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# A Greedy Ant Colony Forwarding Algorithm for Named Data Networking

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**Abstract:** The Named Data Networking (NDN) is a newly proposed Internet architecture based on Content-Centric Networking, which transforms data, instead of hosts, into a first-class entity. However, one of the major challenges is supporting intelligent forwarding of Interests over multiple paths while allowing an unbounded name space. To address this challenge, this paper proposes a Greedy Ant Colony Forwarding (GACF) algorithm which uses the ISP-based aggregation to reduce the content naming space. There are two kinds of ants in GACF. One is Hello Ant which is used to discover the all possible paths and optimize them; the other is Normal Ant which is used to get data and reinforce the optimization of the paths simultaneously. The GACF algorithm is a Quality of Service aware forwarding algorithm. It adaptively reduces the impacts incited by the dynamic complex network.

**Keywords:** Content centric networking; Named data networking; Ant colony optimization; Multipath forwarding; Quality of service.

## 1. Introduction

The Internet was originally designed as a communication substrate enabling the delivery of data between pairs of end-hosts. However, it now mostly serves information-centric applications, e.g., CDNs [1] and P2P. The Internet architecture has evolved substantially from host-centric communication model to content-centric model, e.g., Youtube, Facebook. Content-Centric Networking (CCN) is a novel networking paradigm centered around content distribution rather than host-to-host connectivity. This change from host-centric to content-centric has several attractive advantages, such as network load reduction, low dissemination latency, and energy efficiency [4]. The Named Data Networking (NDN) [3] is a paradigm of the CCN.

Diego Perino and Matteo Varvello took a real check for NDN. The main conclusion of their work is that a NDN deployment is feasible at a Content Distribution Network (CDN) and ISP scale, whereas today's technology is not yet ready to support an Internet scale deployment [2]. NDN shifts the address space from one billion IPs to at least one trillion content names [6], which causes a neat increase of the routing state to be stored at content routers. There are two major challenges in routing: (a) reducing the routing table size while allowing an unbounded name space; and (b) supporting intelligent forwarding of Interests over multiple paths.

Ant Colony Optimization (ACO) principles are based on the natural behaviour of ants while searching for the shortest path between their nest and some food source. The ants communicate indirectly by laying pheromone trails and following trails with higher pheromone. Pheromone will accumulate on the shortest path[7]. The Ant Colony is an artificial swarm intelligence system. Dorigo and Stutzle developed the first ant based algorithm which was called Ant System [6]. It was used to solve the Travelling Salesman Problem (TSP), a well-known NP-Hard problem [10][13]. AntNet [5] is one of the well-known ACO based routing protocols introduced by M. Dorigo and G. D. Caro for packet switched networks. Laura, Matteo, and Gianluca [8] proposed a ACO algorithm which aims at minimizing complexity of the nodes by the expenses of the optimality of the solution, it is particularly suitable for environments where fast communication establishment and minimum signal overhead are requested. Shashank Shanbhag et al [9] presented SoCCeR—Services over Content-Centric Routing. SoCCeR extends CCN with integrated support for service routing decisions leveraging ant-colony optimization.

In this paper, we present a QoS aware Greedy Ant Colony Forwarding (GACF) algorithm for NDN. We adopt the ISP-based aggregation to solve the problems caused by the large name space. In the current Internet, the large part of the popular contents is provided by Service provider, e.g. Youtube, Facebook. This method reduces the Forwarding Information Base (FIB) table size drastically.

We adopt the Ant Colony Optimization (ACO) algorithm as the forwarding strategy for NDN to solve the QoS issues. The main objectives include selecting performance metrics to rank interfaces, e.g. delay, cost, bandwidth, delay jitter; and (2) avoiding instability (frequent oscillation of paths) while maintaining good data delivery performance. Forwarding strategy is a key component in NDN nodes that makes them more powerful than their IP counterparts. NDN's native multipath forwarding and its symmetric routing, data being only sent back by traversing the Interest path, inherently match the natural behavior of ants while searching for the shortest path between their nest and some food source.

