Bandwidth Clustering for Reliable and Prioritized Network Routing using Split Agent-based method

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Abstract

Recent researches have highlighted the importance of developing a network with distributed problem solving abilities thus enhancing reliability with equal share of network resources. While several centralized schemes have been proposed for efficient path marking and capacity reservation, the decentralized approach is one of the motivating reasons for employing adaptive behavior of swarm-based agents. Algorithmically complex problems such as reliable network routing need to be faced with a dynamically adaptive approach. In this work the bandwidth clustering method is presented, a method developed using the Split Agent-based Routing Technique (SART). The SART method is applied in the network, performing path marking activating at the same time the bandwidth clustering method by which nodes within paths are clustered with respect to several levels of available bandwidth. A path freshness degree is estimated and modeled in order to ensure reliability of data traffic flow. Thorough examination is carried out for the performance, path survivability and recoverability using a SART-Bandwidth clustering scheme.

1. Introduction

Agent based routing in large-scale systems is becoming one of the most attractive routing methods in wired and wireless communication networks. By combining various schemes of different agent-based methods one obtains enhanced overall performance of the system which offers to the end user reliability and integrity [14]. The objective of agent-based routing is to achieve high resource utilization and to reduce user contention for network resources. As load is not uniformly distributed, network resources decrease in the form of efficiency, bandwidth, processing power and memory, leading a network to an unpredictable behavior. It becomes evident that the mechanism used for load balancing has to avoid overloaded nodes so that transmission delays (latencies) are minimized. At the same time, whenever load conditions are drastically changing, alternative routes should be activated.

When network dimensions increase, traditional routing algorithms described in [1, 2] do not scale well particularly in the presence of frequent traffic flow changes and the load of prioritized packets. In topologically complicated networks the lack of adaptability of a routing algorithm could become disastrous for the offered Quality of Service (QoS). Routing algorithms must have the ability to adapt in any network changes and cope whenever network state changes (capacity of nodes and links, traffic within paths, load changes etc).

Previous work [2] on efficient network routing (distance vector and link state) has shown that the centralized control of information in a network, "sacrifices" delay for informing the nodes of any changes due to the central supervision of a part of a network. On the contrary, decentralized routing schemes [2, 3, 5] involve a number of controllers each of which supervises a part of the network, allowing the central control to be applied locally to a part of the network and then all "local" supervisors are cooperating thus deploying a decentralized exchange of information.

This work proposes a hybrid technique, which combines a reactive and proactive behavior of message passing and at the same time reserving the required bandwidth. In [14, 16] Split Agent-based Routing Technique (SART) is presented which is a variant of swarm-based routing [4, 6, 9-11] where agents are split after their departure to the next node and occurs on a hop-by-hop basis. Packets that are delay sensitive are marked as prioritized so that agents recognize-as being

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a part of a packet [14]- and try to influence the two way routing tables. This work also uses a hybrid method called swarm-based message passing [14, 16] which provides a model for distributed network data flow organization and continuous (asynchronously) bandwidth reservation on demand (based on user's contentions). This method can be used to solve bandwidth reservation issues in today's communication networks. This agent-based hybrid scheme is borrowing the SART technique [14] using smart packets, to bias the packet network. Then the bandwidth clustering mechanism for priority routing- as will be discussed later-is being activated which marks the paths [12-14] in order to assign a certain bandwidth. Discrimination is made for the class of service offered at any time in the network and for the QoS based on the traffic from a source to a destination. We have considered a number of metrics that are associated with network performance, bandwidth clustering mechanism and characteristics of agents' behavior.

The organization of the paper is as follows: In section 2 a description of the basic principles of the agent-based method and split agent algorithm is presented. Section 3 shows the bandwidth clustering structure and method, in section 4 simulation results are drawn and conclusions are summarized in section 5.

