マルチメディア通信と分散処理　90−16
コンピュータセキュリティ　2−16
（1998. 9. 18）

A Distributed Routing Strategy for Large Scale Networks Using Intelligent Agents [*]

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Abstract

This paper presents a Distributed Artificial Intelligence (DAI) approach for Connection Admission Control (CAC) and routing in high speed large scale networks. We propose a new strategy which is able to scale up the networks in order to deal with the growth of the users demands and the increasing number of switches to be interconnected to support a large number of hosts. This strategy uses the intelligent agents which are based on Fuzzy Theory (FT) and Genetic Algorithms (GAs). The network is partitioned into multiple domains and each domain has its own agents. All agents cooperate together to handle CAC and to achieve a fast routing.

1. Introduction

High speed transmission rates bring forward their specific issues influencing the network design. A fast routing decision, which sometimes is more important than how close the solution is to an optimal solution, should be a predominant condition of a high speed networking solution. To achieve this, the algorithm should be distributed for the purposes of reliability and the routing decision should be made at the source or destination in order to avoid computations at intermediate nodes [1].

The conventional routing algorithms which use the centralized routing method are not well sited for high speed large scale networks. They are computationally expensive and require a substantial amount of bookkeeping. The database increases with the network size and can be large for a network with many nodes [2, 3]. To achieve an efficient control the network needs to be partitioned into multiple domains and the control functions should be distributed in each domain. In this way, the complexity is decreased by decentralizing control tasks [4].

To cope with high speed networks and the rapid changing of network conditions, it is required that the network traffic methods must be adaptive, flexible, and intelligent for efficient network management [5]. The intelligent routing algorithms based on Genetic Algorithms (GAs), Fuzzy Theory (FT), and Neural Networks (NNs) can prove to be efficient in high speed networks [6, 7, 8, 9].

In this work, we propose a distributed routing strategy for large scale networks using intelligent agents. The intelligent agents are based on Genetic Algorithms (GAs) and Fuzzy Theory (FT). The network is partitioned into multiple domains and each domain has its own agents. All agents cooperate together to handle the Connection Admission Control (CAC) and to achieve a fast routing. The proposed strategy is a Distributed Artificial Intelligence (DAI) approach, which considers that simple or complex activities are the outcome of interactions between entities, relatively independent, called agents that work in societies in a cooperative way to achieve some goals.

The remainder of this paper is organized as follows. The next Section is devoted to agent properties. Section 3 introduces distributed network architecture. Section 4 presents Resource Management Agent (RMA). Section 5 treats Connectivity Management Agent (CMA). Destination Node Discovery Agent (DNDA) is discussed in Section 6. Routing Agent (RA) is presented in Section 7. Some conclusions are given in Section 8.

2. Agent Properties

The high speed networks will have to manage an increasing usage demand, provide support for a significant number of services, guarantee their Quality of Service (QoS), and optimize the utilization of network resources. The control in these networks becomes very complex and it seems imperative to focus on a new control perception that introduces "intelligence", which can enable the network to perform adaptive behavior and to decompose the con-

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[*] 知的エージェントを用いた大規模ネットワークのための分散ルーチング方法

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trol to handle complexity while ensuring cooperation between different elements of control.

The term intelligence we use in the sense of control elements which include reasoning capacities, exhibit behavioral autonomy, and are able to interact with each other and to cooperate to achieve collective work. This is related to DAI which deals with the study and design of artificial agents to develop intelligent systems. One of most important subfield of DAI is Multi-Agent System (MAS) paradigm, based on the idea that simple or complex activities are the outcome of interaction between relatively independent entities called agents. A MAS may then be defined as a set of agents that interact with each other and with the environment to solve a particular problem.

The term "agent" generally is defined as a physical or logical entity that has the following properties:

- **Social Ability** - An agent is able to communicate with other agents that constitute a part of its environment. The agents may work toward a single global goal or separate individual goals.
- **Autonomy** - Agents operate without the intervention of external elements (other agents). They can accept, or not, requests coming from other agents and have some kind of control over their actions and internal states.
- **Reactivity** - Agents perceive their environment and respond in a timely fashion to change that may occur in it.
- **Adaptability** - Agents are characterized by their flexibility, adaptation, and facility to set up their own goals based on their interests. One of the major characteristics of agents is their ability to acquire and process information about situations that are spatially and temporally remote. By doing so, an agent may have a chance to avoid future problems or at least reduce the problem effects.
- **Granularity Degrees** - Agents may have different degrees of complexity. They may be simple or complex. Most simple agents are characterized by the lack of intelligence regarding their own behavior. These agents are called reactive. More complex agents are called cognitive or intelligent agents. Their behavior is a consequence of their perception, knowledge and interactions.

