Evolution of unicast routing protocols in data networks

Carles Seguí, Agustín Zaballos, Xavier Cadenas, Josep M. Selga
Enginyeria i Arquitectura La Salle
University Ramon Llull (URL)
Barcelona, Spain
{csegui, zaballos, xcadenas, jmselga}@salleurl.edu

***Abstract*— We provide an overview of the evolution of routing from its origins, even before the ARPANET, to recent algorithms that provide some Quality of Service, focusing on unicast distributed routing algorithms. We start our scheme with shortest path routing and optimal routing and conclude it with constrained routing protocols as well as a quick review of Ad-Hoc Routing protocols.**

Keywords- Best-effort Routing, QoS Routing, IP Routing, Ad-Hoc Routing.

I. Introduction

Traditional Internet routing protocols calculate the shortest path between any source and destination based on a single metric, e.g. hop count, fixed bandwidth. This routing scheme has been deployed the last thirty years for routing best-effort traffic in three ways: source routing, distributed routing and hierarchical routing.

In the last years interest in real-time applications have been growing very fast and have posed a significant challenge to routing protocols because of its need to guarantee a given level of Quality of Service to determine the path of a data flow based on knowledge of network resources availability.

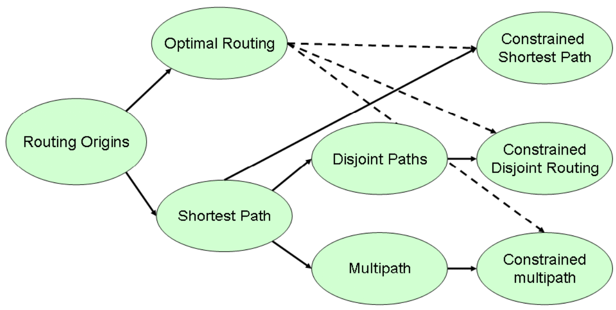

Figure 1. Routing evolution

II. Best-effort routing

Best-effort routing protocols calculate the best path to a destination based on a single static metric.
There are two kinds of shortest path routing protocols: Vector-distance protocols, based on Bellman-Ford algorithm, e.g. RIP [1] or IGRP, and Link-state protocols, based on Dijkstra algorithm, e.g. OSPF [2] or IS-IS [3][4]. Another type of protocol based on a mixture of vector-distance and link-state has been deployed, taking advantage from the best of each one. It's the EIGRP protocol.
The evolution of best-effort routing could be split into two research areas: Disjoint path routing and multipath routing.

A. Disjoint path routing

Disjoint Path Routing provides a pair of minimum total length independent paths from a source to a destination to increase the reliability in communications.

In this line of research it is important to highlight the studies of R. Ogier. In [5] he presents a distributed algorithm to find two disjoint paths with both node-disjoint and link-disjoint versions. In [6], Sidhu presents another way to find two disjoints paths. He works with a label distribution system in order to mark which of them are disjoints paths from a source to a destination.

B. Multipath Routing

In multipath routing, instead of finding the best path to a destination, the algorithm finds "k" best paths to a destination. In this way the information can be load-balanced among all of them and average network delay can be reduced.

In this research area it is important to emphasize the related work made by J.J. Garcia-Luna-Aceves and his disciples. He created MDVA [7] (Multipath Distance Vector Algorithm), after concluding three prior algorithms [8][9][10] based on DUAL algorithm [11].

III. Optimal Routing

Optimal routing optimizes the average global delay of a network, instead of finding the shortest path to a destination. These algorithms, originally of centralized nature, constitute an efficient way to design networks.

The idea of optimization starts with [12] and [13], and culminates with Gallager in [14], where he proposes the first distributed optimal routing algorithm. In order to achieve this objective, he shows that it is necessary to split the traffic among several available paths.

The main disadvantage of these algorithms is that they are not adequate for real networks because they converge very slowly and because they depend on global parameters, which are difficult to know a priori. Nevertheless they constitute a reference and recently they have inspired protocols worth to consider for implementation [32][33].

IV. CONSTRAINED ROUTING

QoS Routing selects a route to a destination with enough resources to cope with the requested QoS parameters.

Two main problems arise with constrained routing: Link optimization routing, with concave metrics, e.g. bandwidth and buffer space; Path optimization routing with additive metrics, e.g. delay or jitter and Multiplicative metrics, e.g. reliability or packet loss.

A combination of some of these metrics derives to the MCP (Multi Constrained Problem). This problem, depending on the used metrics, is NP-Complete [15] and has no practical solution.

A. Link Constrained Routing

Some of the algorithms based on concave metrics are:

- WSP (Widest Shortest Path) [16], which finds the path with less number of hops and, if several paths exist, it chooses the one with less bottleneck restrictions.
- SWP (Shortest Widest Path) [17], that finds the path with less bottleneck restrictions and, if several paths have been found, it chooses the one with less delay.
- MRBHP (Maximum Ratio of Bandwidth and Hop Path) [18], an evolution of previous algorithms that finds the path with smallest number of hops and with the biggest available bandwidth.