2. Agents and Their Contribution to Path Marking and Capacity Reservation

2.1. Previous work on Agent-based technique

The agent-based approach was first introduced and standardized by Appleby and Steward's mobile agents algorithm [3]. Further studies [4, 6, 9-11] have shown that an ant-like mobile agent algorithm could be applied to a network with significant optimization of the QoS metrics of the network. In [11], Dorigo and Gambardella used the metaphor of trail laying by ants to certain combinatorial optimization problems [2-3]. Several agent-oriented approaches [4, 6, 9-14] have recently been proposed that appeal to principles extracted from Swarm Intelligence (SI) and aspire to solve routing problems to wired and wireless communication networks. On the other hand, within these methods there are some trade-offs that have to be taken into account. These trade-offs deal with network overall performance, such as generated overhead in message passing for agents communication, network utilization, simplicity for the implementation etc.

Agent based network routing could be biologically inspired and based on insect colonies which exhibit a simple behavior for their communication and living. Real ants have similar behavior with agents and are represented in the network, as artificial agents that bias the network collecting useful information for the whole environment through their hormones called pheromones. In previous researches of our [14] we developed a hybrid (proactive and reactive) agent behavior in which ants are adapting their communicational behavior to network circumstances simultaneously splitting themselves for passing information to neighbor nodes. In [16] the SART technique was used for path marking and capacity reservation on demand, and proved efficient in marking the path and reserving the capacity required for offering QoS service to end users.

2.2 Network Bandwidth and Split Agents

As depicted in [6] real ants in nature can find the shortest path between two nodes (food-source, nest-destination) by exploiting pheromone information onto ground. The generic ant-based routing scheme consists of three agent types: explorers, allocators and deallocators [12-14]. Explorers exhibit the foraging behavior and follow trails of pheromones laid down by previous explorers (positive feedback). Allocator agents traverse the path determined by explorer agents and allocate the bandwidth on the links used in the path. When the path is no longer required, a deallocator traverses the path and deallocates the bandwidth used on the links.

Ants in real time simply deposit pheromone on the route while walking, which influences the rest of them to follow the same route with some probability. Ant-based algorithm generates mobile agents embodied in packets at regular intervals within the nodes of the network. These packets [14] which agents are a part of, select a purely random destination and try in the next time step in the network to reach the destination by selecting the best path from their source.

The explored pheromone quantity could be 'compiled' into a concept for network bandwidth. Pheromones correspond to bandwidth in terms of capacity reservation as shown in Figure 1. Pheromone values are normalized to capacity corresponding values and registered to routing table.

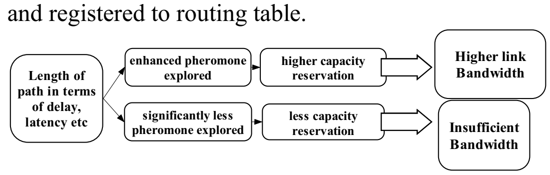

Figure 1: Pheromone - bandwidth relation and intermediate processes.

Congestion control algorithms must be able to offer scalability, robustness and stability in order to handle all kinds of situations including the unforeseen network changes. The Split Agent-based Routing Technique (SART) method [14] undoubtedly represents a solution for significant network optimization particularly for the equal share of network resources. SART allows agents to be split after their departure from source node to the destination node on a hop-by-hop basis. Based on the idea of Fisheye routing [7] where each node can see its absolute neighbors, SART is applied only to the path that packets follow to reduce resource overhead.

In [14] the split agent-based technique is presented and described. The agent forwarding mechanism is activated for sending from a source node packet to destination node. Once agent reaches next node it is split to an ant-based agent which keeps its journey to destination, following the same rules as the ant-based routing scheme [4, 6, 9-11] and also it is split to notify agent. The split agent is mainly the allocator agent which informs the previous node where it came from as well as the link capacity (uplink and downlink) and submits an acknowledgement about the state of the packet (received or not). Yet a split agent informs the previous node about possible link overflow. After the split agent returns back to the previous node, it dies. This procedure continuously occurs until the agent reaches its destination. Additionally, the returned-split agent if necessary changes the priority of node (pheromone table) for delay sensitive services, which is totally based on the class of service of the packet. In this way agents mark the path [16] and reserve the required capacity to offer an end-to-end connection to excessive traffic, ensuring transmission. Congestion may be thought of as a stochastic phenomenon in a highly dynamic environment; thus adaptive hybrid agent based algorithms appear to be a very promising approach. In the next section the bandwidth clustering scheme is presented in cooperation with SART [14, 16].

