.

5 Fuzzy Logic

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth -- truth values between "completely true" and "completely false". It was introduced by Dr. Lotfi Zadeh of UC/Berkeley in the 1960's as a means to model the uncertainty of natural language.

Zadeh says that rather than regarding fuzzy theory as a single theory, we should regard the process of ``fuzzification" as a methodology to generalize ANY specific theory from a crisp (discrete) to a continuous (fuzzy) form [13]. Thus recently researchers have also introduced "fuzzy calculus", "fuzzy differential equations", and so on [14].

Fuzzy sets and logic must be viewed as a formal mathematical theory for the representation of uncertainty. Uncertainty is crucial for the management of real systems: if you had to park your car precisely in one place, it would not be possible. Instead, you work within, say, 10 cm tolerances. The presence of uncertainty is the price you pay for handling a complex system.

Nevertheless, fuzzy logic is a mathematical formalism, and a membership grade is a precise number. What's crucial to realize is that fuzzy logic is a logic OF fuzziness, not a logic which is ITSELF fuzzy. But that's OK: just as the laws of probability are not random, so the laws of fuzziness are not vague.

For more information about Fuzzy you can look also at the following URL [17] where the above information was taken from URL: http://www.cs.cmu.edu/Web/Groups/AI/html/faqs/ai/fuzzy/part1/faq.html

Fuzzy logic has been proposed by several researchers as an alternative method to evaluate path costs under supply metrics that change over time. These fuzzy costs are based on the crisp values of the different metrics possibly used in the network links. For each metric, a fuzzy membership function is defined. The parameters of these membership functions reflect dynamically the requirement of the incoming traffic service as well as the current state of the links in the path. The fuzzy logic approach is beneficial in many situations where the requirement of a traffic service from a metric is not rigid but somehow flexible in a range of values.

The routing system must find a path such that the Quality of Service requirements, which are diverse and application-dependent, are satisfied. These requirements are the constraints to be met. Each constraint is associated with a metric in the network. The more metrics we have the more accurately the network is represented but the harder the problem to be solved. The different metrics in the communication networks can be devided into three categories according to the composition rules of the metrics. Let d(i, j) be a metric for link (i, j) and p = (s, i, j, …, k, t) be a path that connects source s with destination t. Wang, Crowcroft [16] summerized the different composition rules as following:

- Metric d is additive if:

d(p) = d(s, i) + d(i, j) + … + d(k, t)

Example of these metrics are delay, delay jitter and cost

- Metric d is multiplicative if:

d(p) = d(s, i) x d(i, j) x … x d(k, t)
Example of these metrics are loss probability

- Metric d is concave if:

d(p) = min[d(s, i), d(i, j), …, d(k, t)]
Example of these metrics are bandwidth

Wang, Crowcroft [16] proved that the problem of finding a path subject to constraints on two or more additive and multiplicative metrics in any possible combination is NP-complete. So, heuristic approaches are often the only candidate solutions for this problem.

Fuzzifying the requirements increases the feasible solution space with the gain of avoiding the high probability of infeasible solutions as is often the case of crisp requirements. In other words, the fuzzy approach is an effective tool for quickly obtaining a good compromise solution.

The availability of each metric, or in other words the relation between the current call requirements and the current value of the corresponding metrics, can be represented by a group of fuzzy membership functions [17]. A fuzzy-inference rule base can be used to integrate these membership functions into a cost that can be assigned to each path.

Several people introduced the Fuzzy logic into the routing domain and each applies the fuzzy logic into the algorithms they propose. In some approaches fuzy logic is used to find the costs on each link and then use the shortest path algorithm to find the route, while others take a more sophisticated approach where they combine the two and introduce additional steps. For specific implementations of the Fuzzy logic look at [3] and [4].

6 Conclusions

The research community has several proposals on the Dynamic Adaptive routing. A lot of the approaches are designed for specific scenarios but there are certainly many benefits as the Dynamic Adaptive routing can provide the necessary efficiency to maintain high level of Quality Of Service.

Fuzzy logic can be used to deal with events in uncertain conditions

References

[1] RFC 1983 Internet Users' Glossary

[2] Kim, Kang, Chun, Dynamic Qos Routing Algorithm Supporting Point to Multipoint Connections

[3] Aboelela, Douligeris, Fuzzy Inference System for QoS Routing in B-ISDN

[4] Vasilakos, Ricudis, Anagnostakis, Pedrycz, Pitsillides, Evolutionary-Fuzzy Prediction for StrategicQoS Routing in Broadband Networks

[5] Minar, Kramer, Maes, Cooperating Mobile Agents for Dynamic Network Routing

[6] Minar, Kramer, Maes, Tutorial: mobile Software Agents for Dynamic Routing

[7] Chen, Druschel, Subramanian, A new Approach to Routing with Dynamic Metrics

[8] Michail, Ephremides, Routing Algorithms in All-Mobile Wireless Networks, Center for Satellite and Hybrid Communication Networks

[9] Xie, Baras, Performance Analysis of PNNI Routing in ATM Networks: Hierarchical Reduced Load Approximation, Center for Satellite and Hybrid Communication Networks

[10] Liu, Baras, Misra, Performance Evaluation in Multi-Rate, Multi-Hop Communication Networks with Adaptive Routing, Center for Satellite and Hybrid Communication Networks

[11] Liu, Baras, Fixed Point Approximation for Multirate Multihop Loss Networks with Adaptive Routing, Center for Satellite and Hybrid Communication Networks

[12] Chen, Baras, A Dynamic Routing Algorithm in Mixed Media Networks with Integrated Voice and Data Traffic, Institute for Systems Research, University of Maryland

[13] McNeill, Daniel, and Freiberger, Paul, Fuzzy Logic: The Discovery of a Revolutionary Computer Technology, Simon and Schuster, 1992.

[14] Earl Cox, "The Fuzzy Systems Handbook: A Practitioner's Guide to Building, Using, and Maintaining Fuzzy Systems", Academic Press, 1994

[15] IETF Draft, Source tree Adaptive Routing (STAR) Protocol

[16] Wang, Crowcroft, Quality Of Service Routing for Suporting Multimedia Applications, IEEE journal on Selected Areas in Communications, Vol 14, No. 7, September 1996, page 1228-1234

[17] Fuzzy FAQ, http://www.cs.cmu.edu/Web/Groups/AI/html/faqs/ai/fuzzy/part1/faq.html

[18] Dynamic Alternative Routing, http://www.statslab.cam.ac.uk/~frank/DAR/

[19] Real-Time Network routing, http://att.com/technology/technologists/patents/1997_patent_4.html

[20] Peter John Shoubridge, Adaptive Strategies For Routing In Dynamic Networks, http://citeseer.nj.nec.com/did/234014

[21] Greg, Trangmoe, A Comparative Study of Dynamic routing in Circuit-Switched networks