## 2. Design



### *2. 1 Node Design*

Based on the previous work did by Diego Perino and Matteo Varvello, we know that a NDN deployment is feasible at a Content Distribution Network (CDN) and ISP scale, whereas today's technology is not yet ready to support an Internet scale deployment [2]. The mainly challenge is produced by the huge content naming space.

We adopt the ISP-based aggregation to solve the problems caused by the large name space. According to the Cisco Visual Networking Index 2010, global IP traffic will quadruple every year until 2014 and approx. 55% of the overall Internet traffic will be video, and Global mobile data traffic will double every year until 2014 and approx. 65% of the overall mobile traffic will be video. In current Internet, a large part of the popular data is provided on the service platform. Although there is a lot of data produced by the users, they also need a platform to propagate their data. Thus, the closer the Interest packet is forwarded towards the Server, the more possible it can be replied.

This approach has two basic components: (a) hierarchical provider-assigned names to facilitate aggregation; and (b) a mapping service to map user-selected names to provider-assigned names. For compatible with the current Internet, we can directly use the domain name as the first name of the hierarchical content name simply.

In the FIB, the first name of the hierarchical content names has the highest priority. We keep the original routing methods proposed in NDN, however, when there is no space for storing the content name routing information, the routing entry of the content name that has the most hierarchical names will be abandoned firstly. An example of the FIB table is illustrated by the Fig.1 (a). We exploit the inherent advantages of NDN and extend it by ACO to gather this information. We add some parameters which are used by Ant Colony Forwarding algorithm. The FIB table consists of the content name, the associated faces, the corresponding pheromone values, last delay time and the number of matched times.

Every node hosts a FIB Control module which has the responsibility to update the FIB table. In our proposal, each node in the network acts independently and asynchronously.

| **Content name** | **Matched** | **Interfaces** | **Overhead** | **Pheromone** |
|---|---|---|---|---|
| Youtube.com | n(Youtube) | A | $D_A(t)$ | $\tau_{iA}^{You}(t)$ |
| | | B | $D_B(t)$ | $\tau_{iB}^{You}(t)$ |
| | | C | $D_C(t)$ | $\tau_{iC}^{You}(t)$ |
| Facebook.com | n(Facebook) | B | $D_B(t)$ | $\tau_{iB}^{Face}(t)$ |
| | | D | $D_D(t)$ | $\tau_{iD}^{Face}(t)$ |
| | | F | $D_F(t)$ | $\tau_{iF}^{Face}(t)$ |
| … | … | … | … | … |

**(a)**

| ID | Type | Overhead | Timestamp stack | Bandwidth | Hops |
|---|---|---|---|---|---|

**(b)**

| ID | Type | Overhead | Hops | Data |
|---|---|---|---|---|

**(c)**

**Figure 1.** **(a)** An example of the FIB table; **(b)** An example of Hello Data Ant packet; **(c)** An example of the Normal Data Ant.

*2. 2 Overview of GACF Progress*

We treat the entire packet in the NDN as an ant which emerges in the pair of Interest Ant and Data Ant. There are two types of packets, and they have different behaviors. One is Normal packet which is generated by consumers and is used to retrieve the data; the other is Hello packet which is generated by routers and is used to gather the routing and forwarding information. The Hello Ant packet includes more information than the Normal Ant packet. It contains the path overhead, the minimum bandwidth, the round trip delay and hops of the whole path. To reduce the packet size and drop down the router operation time for the Normal Ant packet, the Normal Ant packet only contains the path overhead. Fig. 1 (b) and (c) represent the two kinds of the packets.