3. Bandwidth Clustering Approach

The bandwidth clustering approach is based on the available bandwidth on each data link in the network. At any time in the network due to the unpredictable incoming traffic measurements the capacity of each channel (bandwidth) is reduced progressively with an increased flow of packets. Thus a mechanism must be used in order to efficiently cooperate with the routing protocol used and at the same time ensure the capacity reservation for each channel. The bandwidth clustering method is based on the idea of clustering nodes using different levels of bandwidth.

3.1 Bandwidth Clustering Method

Figure 2(i) illustrates the typical decision selections of a proper node *i* to destination D. In figure 2(i) node *i* has four different options for the D destination. Path options *a* and *b* on one hand are using different intermediate nodes (*j* and *k* respectively) and different clusters leading to D destination (C1 and C2 respectively). On the other hand c and d are using a combination of clusters C1, C2, C3 using intermediate nodes *l* and *m* respectively.

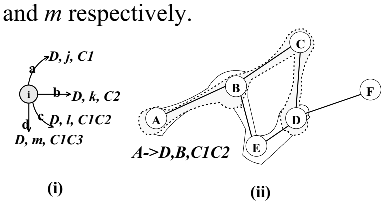

Figure 2(i) and (ii): A topology and the regions arising when clustering with respect to several levels of bandwidth. Color regions represent nodes connected by links with higher free bandwidth (solid lines). Dashed lines indicate more congested links.

Figure 2(ii) shows a topology and the regions arising when clustering with respect to several levels of bandwidth. Having as source node A and a destination node D, agents have already marked the path and allocated the remaining capacity to paths. The same time a cluster is being constructed at each path having the available bandwidth of the channel with the lowest free remaining capacity (1).

$$Max(C_{A \mapsto D}) = BW \qquad (1)$$

where BW is the available bandwidth, which is determined by the lowest free remaining capacity in the path from A to D (bottleneck concept).

Taking figure 2(ii) as an example, there are two clusters marked from the same source to the destination. One intermediate node B is common for both clusters. The packet must decide whether it can follow cluster 1(continuous line) or Cluster 2. Agents adjust the table entries continuously affecting the current network state. Routing tables are represented with pheromone tables having the likelihood of each path to be followed by the artificial ant-packet as depicted in [14, 16]. Pheromone tables contain the address of the destination based on the probabilities for each destination from a source in a bi-directional format. The pheromone table at each node N_i with $k(i)$ neighbors can be measured as:

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$R_i = \left[r_{1,m}^i \right]_{n-1,k(i)}$ with *n-1* destinations and k next nodes for N_i.

Routing tables contain a two-way pheromone table parameters (bi-directional links with different remaining capacities) which are maintained in each node, and are expressed as:

$$P_{k(i)}^{i_t \mapsto n_t} \text{ and } P_{k(i)}^{n_t \mapsto i_t} \quad (2)$$

where $k(i)$ are the next nodes[1] for N_i, *n* is one of the n-1 possible destinations and n_t is the possible next node at a certain time step. All values in routing table are thresholded [16] between $\frac{1}{(number\_of\_neighbors)^2}$ and 0.75 in order to prevent the pheromone saturation state.

After split agents measure the path from a source to destination, the clustering bandwidth mechanism is activated for each node estimating each time step the differences in their links. In figure 2 (i, ii) all nodes are informed and the clusters are constructed according to capacity reservation information spread by agents onto nodes. Thus a packet has to decide whether Cluster 1 or Cluster 2 should be chosen for reaching destination. These decisions are made according to information of the remaining bandwidth where in the previous time step, packets passed and updated the information as follows:

$$r_{i-1,s}^i (t+1) = \frac{r_{i-1,s}^i (t) + \delta r}{1 + \delta r} \quad (3)$$

where δr is the step size parameter and *s* is the source node. Similarly for all neighbors to $i, r_n^i(t)$ is found that:

