Intelligent Packets for Dynamic Network Routing using Distributed GA

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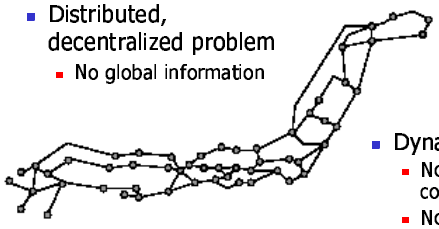
Network Routing Problem

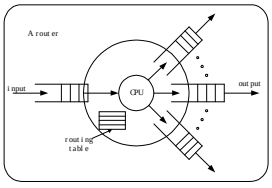
- Distributed, decentralized problem
  - No global information



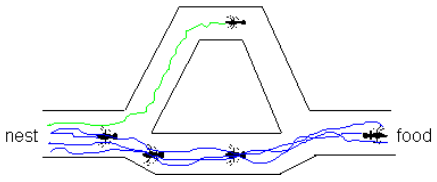
- Dynamic
  - No 'typical' condition
  - No one optimal configuration

Routing Scenario

- Routing Table
  - local connectivity
  - Default paths for 'other'
- Router CPU
- Input and output queues
- Examples,
  - OSPF
  - BGP4



Social Insect Metaphor



AntNet Algorithm [Di Caro & Dorigo]

1. Ants created periodically $\propto$ destination popularity;
2. Next link selected $\propto$ P(routing table) and (o/p queue length)$^{-1}$;
3. IF (node) == (ant dest. Node), THEN (convert to backward ant) ELSE (point 2)
4. Backward ant retraces path updating routing table

AntNet Routing table – Global information

	All network nodes ('M' possible destinations)			
'L' neigh-boring links	P(1,1)	P(1,2)	…	P(1,M)
	P(2,1)	P(2,2)	…	P(2,M)
	…	…	…	…
	P(L,1)	P(L,2)	…	P(L,M)

AntNet Routing table – Local information

	Neighbor node	Other
'L' neigh-boring links	P(1,1)	P(1,d1), d1 ≠ 1
	P(2,2)	P(2,d2), d2 ≠ 2
	…	…
	P(L,L)	P(L,dL), dL ≠ L

Intelligent Ants – Distributed GA

- Ant → GA individual (GA-agent)
- GA-agent defines path for investigation
  - Collects timing and node information from each node visited
  - Returns to source once path completed
- Each node has a 'population' of GA-agents

Basic GA-agents – representation + search operators

- Representation
  - a variable length string of next hop offsets
  - e.g., {1, 5, 0, 4, 2, 3, 5} over interval [0, *L*]
- Next hop selection
  - Modulus: [gene % (# of links)]

Basic GA-agent – fitness function

- Destination(i) Popularity
  - Dynamic property – measure over 50ms window
  - NodePop(k,i) = Num(k,i) / TotalNum(k)
- Overall fitness (normalize w.r.t. trip time, TT)

$$\frac{SUM_{\text{for all } i}\ NodePop(k,i) \times TT(i)}{SUM_{\text{for all } i}\ TT(i)}$$

GA-agent Routing Table

GA-agent ID	Fitness	(TT, nodeID)
95	0.32	(3.2, J), …, (32.1, X)
234	0.355	(2.2, D), …, (30.1, B)
…	…	…
31	0.71	(13.2, F), …, (322.1, P)

Aging and Migration

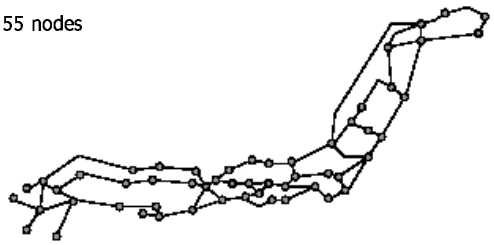
- Aging
  - Fitness(i) = Fitness(i) $\times C_2$
  - TT(i) = TT(i) / C_2
  - $0 < C_2 < 1$
- Migration
  - Best case individual from each population periodically migrate to a neighbor