Let us introduce the forwarding progress of the Hello packet firstly. The source node, usually is a router, generates the Hello Interest packet in a fixed time interval. The node randomly chooses a content name in the FIB table by the roulette method. The roulette wheel is constructed by the probability of the content name being matched. Once the content name is selected, the number of ants is decided by the number of forwarding interfaces in the FIB. There are two particular cases: the one is that at the initial stage there is no forwarding information in the FIB for a new content name; the other is that the packet lost happens. In those cases, the Hello Interest Ant packet will be forwarded to all interfaces of the node.

When the middle node of the path receives a Hello Interest Ant, it will forward the packet to the one of interfaces in FIB probabilistically. The probability of the interface being selected is decided by the pheromone and the length of queue for that interface. When the ISP node receives a Hello Interest Ant, it will generate a Hello Data Ant and calculate the parameters. E.g. the delay is calculated by plus the interface delay value in the Neighbour Link States Table. When the node in the path receives a Hello Data Ant, it will update the pheromone values and rank the interfaces in the FIB by the information contained in the Hello Data Ant.

Normal Ant packet is drove by the consumers. When a consumer generates an Interest packet, the Normal Interest Ant is borne. Normal Interest Ant is different from the Hello Interest Ant in the forwarding policy. The node forwards the Normal Interest Ant greedily to the first interface which has the highest pheromone in the FIB. The Normal Interest Ant packet will be forwarded to all interfaces that the node has only in the case of that there is no forwarding information in the FIB for the content name. The Normal Data Ant only contains the delay parameters. When a node receives a Normal Data Ant, it will update the pheromone values in a different method.

*2.3 Definition*

Let G= (V, E) be the graph representing the network where V are the nodes and E are the edges in the graph. The $\tau_{ij}^{ID}(t)$ represents the pheromone value from the node i to the content name ID via the node j. We normalize the pheromone values as $\sum_{j\in F_i^{ID}} \tau_{ij}^{ID}(t) = 1$ , where $F_i^{ID}$ denotes all the interface through which it can traverse to the node who has the content name ID.

We now introduce the following parameters to characterize the quality of the path. The path overhead of the PID(i, j) is defined as the average of the overhead of all links in that path and can be given by:

$$\boldsymbol{O_{ID}(i,j)} = \frac{\sum_{v\in \boldsymbol{P_{ID}(i,j)}} \boldsymbol{O(v)}}{|\boldsymbol{V}|} \tag{1}$$

Where $P_{ID}(i,j)$ denotes the path from the source node i to the destination node for content name ID via the neighbor node j. And the |V| is the number of network links along the path $P_{ID}(i,j)$.

$$\boldsymbol{O_i} = \frac{\boldsymbol{N_i}}{\boldsymbol{N_{iMax}}} \tag{2}$$

Here the $N_i$ denotes the number of the Ants in the node i, and the $N_{iMax}$ denotes the number of the Ants in the node i when it has the full load.

The round trip delay of the path $P_{ID}(i,j)$ is simply the sum of the delay of all links along the $P_{ID}(i,j)$:

$$\boldsymbol{D_{ID}(i,j)} = \boldsymbol{t}_{forwarding} - \boldsymbol{t_{receiving}} \tag{3}$$

The bottleneck bandwidth of the path $P_{ID}(i,j)$is defined as the minimum available residual bandwidth at any link along the path:

$$B_{ID}(i,j) = min\{b(e), e \in P_{ID}(i,j\} \tag{4}$$

The pheromone value for the a new SP name is calculated as the normalized sum of the cost, delay, bandwidth and jitter parameter values given by the equation:

$$\tau_{ij}^{ID}(t) = \alpha(1 - \frac{O_{ID}(i,j)}{\sum_{k\in F_i^{ID}} O_{ID}(i,k)}) + \beta(1 - \frac{D_{ID}(i,j)}{\sum_{k\in F_i^{ID}} D_{ID}(i,k)}) + \gamma \frac{B_{ID}(i,j)}{\sum_{k\in F_i^{ID}} B_{ID}(i,k)} \tag{5}$$

Where α, β, γ satisfy the equation α+β+γ=1. The weighting constant α, β, γ decide the contribution of the cost, delay, bandwidth and jitter parameters towards calculation of the pheromone.