Yao in [19] proposes a routing algorithm that breaks the total bandwidth requirements into paths with smaller bandwidth and seek multipaths when there is not a single feasible path in the network.

Other studies have been done with disjoint paths with link constrained routing [20][21]. Both of them conclude that the problem of finding two disjoint paths with some QoS requirements is NP-Complete.

B. Path Constrained Routing

These algorithms evolve from the optimal routing but they only work with one path and do not with the entire network. Some examples can be find in [22][23].

C. Multi Constrained Routing

In general this problem is NP-complete and some proposals try to solve this fact by either:

- Establishing a combined metric starting from the less restrictive parameters. With this proposal it is not always possible to determine the best path.
- Establishing each parameter like a different metric. The unique situation in which it is possible to obtain an exact solution is when one of the metrics is the bandwidth and the other one is the delay, jitter, cost or loss probability [17].
- Relax the proposed metric through a change in the cost function [24].

From these proposals, multiple relating articles have appeared in last years, trying to find heuristic solutions with polynomial complexity [24] [25][26][27].

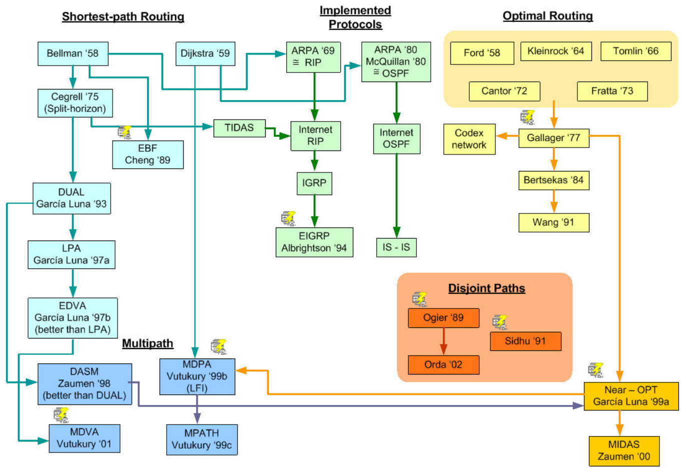

Figure 2. Routing evolution

V. ADHOC ROUTING

Over last years, society has become increasingly mobile. A wireless Ad Hoc network is formed by a collection of nodes disposed in a dynamic way. Due to a limited transmission range of wireless interfaces, more than one network hop may be needed for a single node to transmit data to another node in the network. This is the reason why a great number of routing protocols for Ad Hoc networks are being developed.

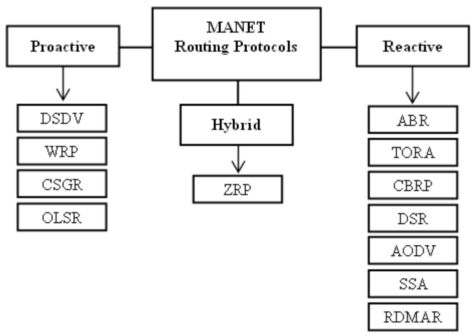

Figure 3. Some MANET routing protocols

A. MANET proactive protocols

These algorithms maintain a fresh list of destinations and their routes. One example is the Optimized Link State Routing (OLSR) [28]. This is a modular proactive routing protocol which works following a hop-by-hop routing basis. As it is a proactive approach, it tries to find routes to all possible destinations in the network continuously. Proactive behavior could increase the congestion in the network due to the routing traffic generated. However, due to its proactive basis, it has the advantage of having routes immediately available at the moment they are required.

B. MANET reactive protocols

A reactive protocol maintains routes only between nodes that need to communicate. Route caching can further reduce route discovery overhead. When no designed route is found, protocol finds one. Some reactive protocols are:

- DSR [29]: An on-demand routing protocol which works in a source routing basis. Each transmitted packet is then routed carrying the complete route in its header.
- TORA [30]: An adaptive on-demand routing protocol designed to provide multiple loop-free routes to a destination, thus minimizing reaction to topological changes. The protocol belongs to the link reversal algorithm family set.
- AODV [31]: An on-demand distance-vector routing protocol, based on hop-by-hop routing. It is a modified DSR protocol incorporating some features presented in the DSDV protocol, such as the use of hop-by-hop routing, sequence numbers and periodic beacon messages.

ACKNOWLEDGMENT

We would like to thank URL (University Ramon Llull) for its support and Agusti Alonso from "Endesa Servicios" for his enthusiasm and active participation.

REFERENCES

[1] G. Malkin, *"RIP version 2"*, RFC1723, November 1998.

[2] J. Moy, *"OSPF version 2"*, RFC2328, April 1998.

[3] *"Intermediate System to Intermediate System intra-domain routeing information exchange protocol for use in conjunction with the protocol for providing the connectionless-mode network service (ISO 8473)"*, ISO/IEC 10589, November 2002.

[4] R.W. Callon, *"Use of OSI IS-IS for routing in TCP/IP and dual environments"*, RFC1195, December 1990.

[5] R. Ogier, N. Shacham "A Distributed Algorithm for Finding Shortest Pairs of Disjoint Paths", IEEE 1989.