Evaluation

- Discrete event sim.
- Network topology
  - NTTNET
- 4 scenario's, each
  - 1250 seconds
  - 1985536 data packets
  - Initial 5 seconds only routing packets
- GA-agent Parameters
- P(Xover) : 0.9
- P(mutate): 0.1
- Aging Rate: 0.9
- Migration Rate: 3%
- AntNet Parameters
- As per DiCaro & Dorigo

NTTNET topology

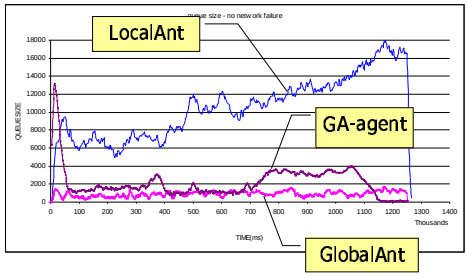
55 nodes



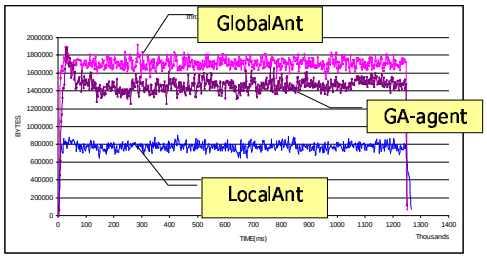
Scenario 1 – No network failure

Algorithm	GlobalAnt	LocalAnt	GA-agent
Finish time (sec)	1,253	1,267	1,252
% routing packets	10%	10.7%	34.8%
Arrived packets (AP)	99.7%	45.5%	85.2%
Average AP time	566ms	398ms	1,171ms

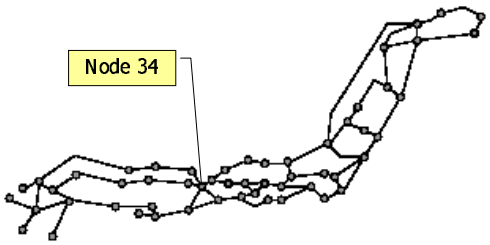
Scenario 1 – Queue Length



Scenario 1 – Throughput



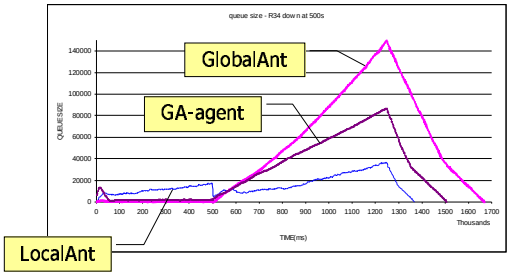
Scenario 2



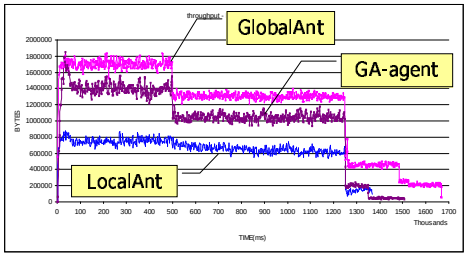
Node 34 lost at 500th second

Algorithm	GlobalAnt	LocalAnt	GA-agent
Finish time (sec)	1,668	1,369	1,507
% routing packets	10%	11%	59%
Arrived packets (AP)	92.3%	41%	70.6%
Average AP time	998ms	2,899ms	356ms