*2. 4 Construction of the solution*

In this section, we discuss the details of GACF algorithm for dynamic NDN networks.

Interest Ants are sent from each source node to all possible destination nodes in the network during the ant foraging phase (see functions AntGeneration() and InterestAntForwarding() in Algorithm 1). Data Ants return along the same path with the Interest Ants but in reversed direction. Data Ants forwarding polices are detailed by the function 4 in the Algorithm 1. When the node receives the Data Ants, they will update the corresponding pheromones by the function 5. If there is no forwarding information in the FIB table for content name ID, the node will generate the Hello Interest Ants by the function 2.

For the next hop selection problem, Hello Interest Ants calculate the probability of interface being selected for forwarding by the similar method proposed in the AntNet[5], while the Normal Interest Ants only select the best interface decided by the pheromone and current queue length of that.

**Algorithm 1.** Greedy Ant Colony Forwarding Algorithm for NDN

```
1: Function: AntGeneration()
   Repeat
   For each node in the network do
        If the node i is a router then
                Randomly select an ID in the FIB table and Execute  HelloAntGeneration(ID)
        Else
                Generate some different Normal Interest ants,
                Forward them by  InterestAntForwarding(ID)
        End if
   End for
   Increase the time by a time-step for ants' generation
   until end of simulation

2. Function HelloInterestAntGeneration(ID)
      If  the ID exists in the FIB of node i then
                Generate |F_i^ID| Hello Interest ants for name ID
                Forward the Hello Interest ants to each interface j, j∈F_i^ID
      Else
                Broadcast  Hello Interest ants
      End If

3. Function InterestAntForwarding(ID)
      If the ID exists in the FIB then
                If the packet is Normal Interest Ant then
                        Forword the Normal Interest ant to the best interface j, j∈F_i^ID
                Else
                        Forword the Hello Interest Ant to a randomly selected interface j, j∈F_i^ID
                End if
      Else
                Broadcast the Normal Interest ants and execute  HelloInterestAntGeneration(ID)
      End if

4.  Function: DataAntForwarding(ID)
      If the node is a middle node of path then
                Update the information of data ant and forward the packet to the packet coming interface
                Update the j by the equation (6) and (7), update the other interfaces by equation (8)
      End if

5.  Function: HelloDataAntReceive()
      If it is the initial stage then
                Wait until All possible Data packet returned
                Update the corresponding pheromone by the equation (5)
      Else
```

Wait until All possible Data packet returned
Update the corresponding pheromone by the equation (9)

**End if**

*2.5 Pheromone Update*

After the construction of all solutions, the pheromone update is performed according to the following update function:

$$\boldsymbol{\tau_{ij}^{ID}(t+1) = (1-\rho)\,\tau_{ij}^{ID}(t) + \rho\Delta\,\tau_{ij}^{ID}(t)} \quad (6)$$

Where ρ represents the pheromone update rate, $\rho \in [0, 1]$.

When the middle node i of the path receives a Normal Data Ant or a Hello Data Ant from interface j, the node updates the path overhead $O_{ID}(i, j)$ firstly, then calculates the $\Delta\,\tau_{ij}^{ID}(t)$ by the following equation:

$$\Delta\,\tau_{ij}^{ID}(t) = 1 - \frac{O_{ID}(i,j)}{\sum_{k\in F_i^{ID}} O_{ID}(i,k)} \quad (7)$$

If there is no r eply for Interest, we equate the $\tau_{ij}^{ID}(t+1)$ to -1 to express that the link is failure or congestion at the time t+1, and equate the $\Delta\,\tau_{ij}^{ID}(t)$ to $\tau_{ij}^{ID}(t)$ for the calculation of the evaporation function.

