Designing Genetic Algorithms for Adaptive Routing Algorithms in the Internet

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Contents

- Intoduction to routing algorithms in the Internet.
- Introducing the *Genetic Adaptive Routing Algorithm* (GARA) and its *path genetic operators*.
- Discuss future direction toward evolutionary-computation-based adaptive routing algorithms in the Internet.

Routing algorithms

- Constructing routing tables to forward communication packets to destination.
- Routing table: for each destination, route(s) or next hop(s) is specified.

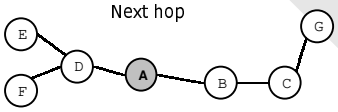
Destination	NextHop	Distance
B	B	1
C	B	2
D	D	1
E	D	2
F	D	2
G	B	3

Next hop

Destination	Route	Distance
B	(A B)	1
C	(A B C)	2
D	(A D)	1
E	(A D E)	2
F	(A D F)	2
G	(A B C G)	3

Source routing

(Specifying complete paths)



Routing in the Internet

A hierarchy structure:

- IGP (Interior Gateway Protocols)

  Routing inside an Autonomous System(AS)

- EGP (Exterior Gateway Protocols)

  Routing between ASs

  BGP (Border Gateway Protocols), etc.

Interior Gateway Protocols

- Routing Information Protocol (RIP)

  Based on Bellman-Ford's distributed algorithm

  Broadcasts routing tables to calculate distance.

- Shortest Path First (SPF) algorithms such as OSPF (Open Shortest Path First) protocol.

  Calculates shortest paths by Dijkstra's shortest path algorithm based on collected topological database - broadcasts only link status.

Why difficult to be adaptive?

- RIP and OSPF employ **static** distance measure such as hop count metric.
- Uncertainty due to delayed information
- Adaptive algorithms may cause oscillation, unreachable routes, etc.
- To be adaptive, need to observe frequently
- Unable to observe frequently by broadcasts. Overheads of observation changes network status

How to reduce overheads?

- Broadcast as less frequent as possible
- Restrict observations - perform observations of limited routes that is frequently employed (and is worth observation overheads).
- Autonomous control - each node should determines routes independently employing locally obtained infomation.
- Intelligent control needed - prediction algorithm, learning scheme, constructiong solution database, etc.

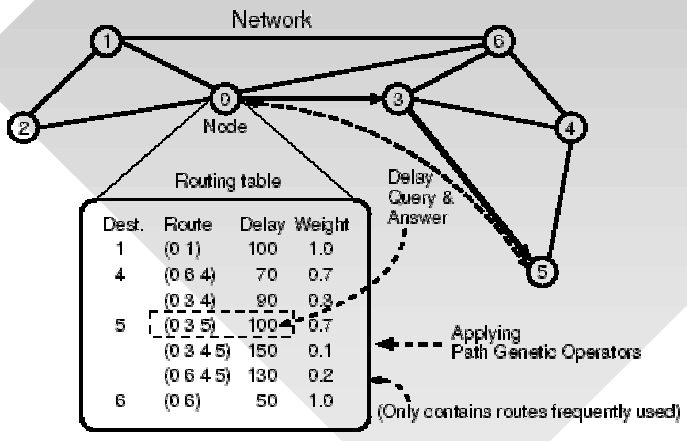
Evolutionary computation(EC): a promising answer

- Evolution is essentially a distributed process: each creature determines its action autonomously.
- Adaptation in evolutionary process needs less frequent communications (eg. no broadcast is necessary) among individuals.
- Evolution is considered robust to environmental changes.

The Genetic Adaptive Routing Algorithm (Munetomo et. al, 1997)

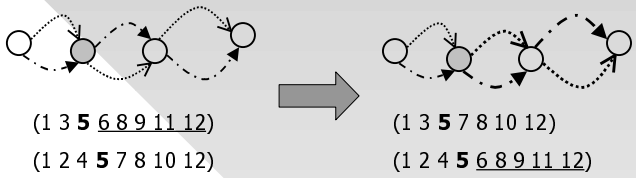
- Each node keeps a population of alternative routes generated by *path genetic operators*.
- Alternative routes are generated only for destination frequently communicated - otherwise, a static route is employed (same as OSPF).
- Delay observation only for routes frequently used - a selection is applied to reduce size of routing tables.