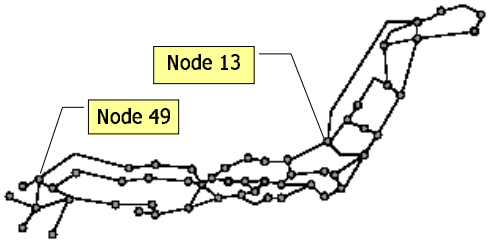
Scenario 2 – Queue Length



Scenario 2 – Throughput



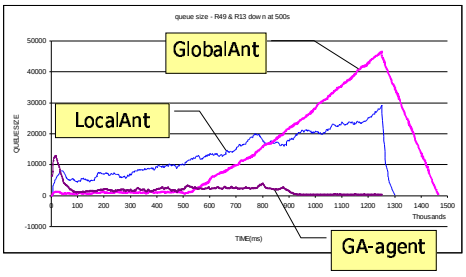
Scenario 3 & 4



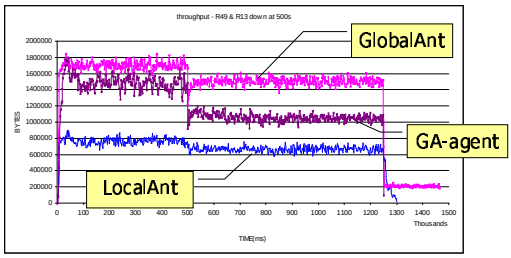
Nodes 49 and 13 lost at 500th second

Algorithm	GlobalAnt	LocalAnt	GA-agent
Finish time (sec)	1,466	1,300	1,252
% routing packets	10%	11%	52%
Arrived packets (AP)	94.2%	41.6%	71.4%
Average AP time	1,325ms	1,617ms	861ms

Scenario 3 – Queue Length



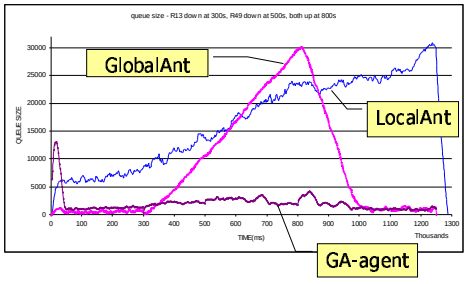
Scenario 3 – Throughput



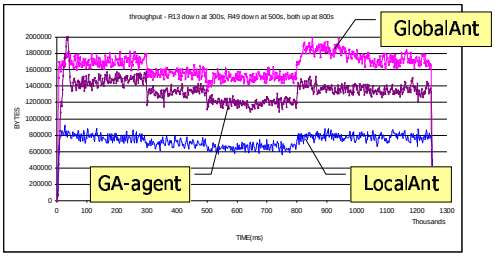
Nodes 13 and 49 lost at 300th and 500th, both return at 800th

Algorithm	GlobalAnt	LocalAnt	GA-agent
Finish time (sec)	1,252	1,289	1,252
% routing packets	10%	11%	54.5%
Arrived packets (AP)	96.5%	43.6%	78.3%
Average AP time	677ms	3,259ms	1,012ms

Scenario 4 – Queue Length



Scenario 4 - Throughput



Conclusion – 1

- AntNet algorithm
  - GlobalAnt
    - Best raw performance
    - Does not consider security
    - Assumes access to some global information
  - LocalAnt
    - Satisfies security and local information limits
    - Very poor quality of service

Conclusion – 2

- GA-agent
  - Representation independent of network topology
  - Satisfies some security requirements
  - No global information
  - Quality of service between Local and Global variants of the AntNet algorithm

Conclusion – 3

- Dynamic Routing problem
  - Still unsolved with respect to practical constraints
  - Opportunities for co-operative approaches
  - Currently little consideration of security implications in 'intelligent' solutions
    - Limits communication and sharing of information between routing agents

Further Reading - Routing

- Liang S., Zincir-Heywood A.N., Heywood M.I., "Intelligent Packets for Dynamic Network, GECCO 2002, W. B. Langdon, et al. (eds), New York, Morgan Kaufmann, pp 88-96, 2002.
- Di Caro G., Dorigo M., "AntNet: Distributed Stigmergetic Control for Communications Networks," Journal of Artificial Intelligence Research, 9, pp 317-365, 1998.
- Heusse M., Snyers D., Guerin S., Kuntz P., "Adaptive Agent-driven Routing and Load Balancing in Communication Networks," Advances in Complex Systems, 1, pp 237-254, 1998.

Further Reading - Optimization

- Dorigo M., Maniezzo V., Colorni A., “Ant System:Optimization by a Colony of Cooperating Agents,” IEEE Transactions on Systems, Man and Cybernetics – B, 26(1) pp 29-41, Feb 1996.
- Maniezzo V., Colorni A., “The Ant System Applied to the Quadratic Assignment Problem,” IEEE Transactions on Knowledge and Data Engineering, 11(5), pp 769-778, Sept/ Oct 1999.