$$r_{n,s}^i (t+1) = \frac{r_{n,s}^i (t)}{1 + \delta r}, n \neq i-1 \quad (4)$$

Previous values and updated entries of the pheromone table of node *n* should satisfy the following:

$$p_b = \sum_i r_{n,s}^i = 1 = full\_BW \quad (5)$$

Then decision of which path should be followed can be measured as follows:

$$Max\left(C_{A_{C1} \mapsto D_{C1}}\right) > Max\left(C_{A_{C2} \mapsto D_{C2}}\right) \quad (6)$$

for which the ideal path ensuring packet transmission with adequate capacity is $\left(C_{A_{C1} \mapsto D_{C1}}\right)$. This clustering scheme will enable the reduction of lookup tables and generated overhead, thereupon-additional queries to neighbors are avoided.

[1] Nodes can be both endpoints (can be source and destinations) and switches (can perform routing functions).

3.1.1 Apparatus for Reliable Traffic Flows in Constructed Clusters

A freshness degree evaluation and comparison with the reliability of links are substantial metrics to ensure reliability for data traffic flow.

Each node measures the number of links at the beginning of each time step τ and the number of its broken links τ_{Tot} (if any). It becomes evident that the rate of broken links is equal to: $\frac{\tau_{Tot}}{\tau_b}$, where τ_b is the number of node's broken links. One way to evaluate reliability is by using the following notation:

$$\left(1 - \frac{\tau_{Tot}}{\tau_b}\right)^{T_i \cdot N} \quad (7)$$

where T is the time steps have passed since the creation of the cluster(*i*), and N is the number of nodes in the cluster.

According to (7) we have measured the total path reliability notation and the link survivability factor as follows:

$$R = \left(1 - \frac{\tau}{\tau_b}\right)^{T_i \cdot N + \sum_{i=1}^{hops} \frac{i-1}{Rf}}, \text{hops} > 1 \quad (8)$$

where *Rf* is the link capacity refreshment factor and *i* is the number of links in the path.

In this way we know the reliability degree of each link where we can evaluate the total reliability by using equation (8) above.

3.2 Network Generated Overhead

As known routing and bandwidth reservation generated overhead is the number of control packets that are sent relative to the data packets. In the described hybrid agent-based scenario using bandwidth clustering, packets are delivered from one node to another following the predetermined path allocated by agents. However routing related transmissions can affect the overall performance of the system causing significant end-to-end delays and delay variations. The split agent-based scenario does not use specific control packets like other routing schemes since agents pursue the control by being a part of the packets (smart-active packets). Therefore agents map and control the traffic at any time during transmission in the network, and consequently overhead is potentially reduced. Another issue that has to be taken into account for resource overhead reduction is that split agent scheme enables each node to view its absolute neighbor(s), thereupon-additional queries to neighbors are avoided. Finally the inexistence of generated overhead is as a result of the non-transmitted routing tables values or other information blocks to neighbors or to all nodes of the network [16].

4. Simulation and Results Obtained

To demonstrate the design methodologies discussed in this paper, we performed exhaustive simulations to a partially meshed 100-node network. Nodes capacity has been chosen to be relatively high on each node's buffer (680kb). Network's performance is examined through a number of various metrics that characterize the efficiency of the proposed scheme.

In the implementation-simulation of this work we used our own libraries implemented in C programming language. We have modeled and simulated (based in C/Objective C programming language) the previously discussed scenario soundly based on our source code and our C libraries built. There is no specific underlying platform for this implementation since agents represent individually the packets entering the system and being a part of them so-called active/smart packets [14]. In the implementation of the BW clustering scheme different traffic input streams have been tested. The network traffic is modeled by generating constant bit rate (CBR) flows. Each source node transmits one 512-bytes (~4Kbits-light traffic) packet. In the described scenario link capacity is 6Mbps (bi-directional) each.

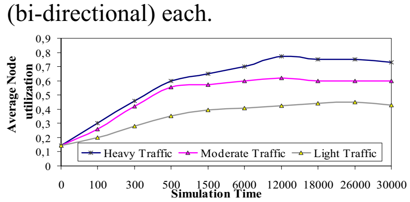

Figure 3: Average utilization of nodes during simulation time.