The evaporation function is:

$$\tau_{ij}^{ID}(t+1) = (1-\rho)\,\tau_{ij}^{ID}(t) - \rho\frac{\Delta\,\tau_{ij}^{ID}(t)}{\left|F_i^{ID}\right| - 1} \quad (8)$$

The evaporation function is associated to the $\Delta\,\tau_{ij}^{ID}(t)$ value, it keeps the normalized pheromone values as $\sum_{j\in F_i^{ID}} \tau_{ij}^{ID}(t) = 1$.

When the source node i receives all the Hello Data Ants for interface j, the update function is:

$$\tau_{ij}^{ID}(t+1) = (1-\sigma)\,\tau_{ij}^{ID}(t) + \sigma\tau_{new}, \forall\, j \in F_i^{ID} \quad (9)$$

Where $\tau_{new}$ is calculated by equation (5) and σ represents the pheromone update rate and $\sigma \in [0, 1]$. This progress is similar to the pheromone initial stage.

In GACF, packet forwarding is QoS aware. We rank the interfaces by utilizing the QoS values of the path inherently.

## 3. Evaluations

In order to assess the effectiveness of our algorithm to increase the usability of NDN, we are building the simulations that run on the ccnSim [11] simulator and the OMNET++ simulator [12].

We analyse the effectiveness of GACF compared with original NDN where a router forwards the Interests to all faces through which the Data is available. We implement our method based on the ccnSim source code. We run our simulation on an Intel Core 2 Duo CPU T9400 running at 2.53 GHz and 4 GB of memory.

In our simulation, we randomly generate a network topology with 20 nodes. The probability of an edge between any two nodes is 0.5. Each link has a bandwidth of 50 Mbps. Among the nodes, we randomly select 2 nodes as the service node and randomly select 4 nodes which are attached to the users. The delay of each link is randomly set and the range of delay values is from 1ms to 10ms. For the routers, we select cache sizes of 5 GB; the routers use standard replacement method LRU (evicts the least recently used packet) and decision polices ALWAYS (caches every chunk it receives).

In our network, we adopt the chunk size is 10KB; File size is about 103 chunks; Catalog size is up to 105 files. We use the Mandelbrot-Zipf distribution model to calculate the content popularity, where α=1.5 and q=0. The 4 users perform object-level requests with exponentially distributed arrival times at a 1 Hz rate. In the GACF algorithm, we set $\alpha = 0.4, \beta = 0.6, \gamma = 0, \rho = 0.2$ and $\sigma = 0.5$. Because there is only one server ID which has two server instances, the Hello Interest Ants are generated only when there is no content name information in FIB or packet lost happens.

Tab. 1 Average path delay of network

| | Requested Files | The number of lost packet | Average round trip |
|---|---|---|---|
| NDN | $10^4$ | 37 | 27.95ms |
| GACF | $10^4$ | 42 | 36.47ms |
| NDN | $10^6$ | 2373 | 105.72ms |
| GACF | $10^6$ | 482 | 60.33ms |

At the earlier stage of simulation, the network overhead is low. The NDN has the slightly better performance than GACF. However, when the network overhead is high, the GACF has the dramatically better performance than original NDN method. This is due to the fact that NDN forwards Interest to all reachable service instances, which take up the large of bandwidth. The results are represented in the Table 1. For the same size of requested files, NDN will consume more than twice the bandwidth than GACF.

## 4. Conclusions

In this paper we present a Greedy Ant Colony Forwarding(GACF) algorithm for NDN network. GACF algorithm utilizes two kinds of ants to complete the entire routing and forwarding optimization progress. The responsibility of Hello Interest Ants is routing and optimizing the path for Normal Interest Ant packets. The Normal Interest Ants reinforce the optimization of the quality of service aware path. The Normal Interstate Ants adopt the greedy method for next hop s election. However, the Hello Interest Ants select the next hop probabilistically for the purposes that the current network states can be updated in time and the new path can be found. The GACF algorithm adaptively reduces the impacts incited by the dynamic complex network, e.g. link failure, network congestion and dynamic network topology.

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