Overview of the GARA



Path genetic operators

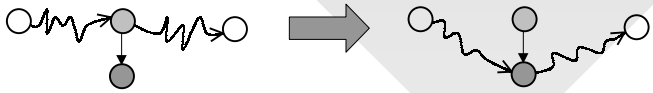
- Path crossover - exchanges sub-routes



(1 3 **5** 6 8 9 11 12)
(1 2 4 **5** 7 8 10 12)

(1 3 **5** 7 8 10 12)
(1 2 4 **5** 6 8 9 11 12)

- Path mutation - apply a perturbation



Fitness evaluation

- After a specified number of packets are sent along a route, we send a packet to observe delay along it.
- We calculate its fitness by employing the delay according to the following:

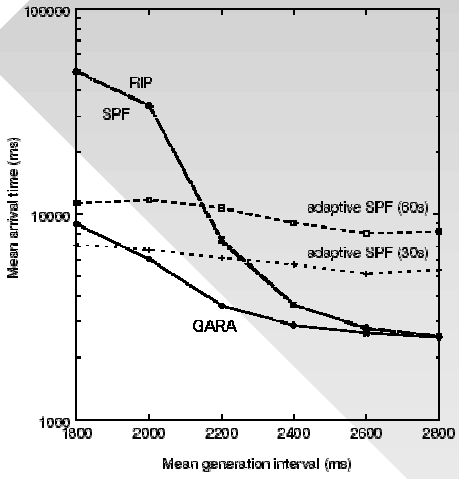
$$f_i = \frac{1/r_i}{\sum_{i=1}^{n} 1/r_i}, \text{ where } r_i = d_i / \sum_{i=1}^{n} d_i$$

- Selection is made based on the fitness after exceeding specified limit of table size.

Execution flow

- Initially, routing table is empty.
- If empty, generate a default route by using Dijkstra's shortest path algorithm.
- Else, randomly select a route from alternative routes probabilistically according to its fitness.
- At a specified interval, send a packet to observe delay, and perform fitness evaluation
- After evaluation, invoke genetic operators at a specified probability to generate routes.

Results: average delay



RIP : static metric

SPF : static metric

adaptive SPF

SPF with delay observation

GARA :

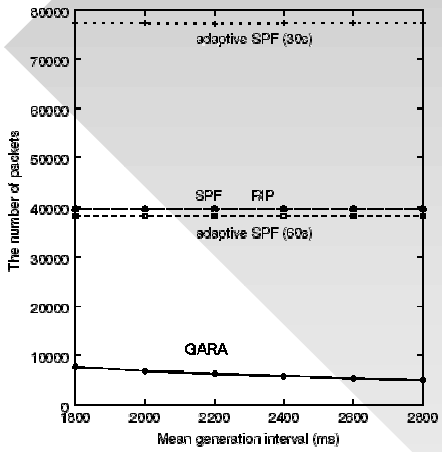
population: 100

Observation interval: every 100 packets

Genetic operators:

invoke 0.1 after eval.

Results: routing overheads



- Overheads of the GARA is the smallest
- In the GARA, the number of packets is dependent upon overall communication frequencies - when interval is large (and less frequent communication), overheads decrease - adaptive control of the observation.

Future directions

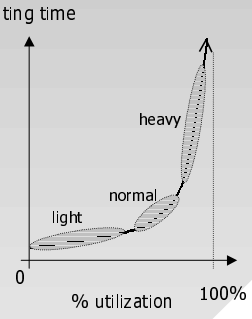
- Another genetic operators - Introducing migrations, etc.
- How to evaluate fitness? - Observed delay itself might be unstable, changing too rapidly.
- Is source routing OK? - in the Internet, next hops are specified and source routing is rarely employed.
- Implementation to EGPs such as BGP4?

Introducing migrations

- Strings are location dependent - for example, all routes in node 3 must start with "3", therefore, migrated strings are necessary to be modified.
- When a string **s** is migrated from node **n** to **m**, we perform the following operators:
  - Addition : when **n** is not in **s**, it is added in top of **s** = (n, s_1, s_2,...,s_n)
  - Deletion : when **n** = s_k is included in **s**, sub string before **n** is deleted. **s** = (n, s_{k+1},...,s_n)

Evaluation

- Delay might be unstable, changing so rapidly - another index? - a threshold policy
- Communication link is essentially a queuing process: waiting time grows fast in heavy load.
- Employing load index such as (light, normal, heavy), which is usually employed in dynamic load balancing system.



(metric) =
(link cost) x (load index)
(load index) =
1.0 for light load
3.0 for normal load
10.0 for heavy load

Source routing?

- Source routing is rarely employed inside ASs.
- Next hop routing is common, but it is difficult to be adaptive: it may create loops.
- Partial source routing possible?
- Between ASs, BGP employs a source routing approach listing up compete path of ASs - application of the GARA to BGP

Concluding remarks

- We believe that evolutionary approach is essential to realizing robust, autonomous, and scalable routing algorithm.
- In addition to GAs, we need to investigate other evolutionary algorithms such as ES, GP, EP, ACS(Ant Colony System).
- ACS seems to be one of the most interesting approach for telecommunication networks. (ants = packets?)