QoS-aware Ant Routing with Colored Pheromones in Wireless Mesh Networks

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ABSTRACT

Inspired by the collective foraging behavior of specific ant species, ant-based routing algorithms are able to find optimal or near optimal packet routes for Wireless Mesh Networks. Ant-based algorithms work by deploying artificial pheromone at the network paths, which is then used for future routing decisions.

Using this approach, the routing can be optimized according to different criteria like packet delay, delay jitter, or maximum bandwidth. For a typical mesh network, we assume to have different classes of traffic posing different requirements on the quality of service of the communication. Therefore, we propose a concept for ant routing with colored pheromones (CPANT), where a color corresponds to a particular class of traffic. Thus, the network will treat the packets of an application according to the specific application requirements packet delay, delay jitter, and bandwidth. We show that this approach can outperform ant routing approaches that are not aware of different traffic classes when the specific traffic requirements are taken into account.

Categories and Subject Descriptors

C.2 [**Computer-Communication Networks**]: General

General Terms

Algorithms

Keywords

Self-organizing networking, ant routing, bio-inspiration, QoS

1. INTRODUCTION

A Wireless Mesh Network (WMN) is a wireless networking architecture in which nodes are connected via a wireless backbone which typically connects client nodes to the Internet. A prominent example for the idea of a WMN is provided by the One Laptop Per Child (OLPC) initiative [11] where end-user laptops form a multi-hop mesh network for collaboration or accessing the internet via a few access points.

Mesh networks, especially when built with mobile devices put a high demand on robust and adaptive routing algorithms in order to overcome disconnection and congestion problems. A promising approach for such a routing algorithm are so-called ant algorithms based on mechanisms inspired by the collective foraging behavior of specific ant species. In order to find an efficient trail between food source and nest, ants in nature are using pheromone to mark their trails. Basically, this involves three principles [13]: (i) each time an ant moves, it lays a pheromone trail, (ii) to find its way, an ant senses its environment; the higher the amount of pheromone, the more likely the ant chooses this path, and (iii) pheromone evaporates over time. So, if a trail is not used (anymore), it will vanish. On the other hand, a trail that is used more often, e. g., because it is shorter than others, gets more pheromone and thus becomes the trail that is prominent among the other less-optimal trails. As an interesting aspect, the ants manage to organize their task in a cooperative way by communicating only *indirectly* to each other via the pheromone used on the trails. This mechanism of spontaneous, indirect coordination between agents is also known as *stigmergy.*

In technical systems, ant algorithms can be used, e. g., to find optimal or at least sufficiently good packet routes in a network. Therefore, a packet route is seen as a trail and the pheromone is simulated by a variable assigned to each network node. Ant algorithms for wireless networks have been already proposed by [2, 4, 6, 7], however these approaches have the disadvantage that different types of traffic are treated with the same routing properties. Thus, an application with high bandwidth requirements but less stringent timing requirements might influence the routing of packets for an application with real-time requirements, although a routing solution would exist where the first application takes a different, probably slower route for its packets.

In this paper we propose an ant-based algorithm that takes the required Quality of Service (QoS) into account by using different "colors" of pheromone for different classes of traffic. The different colors are aligned to four traffic classes which differ in provided bandwidth, delay, and jitter. Thus,

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the algorithm finds network routes providing a QoS tailored to the particular application requirements, which enables better overall network efficiency for a system of applications with heterogeneous QoS requirements.

The remainder of this paper is organized as follows: Section 2 discusses the related work in the area of self-organizing ant algorithms. Section 3 specifies the problem that is attacked by our algorithm. The QoS-aware ant routing is explained in Section 4. Section 5 describes a simulation set-up of the algorithm and the results of an experimental evaluation. The paper is concluded in Section 6.

