Ant Colony Optimization for ad-hoc networks

*The First MICS Workshop on Routing for Mobile Ad-Hoc Networks*

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Ant Colony Optimization Algorithms

- ACO algorithms are inspired by the observation of real ants (Dorigo, Colomi, Maniezzo, 1991)
- Real Ants are social insects organized in colonies.
- Ant colonies show a high structural level compared to the simplicity of the single individual
- Ants coordinate their activities by an indirect form of communication (stigmergy) based on pheromone laying
- Foraging behavior: searching for food by parallel exploration of the environment
First they explore. Individual ants mark their path by emitting a chemical substance - a pheromone - as they forage for food. Ants smell pheromone and they tend to choose path with strong pheromone concentration. Other ants use the pheromone to find the food source. When the "system" is interrupted, the ants are able to adapt by rapidly adopting second best solutions. Social insects, following simple, individual rules, accomplish complex colony activities through: flexibility, robustness and self-organization.
Pheromone Trail Following

Ants and termites follow pheromone trails
Asymmetric Bridge Experiment

Goss et al., 1989
ACO for routing in Transport Problems

Clients
- Requests
- Time Windows
- Pick-up and delivery
- Access Limitation

Fleet
- Non-homogeneous vehicles
- Costs (trucks own/external)
- Drivers
- Time limitation

Information
- Driving time
- Limitation on max km.
- Depots, number, location
**ACO for transport problems**
3 FNSs 1994-2003, CTI 2000/2, EU5 Metanet 2001/4, EU5 Mosca 2002/3

Given a transport optimization problem

Ants probabilistically build solutions using cost and pheromone

Best solutions are rewarded with new pheromone

The Algorithm learns from experience to compute always better solutions
**IDSIA Algorithms best-known in literature in their domain (2002)**

- **MACS-VRPTW: Vehicle Routing Problem with Time Windows**
  
  (best of 8 algorithms over 100 test problems, 16 new best known results)

- **HAS-QAP: Quadratic Assignment Problem**
  
  (best known for structured problems)

- **HAS-SOP: Sequential Ordering Problem**
  
  (22 new best known results on 33 test problems)

- **Flexible Job Shop Problem**
  
  (116 results improved on 221 problems, 10 time faster than the previous best)
CADIS-OPT-FLEET (2001-2002)

AntOptima IDSIA MIGROS

Tours optimization in all Switzerland for non-food goods from the new hub center in Suhr (150-200 vehicles)

Non-homogeneous trucks
Trailers
Soft TW
Hub use restrictions

Tours Minimization
Distance Minimization
Integration with CADIS
AntNet Applied to Routing in Internet-like Networks

Di Caro and Dorigo, 1997

Probabilistic rule to choose the path

Pheromone trail depositing

Source

Destination
AntNet is an instance of an ACO algorithm for: distributed and adaptive routing in communications networks

• In distributed adaptive routing at each network node the routing policy is continually adapted to the variations in the input traffic patterns

• A routing policy is a local mapping parametrized by a data structure called routing table

• It is assumed that a robust model of the input traffic is not available: the policy should be learned
The Routing Problem

- The practical goal of routing algorithms is to build routing tables.

Routing is difficult because costs are dynamic.

Adaptive routing is difficult because changes in the control policy determine changes in the costs and vice versa.
• Ants are launched at regular instants from each node to randomly chosen destinations
• Ants are routed probabilistically with a probability function of:
  (i) some artificial pheromone values, and
  (ii) some heuristic values, maintained on the nodes

• Ants memorize visited nodes and elapsed times
• Once reached their destination nodes, ants retrace their paths backwards, and update the routing tables

AntNet is distributed and not synchronized
The AntNet data structure

- Network Node
  - Queues status
  - Ant-Routing Table
  - Data Routing Table
  - Parametric Delay Models

- Network Nodes
  - $P_{11}$, $P_{12}$, ..., $P_{IN}$
  - $P_{21}$, $P_{22}$, ..., $P_{2N}$
  - $P_{L1}$, $P_{L2}$, ..., $P_{LN}$

- $M_i$
  - Exponential Mean
  - Exponential Variance
  - Window Best
  - Window Count
Next hop nodes are selected according to a stochastic decision rule parametrized by:

