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AntNet: ACO routing algorithm in practice

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Keywords: routing, Ant Colony Optimization, AntNet

1. Introduction

AntNet is a routing protocol for packet switched networks, invented by M. Dorigo and G. Di Caro[1]. It is an alternative routing algorithm for the well-known OSPF protocol[1], based on Ant Colony Optimization (ACO). ACO studies the behaviour of ants in a colony and mimics this behaviour in software. The problem to be solved, is represented by a graph. Artificial agents, i.e. software ants, gradually construct paths in this graph. This phase is repeated until an optimal (or in some cases a sub-optimal) solution is found. ACO has been applied to many domains, e.g. the Traveling Salesmen Problem, manufacturing control systems, etc. A good overview of the ACO meta-heuristic and a number of applications can be found in [2].

ACO itself is a metaheuristic. When combined with an actual problem area, it can lead to several heuristics. AntNet is a result of the application of ACO on the problem of Internet routing. Intelligent agents, ants for short, are sent over the network. They communicate indirectly by information they leave behind in the routers on their path. Over time, this information leads to optimal routing paths between the routers in the network.

The goal of our research was to implement this behaviour on a small network, as AntNet has only been simulated so far. In section 2. we present an adapted version of the AntNet algorithm. Section 3. contains the results of some tests, as well as a comparison of AntNet and OSPF. Section 4. finally states our conclusions.

2. The AntNet algorithm

The operation of AntNet is based on two types of agents:

- Forward Ants who gather information about the state of the network, and
- Backward Ants who use the collected information to adapt the routing tables of routers on their path.

An AntNet router contains a special routing table where each destination is associated to all interfaces and each interface has a certain probability. This probability indicates whether or not it is interesting to follow that link in the current circumstances. The router also contains a statistical model to store the mean and variance values of the trip times to all destinations in the routing table. These are used as reference values.

On a regular time base, every router sends a Forward Ant with random destination over the network. The task of the Forward Ants is collecting information about the state of the network. In each router they pass, the elapsed time since the start is stored on an internal stack together with the identifier of the router. Then the next hop is determined. Normally this is based on the probabilities in the routing table. There is however a small chance (exploration probability) that the next hop is randomly chosen. This is necessary to constantly explore the network and to be able to react fast to network changes like link failures or congestion. When the Forward Ant reaches its final destination again the elapsed time since the start and the identifier of the router

[1]Open Shortest Path First, a distance-vector routing protocol, based on the Dijkstra algorithm

are stored on the stack of the ant. The Forward Ant is transformed into a Backward Ant. This Backward Ant will follow exactly the same path as the Forward Ant but in the opposite direction. The Backward Ants use the information collected by the Forward Ants to update the different data structures in each router along their path. The time information on the stack is compared with the model in the router and based on this comparison, the probabilities in the routing table are updated. When the Backward Ant arrives in the start router, it dies. Backward Ants have a higher priority than data packets, so that they are processed as fast as possible making the algorithm more adaptive. Forward Ants have the same priority as data packets, to suffer the same delays so that the algorithm can react to network congestion.

A trip time better than the mean value will boost the probability on that interface, while a bad trip time will only slightly increase the probability. The variance value is an indication for the stability of the network. A relatively large value indicates an unstable network state; a small value indicates a stable state. In an unstable state the effects on the probabilities are weakened as it is unsure that a bad trip time indicates a long path.

Router clock synchronization issue
When implementing AntNet on a real network, our biggest problem was the synchronization of the internal clocks of the routers. The solution was offered by an abstraction mechanism: the times that are saved onto the stack of the Forward Ants, are not computed as the difference between two timestamps. Instead they are computed as the sum of two terms, one representing the delay due to link load, and one for the router load. When the load on a link becomes very high, the term representing the link load is increased to improve the load balancing over multiple paths.

3. Practical results

We implemented the AntNet algorithm on a small network, consisting of five routers and two hosts (Figure 1). A first step was the optimization of the parameters of the algorithm. Secondly, the algorithm was extensively tested. Finally, AntNet was compared with one of the most important routing standards: OSPF[3].