2. RELATED WORK

Ant algorithms have been proposed for routing in [3] and for wireless networks in specific in [2, 4, 6]. In these works, the "goodness" of a link is expressed by a proportional amount of pheromone where higher amounts of pheromone indicate better paths. However, they use only one dimension (or color) of pheromone. While ARAMA [7] makes an attempt to account for different dimensions of link "goodness" it does not treat orthogonal requirements separately and also uses only one color of pheromone.

Based on the insight that traffic can be grouped into different classes [1] with partly orthogonal requirements "colors" to represent the orthogonal values of "goodness" of paths and links are introduced. Several ant algorithms using colored pheromones exist: the CAS (Colored Ant System) [5] introduces so-called multicolored pheromones to solve a graph coloring problem and distribute agents to clusters of nodes. MACO (Multiple Ant-Colony Optimization) [12] tackles the problem of stagnation and adaptivity in ant routing using multiple ant colonies – each using their own color – but does not account for orthogonal values of "goodness". The most similar work is by Labella and Dressler [8] who use colored pheromones for division of labor and routing of traffic between nodes in Sensor/Actuator Networks (SANETs).

Our proposed CPANT (Colored Pheromone ANT routing) algorithm extends AntHocNet [4] with colored pheromones taking some further inspiration about path grading from ARAMA [7].

3. PROBLEM STATEMENT

Classical ant routing algorithms grade paths using only one dimension of "goodness" and mark "good" links with a proportionally higher amount of pheromone. In a WMN different classes of traffic are encountered which have partly orthogonal requirements of the network. Using an approach similar to [1] we group traffic into the following classes:

Conversational, such as VoIP or video conference traffic. Due to the live interaction between the people having the conversation this type of traffic requires high bandwidth, low jitter, and low delay.

Streaming, such as watching a video stream or listening to a pod-cast where a play-out buffer can mitigate the effects of jitter. Since no interaction takes place, delay is only incurred once at the beginning of the session. Therefore, only bandwidth is the critical factor.

Interactive with lower bandwith requirements such as Web surfing and Web applications. Here, delay is the most critical factor as users expect rapid response to their clicks.

Background, such as Email and large File transfers (eg. ftp or P2P-Filesharing) where delay and jitter are non-critical as well as bandwidth (assuming that at least a somewhat reasonable bandwidth is available).

Table 1 shows the traffic classes and their requirements in terms of network QoS.

Class	Name	Critical Requirements	Uncritical Requirements
1	Conversational	Bandwidth, jitter, delay	
2	Streaming	Bandwidth	Jitter, Delay
3	Interactive (Web)	Delay	Jitter, (Bandwidth)
4	Background (Data)		Jitter, delay, (Bandwidth)

Table 1: Traffic Classes and Requirements.

4. QOS-AWARE ANT ROUTING

To support the requirements of the traffic classes described above, the notion of "color" is introduced to the concept of pheromones. Like in other Ant-routing algorithms, the ants mark paths in the network by depositing pheromone at each node along the way, thereby marking a "trail" along which data traffic can then be routed. In the colored pheromone approach, the ants mark the paths through the network by depositing pheromone with different colors depending on the suitability of the path for the corresponding traffic classes. Each traffic class is mapped to a color. E. g., a path with high bandwidth, low jitter, and low delay is suitable for traffic in the "Conversational" class and would therefore be marked with pheromone of type (or "color") "A". Table 2 shows how the traffic classes are mapped to the four colors (named A, B, C, and D).

Class	Name	Color
1	Conversational	A
2	Streaming	B
3	Interactive (Web)	C
4	Background (Data)	D

Table 2: Mapping of Colors to Traffic Classes.

As shown in Figure 1 the algorithm starts by sending a forward ant (FA) from the source node. The FA is sent according to the values in the pheromone table using Eq. 1. When it is received by an intermediate node and its time to live (TTL, expressed in number of hops) is reached, the ant is killed. In this case the ant did not find a viable path. If the ant's TTL is not yet reached it calculates the color values for the next hop based on MAC layer measurements at the node (see Eqs. 2 and 3). The values are stored in the ant and it is then sent on according to the values in the pheromone table. When the ant eventually reaches the destination node the path is graded (see Eq. 4), a backward ant (BA) is created and the path grade is stored in the BA. The FA expires and the BA is sent back to the source node on the reverse path. When the BA is received by a node it updates the local pheromone tables (cf. Eqs. 5 and 6) according to the path grade and is sent on until it reaches the original source node where it expires.