In this paper, we propose intelligent agents which are based on FT and GA. They are organized and their activities are coordinated in order to achieve a fast routing.

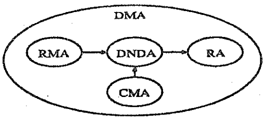


Figure 1: DMA structure.

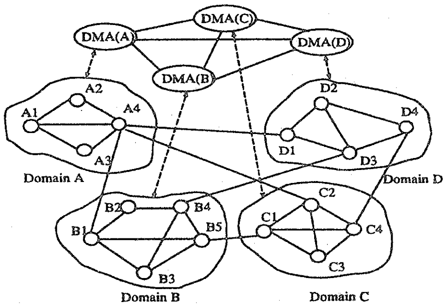


Figure 2: Distributed network architecture with DMAs.

3. Distributed Network Architecture

In this section we will describe the Domain Management Agent (DMA) components. Each DMA is expected to perform four functions: *resource management*, *connectivity management*, *destination node discovery*, and *routing*. The DMAs are distributed in each domain and have cooperation between them. The DMA structure is shown in Fig.1 and the distributed network architecture with DMAs is shown in Fig.2.

The RMA is an intelligent agent that performs the CAC procedure. The main component of the RMA is the Fuzzy Admission Controller (FAC), which decides to accept or reject a connection that is attempting to enter the network. If the new connection is accepted the bandwidth of the new connection is subtracted from the available capacity of the network. Otherwise, if a connection is released the connection bandwidth is added to the available capacity of the network.

The CMA is a simple agent. It provides connectivity information for routing purpose. Its main function is to manage the database of the individual domains and to exchange the individual domains information among DMAs.

The RA has two components, one for Intra Domain routing which we call IntraD agent and another one for Inter Domain routing which we call InterD agent. The IntraD agent is responsible for routing inside each domain, whereas the InterD agent is responsible for routing in different domains. The IntraD agent is an intelligent agent based on GAs, whereas the InterD agent is a destination-based routing algorithm.

The DNDA checks to find out if the source and

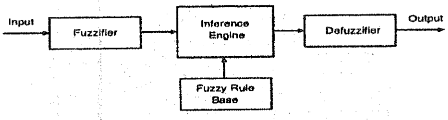


Figure 3: FLC structure.

destination nodes are or aren't in the same domain. If they are in the same domain the DNDA activates the IntraD agent, otherwise if they are in different domains the DNDA activates the InterD agent.

In the next sections, we will give a detailed description of the abovementioned agents.

4. RMA

The RMA of the network domain uses a Link State Database (LSD) to manage the network resources and provide connectivity information for routing purposes. The RMA manages each link in terms of link capacity. It manages the resource allocation for the connection setup requests from any user of its network domain using the LSD, and send the available resources to the DMA of its network domain. When ever a connection request is received by the RMA, it performs a CAC function based on the traffic parameters and the requested QoS of the connection. The RMA determines whether allowing a new connection violates the QoS guarantee of the existing connections in the network domain.

The main component of the RMA is the FAC, which decides to accept or reject a connection that is attempting to enter the network. If the new connection is accepted the bandwidth of the new connection is subtracted from the available capacity of the network. Otherwise, if a connection is released the connection bandwidth is added to the available capacity of the network. The procedure for CAC is based on the connection equivalent capacity, in order to gain from statistical multiplexing of the bursty connections [10].

The Fuzzy Logic Controller (FLC) is the major element of the FAC. The basic components of the FLC are shown in Fig.3. They are the fuzzifier, inference engine, fuzzy rule base and defuzzifier.