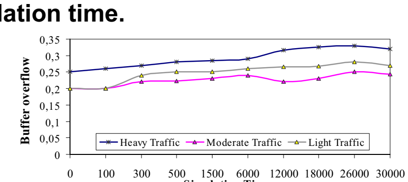

Figure 4: Buffer overflow compared for different traffic input streams.

Average utilization of nodes versus the total buffer capacity that is used to carry data traffic is shown in figure 3. Having as maximum for the total buffer capacity the value 1(100%), heavy traffic seems to utilize in a higher degree each node during simulation time (steady state). Figure 4 shows the buffer overflow compared for different traffic input streams. It is undoubtedly evident that heavy traffic increased each node's buffer overflow, the same time not being remotely valued from moderate and light traffic.

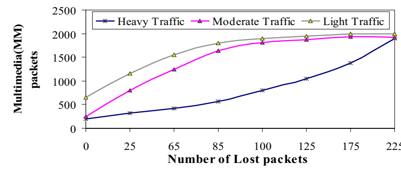

Figure 5: Number of multimedia (MM) packets versus the packet loss.

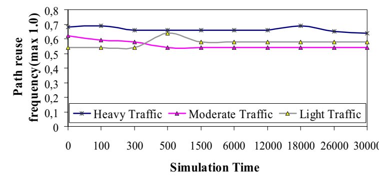

Figure 6: Path reuse frequency

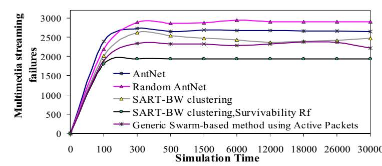

Figure 7: Multimedia streaming failures for different swarm-based methods.

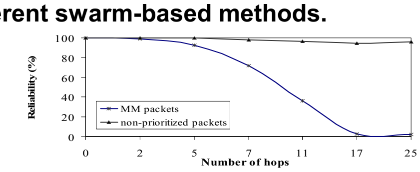

Figure 8: Reliability (%) for data traffic flow, for Multimedia streams versus non-prioritized packets while increasing the number of hops.

Extremely lower than the expected values is the number of multimedia packets versus the packet loss and are presented in Figure 5. Heavy traffic proved not to enable better utilization of network resources using SART-BW clustering scheme where packet loss compared with sent multimedia packets is high enough. On the contrary moderate and light traffic behave significantly better having less total number of sent multimedia packets, lost. Figure 6 shows the path reuse frequency based entirely on SART for path marking avoiding –as explained earlier- the pathlock.

Figure 7 is presenting the different behavior of swarm-based methods. A comparison being done using two different approaches of SART: (i) SART-BW clustering (generic) and (ii) SART-BW clustering using reliability factor. The versions of the AntNet and Random AntNet are the ones used by the popular simulation software packet NS-2 [8]. SART-BW clustering using Rf proved to have significantly fewer MM streaming failures during simulation time. Figure

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8 on the other hand shows the reliability as the number of hops increases, for data traffic flow for MM streams versus non-prioritized packets.

5. Conclusions and Further Research

This work presents the bandwidth clustering method which is associated with a cooperative learning environment producing a decentralized way capable of adapting quickly to changing capacities. The bandwidth (BW) clustering method is implemented using the Split Agent-based Routing Technique (SART) and applied in the network performing path marking and capacity reservation. The bandwidth clustering method is then activated where nodes within paths are clustered with respect to several levels of available bandwidth enabling at the same time path reliability estimation as well as path freshness degree for data traffic flow.

The implementation of split-based bandwidth clustering scenario proved that pheromone table entries do not only represent the cost effective path (best route) or a likelihood of a node being congested, but furthermore relative merits of stability of nodes, and the reflection of delay sensitive packets (activeness of smart packets).

This research could be extended for network scalability examination using variants and hybrid-agent based schemes and combined with a Mobile Ad-hoc Network (MANET) configuration where no infrastructure exists. This scenario is our on going research with agents having special characteristics. These characteristics will position the agent's behavior. Thus agents could be entirely responsible for adapting -on demand- the proper resource allocation to the type of service.

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