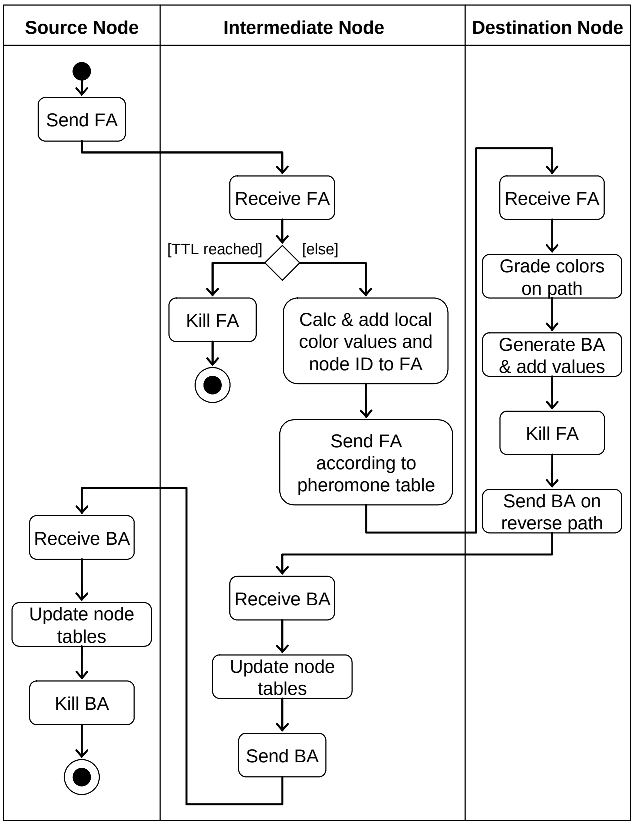

Figure 1: Route Discovery in CPANT. FA ... Forward Ant, BA ... Backward Ant.

4.1 Link Selection

When an ant is to be sent as described above ("send FA according to pheromone table" in Figure 1) the next hop is chosen with probability $P_{n,d}$ according to the transition rule

$$P_{n,d} \sim \frac{\tau x^i_{n,d}}{\sum\limits_{j \in N^i_d} \tau x^i_{j,d}} \qquad (1)$$

with i ... the current node
n ... the next node
d ... the destination node
$\tau x^i_{n,d}$ ... the pheromone value for a certain color for the link from node i to node n with intended destination d
N^i_d ... the set of neighbors of node i which know a path to destination d.

The pheromone color x of τx is randomly chosen as one of $\{A, B, C, D\}$ when the first link is taken; after the first link the color of the current ant is determined and stays fixed for the lifetime of the ant. While the ant still continues to collect information about the other color values it will only search for a path of the color it has been assigned.

Since the transition rule in Equation 1 defines a probability distribution there is a certain probability that an ant will not choose the best path. In this case the ant has become a so-called exploring ant. While exploiting ants reinforce existing paths exploring ants try to find new alternative paths.

4.2 Measuring "Goodness" and Path Grading

Nodes keep running averages of MAC-layer measurements of the link's bandwidth, jitter, and delay. Let

$$f_{good} : \langle BW_{avg}, J_{avg}, D_{avg} \rangle \mapsto \vec{X} \qquad (2)$$

be the "goodness function" with BW_{avg} the average bandwidth, J_{avg} the average jitter, and D_{avg} the average delay on the link calculated using a sliding window average and

$$\vec{X} = \begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix} \qquad (3)$$

the color vector for the current link taken. The color values a, b, c, and d are in the interval $[0; 1]$ and calculated using thresholds which map link attribute values (eg. a certain bandwidth) to percentage values of the color. This mapping can be implemented using a simple lookup table in the nodes. The ant keeps an ordered list $L_{ant} = \{\vec{X_1}, \vec{X_2}, \ldots, \vec{X_n}\}$ of the color vectors $\vec{X}$ encountered along the way.