- entries of the ant-routing stochastic matrix
- local heuristic values based on the state of the local link queues
- memory of the past visited nodes
At each node the Backward Ant updates the Local Traffic Model, then scores the path and uses the score to reinforce the link followed (Routing Tables updating).
Ants’ Pheromone Trail Depositing

\[
\tau_{ijd}^k(t + 1) \leftarrow (1 - \rho) \cdot \tau_{ijd}^k(t) + \Delta \tau_{ijd}^k(t)
\]

where the \((i,j)\)'s are the links visited by ant \(k\),

and

\[
\Delta \tau_{ijd}^k(t) = \text{quality}^k
\]

where \(\text{quality}^k\) is set proportional to the inverse of the time it tooks ant \(k\) to build the path from \(i\) to \(d\) via \(j\)
AntNet: Experimental setup

- Realistic simulator (though not industrial)
- Many topologies
- Many traffic patterns
- Comparison with many state-of-the-art algorithms
  (Open Shortest Path First, SPF Straight Packet Forwarding, Adaptive Bellman-Ford, Q-routing, Predictive Q-routing, Ideal Deamon)
- Performance measures:
  throughput (bit/sec) measures the quantity of service, and average packet delay (sec) measures the quality of service

Japanese NTT net

American NSF net
AntNet: Some Results (1)

NSF net

NTT net

Increasing traffic
traffic increased by reducing the mean session inter arrival time

From Di Caro and Dorigo, 1998, Journal of Artificial Intelligence Research
AntNet: Some Results (2)

Data averaged over a 5 seconds sliding window

From Di Caro and Dorigo, 1998, Journal of Artificial Intelligence Research
• AntNetMobile: a pheromone based routing algorithm based on AntNet for mobile ad hoc networks.

• Reactive vs Proactive routing

• We are investigating a mixed approach where updated information are maintained for few nodes only. New paths are discovered on demand by using the pheromone information

• We expect to be able to maintain multiple disjoint routes. One of the goal is the identification and the management of critical links
We are evaluating the overhead of sending around artificial ants.

Two possible ways to reduce overhead are piggyback information on standard data package or move some functionality to the MAC level.

AntNet uses time as measure for path performance. This requires clock synchronization between nodes.

We are investigating the use of the number of hops or power consumption.
• QoS negotiation
• Combining routing with other functions like searching or discovery
• Completely distributed or hierarchical organization?
• Bio-inspired pheromone based cluster of nodes
Bison: Biology-Inspired Techniques for Self Organization in Dynamic Networks

Bison is a three years European FET project starting January 2003.

Partners:
• University of Bologna, Italy (Coordinator)
• Telenor Communication, Norway
• Technische Universitaet Dresden, Germany
• IDSIA, Switzerland
• Santa Fe Institute, USA
Bison: Goals

• BISON explores ideas derived from complex adaptive systems (e.g. Ant Colony Optimization) in highly dynamic network environments.

• Systems: Ad Hoc networks, P2P and Grid computing

• Themes: Flexible, adaptive, and decentralized network functions

• Routing, searching, discovery, document sharing, load-balancing

• New simulation environment
Failure location, restoration and resilience in optical and ad-hoc networks

Is a three years Swiss Hasler Foundation project started in November 2002.

Partners:

EPFL I&C-IIF, DIE Lugano

- Critical links
- Repairing and reroute in case of failure
- Dynamic computation of alternative paths
- Dynamic clustering

MOBILE MAN

FET EU Project of 3 years

Partners

CNR Pisa
DIE/DLS Lugano
Uni Cambridge
Eurocom France
Uni Helsinki
SWARM-BOTS EU5 (2001-2004)
IRIDIA, EPFL, CNR-IP, IDSIA
Collective robotics inspired by colony behaviour

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Ant Colony Optimization Major Publications

nature
New fronts in the war on cancer

EUROPEAN JOURNAL OF OPERATIONAL RESEARCH

SCIENTIFIC AMERICAN

DER SPIEGEL

The New York Times

Journal of Scheduling

I.D.E.A.S. WITH IMPACT
Harvard Business Review
April 2002
IDSIA people involved in ACO Projects

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