[6] Sidhu, D., Nair, R., "*Finding Disjoint Paths in Networks"*, ACM, 1991

[7] Vutukury, S., Garcia_luna-Aceves, J.J., *"MDVA: A Distance-Vector Multipath Routing Protocol"*, Proceedings of INFOCOM 2001, IEEE, 2001.

[8] García-Luna-Aceves, J.J., *"Loop-free Routing using Diffusing Computations"*, IEEE/ACM Transactions on Networking,, Vol.1,No.1, February 1993.

[9] García-Luna-Aceves, J.J. and Murthy, S., *"A path finding algorithm for loop-free routing"* IEEE/ACM Transactions on Networking, Vol.5, No.1, pp.148-160, Feb. 1997.

[10] García-Luna-Aceves, J.J., *"A more efficient distance vector routing algorithm"* IEEE, 1997.

[11] Albrightson R, García-Luna-Aceves, J.J. and Boyle J., *"EIGRP-A Fast Routing Protocol Based on Distance Vectors"*, Proceedings Networld/Interop 94, Las Vegas, Nevada, May 1994.

[12] Cantor, D. and Gerla M., *"The Optimal Routing of Messages in a Computer Network via Mathematical Programming"*, IEEE Comp. Conference, San Francisco, September 1972.

[13] Fratta, L., Gerla M., Kleinrock, L., *"The Flow Deviation Method: An Approach to Store-and-Forward Communication Network Design"*, Networks, 3, pp. 97-133, 1973.

[14] Gallager, R.G., *"A minimum Delay Routing Algorithm Using Distributed Computation"*, IEEE Transactions on Communications, Vol. COM-25, No.1, January 1977.

[15] M. Carey, D. Jonson, *"Computers and intractability: A Guide to the theory of NP-Completeness"*, New York: W.H Freeman and Co. 1979.

[16] G. Apostolopoulos, D. Williams, A. Orda et al, "QoS Routing Mechanisms and OSPF Extensions", RFC2676, August 1999.

[17] Z.Wang and J. Crowcroft, *"Quality-of-Service Rouiting for Supporting Multimedia Applications"*, IEEE Journal on Selected Areas in Communications, Vol 14, no. 7, September 1996.

[18] Shi Ming-Hong, W. si-Bing, *"A Bandwidth Constrained QoS Routing Optimization Algorithm",* 2003.

[19] Y. Yang, L. Zhang, J. K. Muppala, S. T. Chanson, *"Bandwidth-delay constrained routing algorithms"*, Dept. Computer Science, HK University, January 2003.

[20] A. Orda, A. Sprintson, *"Efficient Algorithms for Computing Disjoint QoS Paths"*, IEEE INFOCOM 2004, 2004.

[21] Y. Guo, F. Kuipers, P. Van Mieghem, *"Link-Disjoint paths for reliable QoS rotuing"*, International Journal of Communications System, 2003.

[22] Garcia-Luna-Aceves, J.J., Vutukury, S., Zaumen, W.T., *"A Practical Approach to Minimizing Delays in Internet Routing"*, IEEE, 1999.

[23] Zaumen, W.T., Vutukury, S., Garcia-Luna-Aceves, J.J., *"Load-Balanced Anycast Routing in Computer Networks"*, IEEE, 2000.

[24] S. Chen, K.c Nahrstedt, *"On Finding Multi-Constrained Paths"*, Tech. Report UIUCDCS-R-97-2026, UIUC, August 1997.

[25] P. Van Mieghem, H. De Neve, *"Hop-by-hop Quality of Service Routingg"*, Computer Networks, December 2001.

[26] H. De Neve, P. Van Meghem, *"TAMCRA: A Tunable Accuracy Multiple Constraints Routing Algorithm"*, Comp. Communications vol. 23, 2000.

[27] G. Liu, K. G. Ramakrishnan, *"A*Prune: An Algorithm for Finding K shortest Paths subject to multiple constraints"*, Proc. INFOCOM 2001, April 2001.

[28] Clausen, T.; Jacquet, P. *"Optimized link state routing protocol"*. RFC 3626, 2003.

[29] Johnson, D. B.; Maltz, D. A.; Broch, J. *"DSR: The dynamic source routing protocol for multi-hop wireless Ad Hoc networks"*, 1999.

[30] Park, V. D.; Corson, M. S. *"A highly adaptive distributed routing algorithm for mobile wireless networks"*. University of Maryland. College Park, MD (USA), 1997.

[31] Perkings, C. E.; Belding-Royer, E.; Das, S. R. *"Ad Hoc on-demand distance vector routing"*. RFC 3561, 2003.

[32] Zaumen, W.T., Vutukury, S., Garcia-Luna-Aceves, J.J., *"Load-Balanced Anycast Routing in Computer Networks"*, IEEE, 2000.

[33] Garcia-Luna-Aceves, J.J., Vutukury, S., Zaumen, W.T., *"A Practical Approach to Minimizing Delays in Internet Routing"*, IEEE, 1999.