When the ant reaches the destination node (see Fig. 1, "grade colors on path") the path grade is calculated for all colors as

$$\vec{G_P} = \prod_j \vec{X_j} \qquad \forall \vec{X_j} \in L_{ant} \qquad (4)$$

by element-wise multiplication of the color vectors. I.o.w. $a(\vec{G_P}) = a(\vec{X_1}) * a(\vec{X_2}) * \ldots * a(\vec{X_n})$ and $b(\vec{G_P}) = b(\vec{X_1}) * b(\vec{X_2}) * \ldots * b(\vec{X_n})$, etc. In this way, the worst hop in the path is accurately reflected as being the path bottleneck.

4.3 Pheromone Table Updating

The path grade is then stored in the backward ant (BA) which is sent back to the source node. Along the way it updates the pheromone values of all the nodes it passes. If a link is on the path the pheromone value for choosing this link (choosing node n as the next hop) is updated as

$$\tau x^i_{n,d} := \tau x^i_{n,d} \cdot f_{evap} + g(Gx_P) \qquad (5)$$

where Gx_P denotes that element of the path grade vector which matches the color of the pheromone being updated (τx and Gx_P with identical values for x).

For all other links, where node m is not on the path, the amount of pheromone is decreased:

$$\tau x^i_{m,d} := \tau x^i_{m,d} \cdot f_{evap} \qquad (6)$$

where f_{evap} denotes the evaporation function and $g(Gx_P)$ the enforcement function.

As shown in [7] these functions can be chosen as $f_{evap} = 1 - Gx_P$ and $g(Gx_P) = Gx_P^K$ which results in $0 \leq f_{evap} \leq 1$ and $0 \leq g(Gx_P) \leq 1$ for $0 \leq Gx_P \leq 1$.

4.4 Traffic Sending

Traffic is always sent along the best suitably colored path found and FAs are piggy-backed on the data packets. In this way, when the path becomes overloaded, its pheromone value will fall over time because its goodness decreases. Once it becomes worse than the second-best path traffic will automatically switch to the second-best path.

When no suitable path is found traffic may choose paths which are "better than necessary" according to the mapping in Fig. 2.

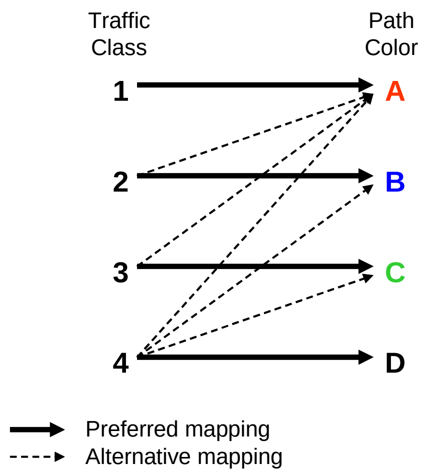

Figure 2: Mapping Traffic Classes to Alternative Paths.

When TCP traffic is sent, the backward ant is piggybacked onto the TCP acknowledge packet (ACK). Therefore, depending on the current window size one BA will travel the reverse path of several FAs just like one TCP ACK may acknowledge several TCP segments.

4.5 Algorithm Initialization

When the algorithm starts the pheromone tables are initialized with equal values for all $\tau x^i_{n,d}$ resulting in an equal probability for each link to be chosen. Then the route discovery part of the algorithm proactively starts to send out forward ants.