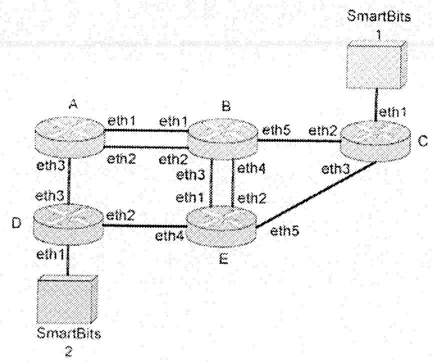

Figure 1: *Test Network*

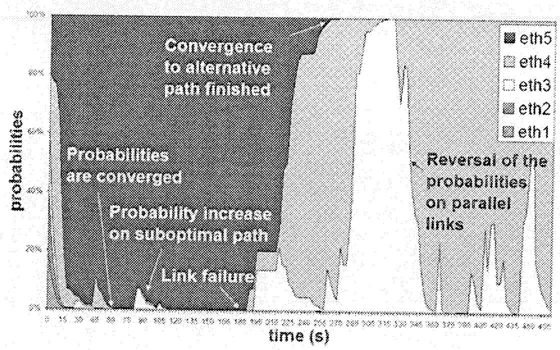

Figure 2: *Probabilities with link failure*

Parameter optimization
The AntNet algorithm has a lot of parameters. The first step in our evaluation was to optimize these parameters. We tuned them sequentially, always letting only 1 parameter vary. In every experiment, the convergence time of the probabilities in 1 routing table was measured. After optimization, the convergence was about 10 times faster than with the values of [1].

After the optimization, we evaluated AntNet in several circumstances (link and router failures, addition of new links, heavy network load, etc.). A nice illustration of the operation of AntNet is presented on Figure 2. It shows how the probabilities in the routing table of Router B evolve for destination Router C in the case

Table 1: OSPF vs AntNet: throughput

Load (%)	Packet loss OSPF (%)	Packet loss AntNet (%)
110	8,95	2,19
150	33,2	12,86
200	49,9	26,65

of a link failure. Initially we see the convergence to the shortest path (via eth5). Every now and then, the probability increases on suboptimal paths (via eth3 and eth4). This is a consequence of the dynamic character of AntNet: paths that are just a little longer than the shortest path, are also interesting. After 3 minutes we introduced a link failure on eth5 and we see the probabilities converge to the alternative path via eth3 and eth4. As we have 2 parallel paths, the probabilities constantly alternate between those paths.

Comparison with OSPF

We evaluated AntNet by comparing it to OSPF in terms of throughput and adaptivity. To compare the throughput we generated a heavy load (higher than the capacity of a single link) and measured the number of lost packets. Table 1 shows the results. We see that AntNet performs a lot better than OSPF. In an OSPF network the surplus of packets is completely lost whereas AntNet succeeds in forwarding a lot of these packets to their destination. With OSPF it is often the case that some links in a network are heavily loaded, while others are almost not used. As AntNet distributes a heavy load over several paths, it is more network optimal and uses the capacity of the entire network in a more efficient way.

To measure the adaptivity, we tested how long it took before the network converged after a link failure or the addition of a new link. Especially the case of a link failure is important. Unfortunately, in that case AntNet does not perform as well as OSPF. In our tests, it took about 45s for OSPF to switch to the alternative path whereas AntNet needed 112s. The reason is that it takes quite some time before enough ants have followed the alternative (long and therefore inferior) path. It is however possible to extend the AntNet protocol with mechanisms to detect link failures locally. This technique allows for a very fast detection of link failures and provides a solution to the high convergence times. When a new link was added (shorter path), AntNet performed well. OSPF needed 21s to use the new link whereas AntNet needed only 17s. However, as no data can be lost by adding a new link, this difference is less crucial.

4. Conclusion

Up until now, AntNet was only simulated. Our goal was to implement the AntNet algorithm on a physical network, adapting and extending the algorithm where needed, and comparing our performance measurements with the conclusions of [1] and [4]. AntNet surpasses OSPF when it comes to throughput. With respect to link failures, OSPF still performs better, but a mechanism of local link failure detection has been proposed. This should result in a similar adaptability of AntNet and OSPF.

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