5. EXPERIMENTAL EVALUATION

The CPANT algorithm has been implemented in the ns-2 network simulator [10], version 2.31 based on the AntNet implementation by Lavina Jain [9]. We performed 20 simulation runs for AntNet and CPANT each. For this first evaluation we use the arbitrary topology as provided in the documentation for [9] with link qualities set as shown in Fig. 3. We assume four different types of links: (i) suited to class 1 traffic (Conversational) with a bandwidth of 20Mbps, a delay of 1ms and a jitter of 1ms, (ii) suited to class 2 traffic (Streaming) with a bandwidth of 20Mbps, a delay of 40ms and a jitter of 8ms, (iii) suited to class 3 traffic (Interactive) with 8Mbps bandwidth, 1ms delay and 16ms jitter, and (iv) suited to class 4 traffic (Background) with 4Mbps bandwidth, 80ms delay and 32ms of jitter.

We compare the quality of the routes created by the route discovery part of CPANT againts AntNet as follows: for each pair of nodes we take the route with the highest pheromone value for each color (in the case of AntNet just the highest pheromone value) and calculate

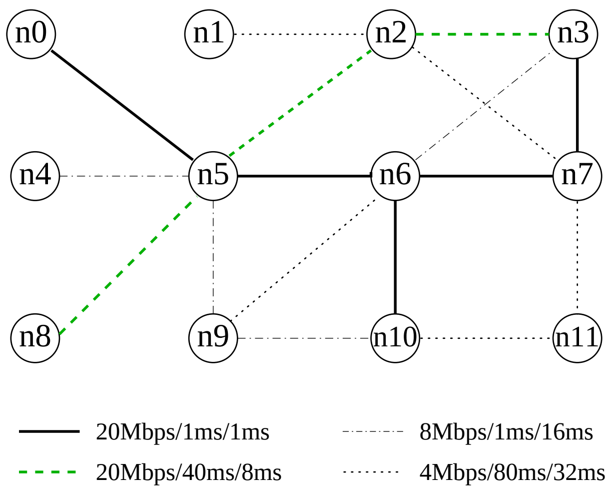

Figure 3: Simulation Topology, showing Bandwidth, Delay, and Jitter for each Link.

- the bottleneck bandwidth BW of the route R: $BW = min(BW_i) \forall BW_i \text{in} l_i \in R$ with l_i the links of the route.
- the cumulative delay D of the route R: $D = \sum_R D_i \forall l_i \in R$ with D_i the delay on the link $l_i \in R$.
- the cumulative jitter J of the route R: $J = \sum_R J_i \forall l_i \in R$ with J_i the jitter on link $l_i \in R$.

Figure 4 shows the Cumulative Distribution Function (CDF) of the bottleneck bandwidths BW on the chosen routes for AntNet and all four colors of CPANT respectively. For color A (CPANT-A in the Figure) corresponding to traffic class 1 the majority of routes (approx. 85%) are chosen so that the traffic uses the highest available bandwidth. CPANT-B (color B, corresponding to traffic class 2) chooses still roughly 80% of its routes with the highest available bandwidth. For colors C and D we see that routes with lower bandwidths are preferred and only about 25% / 20% of the chosen routes have the highest bandwidth. Antnet (denoted ANTNET in the figure) choses routes without consideration of bandwidth. Its routes exhibit predominantly low to medium bottleneck bandwidths which would not be suitable to traffic classes 1 and 2.

In Fig. 5 the results for cumulative delay are shown. As expected, the routes chosen by CPANT-A exhibit the lowest cumulative delays, followed by CPANT-C (traffic class 3, Interactive, which is delay sensitive), CPANT-B (traffic class 2, Streaming, which is not delay sensitive), and CPANT-D. AntNet routes perform similar to CPANT-D routes for delay.

Finally, Fig. 6 shows the CDF for cumulative jitter on the chosen routes. CPANT-A chooses the most routes with the lowest possible jitter, followed by CPANT-B, CPANT-C, and CPANT-D. AntNet again performs about similar to CPANT-D.

Thus, in contrast to the AntNet algorithm, the presented CPANT approach is able to provide routes a significantly better QoS for traffic classes 1, 2, and 3 (conversational, streaming, and interactive).

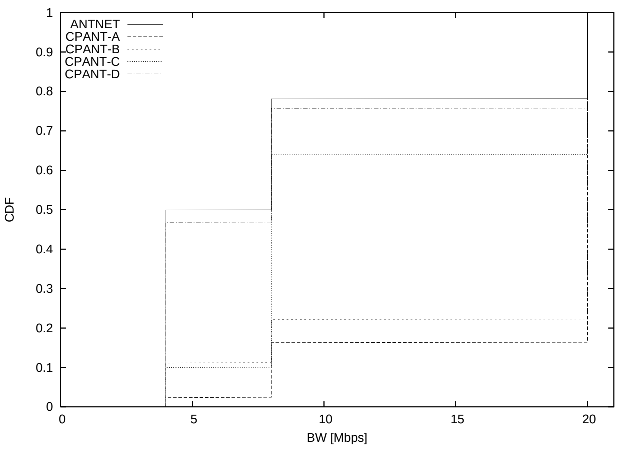

Figure 4: Minimal bandwidth on chosen routes.

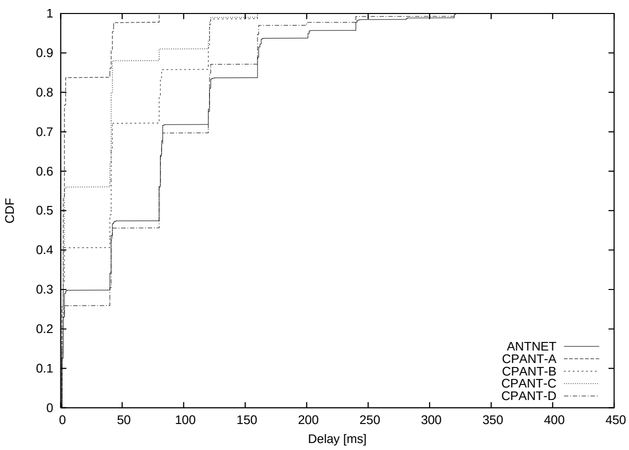

Figure 5: Cumulative delay on chosen routes.

6. CONCLUSION AND FUTURE WORK

We have introduced CPANT (Colored Pheromone ANT routing), a novel ant routing algorithm which extends AntHocNet with colored pheromones to support different QoS classes of traffic. Traffic poses partly orthogonal requirements on the underlying network with regards to bandwidth, delay, and jitter. Our algorithm uses colored pheromones to grade links for orthogonal values of "goodness" and mark different routes suitable for these classes of traffic. First simulation results are provided which show that CPANT can outperform AntNet for certain classes of traffic and chooses routes more suitable to these traffic classes than AntNet.

Future Work will include testing CPANT on a wide variety of topologies and load situations and fine-tuning of algorithm parameters.

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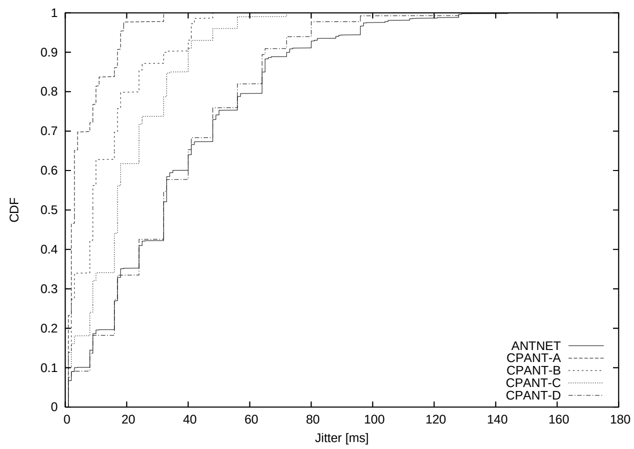

Figure 6: Cumulative jitter on chosen routes.

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