As the membership functions for the FAC, we use the shape of triangular and trapezoidal functions. The functions $f(x, x_0, a_0, a_1)$ and $g(x, x_0, x_1, a_0, a_1)$ for triangular and trapezoidal shapes, respectively, are defined (see Fig.4) below:

$$f(x,x_0,a_0,a_1) = \begin{cases} \frac{x-x_0}{a_0}+1 & x_0-a_0 < x \le x_0 \\ \frac{x_0-x}{a_1}+1 & x_0 < x \le x_0+a_1 \\ 0 & \text{otherwise} \end{cases}$$

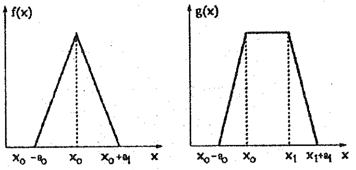


Figure 4: Triangular and trapezoidal membership functions.

$$g(x,x_0,x_1,a_0,a_1) = \begin{cases} \frac{x-x_0}{a_0}+1 & x_0-a_0 < x \le x_0 \\ 1 & x_0 < x \le x_1 \\ \frac{x_1-x}{a_1}+1 & x_1 < x \le x_1+a_1 \\ 0 & \text{otherwise} \end{cases}$$

where x_i is the center of triangular function ($i = 0$) or the right/left edge of trapezoidal function ($i = 0/1$), and a_j is the right/left width of the monotonic part of triangular or trapezoidal function ($j = 0/1$).

The input linguistic parameters of the FAC are Quality of service Qs, Network congestion parameter Nc, Available capacity Ac, and User requirements Ur. The output linguistic parameter is the Acceptance decision Ad.

The term sets of Qs, Nc, Ac, and Ur are defined respectively as:

$$\begin{aligned} T(Qs) &= \{Satisfied, NotSatisfied\} = \{S, NS\}; \\ T(Nc) &= \{Negative, Positive\} = \{N, P\}; \\ T(Ac) &= \{NotEnough, Enough\} = \{NE, E\}; \\ T(cs) &= \{small, medium, big\} = \{sm, me, bi\}. \end{aligned}$$

The set of the membership functions associated with the term set Qs, $T(Qs) = \{S, NS\}$, are denoted by $M(Qs) = \{\mu_S, \mu_{NS}\}$, where μ_S and μ_{NS} are the membership functions for S and NS, respectively. They are given by (see Fig.5(a)):

$$\begin{aligned} \mu_S(Qs) &= g(Qs, 0, S_e, 0, S_w); \\ \mu_{NS}(Qs) &= g(Qs, NS_e, 1, NS_w, 0). \end{aligned}$$

The membership functions for term set of Nc are $M(Nc) = \{\mu_N, \mu_P\}$. The membership functions μ_N and μ_P are given by (see Fig.5(b)):

$$\begin{aligned} \mu_N(Nc) &= g(Nc, -1, N_e, 0, N_w); \\ \mu_P(Nc) &= g(Nc, P_e, 1, P_w, 0). \end{aligned}$$

The membership functions for term set Ac are $M(Ac) = \{\mu_{NE}, \mu_E\}$, and μ_{NE}, μ_E are given by (see Fig.5(c)):

$$\begin{aligned} \mu_{NE}(Ac) &= g(Ac, 0, NE_e, 0, NE_w); \\ \mu_E(Ac) &= g(Ac, E_e, 1, E_w, 0). \end{aligned}$$

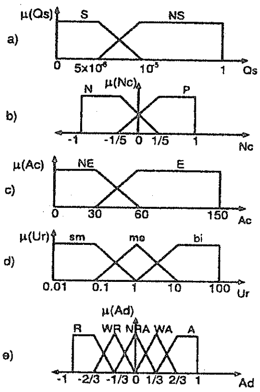


Figure 5: Membership functions for a) Qs, b) Nc, c) Ac, d) Ur, and e) Ad.

The membership functions for term set Ur are $M(Ur) = \{\mu_{sm}, \mu_{me}, \mu_{bi}\}$, and μ_{sm}, μ_{me}, μ_{bi} are given by (see Fig.5(d)):

$$\begin{aligned}
\mu_{sm}(Ur) &= g(Ur, 0, sm_e, 0, sm_w);\\
\mu_{me}(Ur) &= f(Ur, me_c, me_{w0}, me_{w1});\\
\mu_{bi}(Ur) &= g(Ur, bi_e, 1, bi_w, 0).
\end{aligned}$$

We define the term set of the output linguistic parameter $T(Ad)$ as {Reject, Weak Reject, Not Reject Not Accept, Weak Accept, Accept}. We write for short as {R, WR, NRA, WA, A}.

The set of the membership functions for Ad are denoted by $M(Ad) = \{\mu_R, \mu_{WR}, \mu_{NRA}, \mu_{WA}, \mu_A\}$, which are given by (see Fig.5(e)):

$$\begin{aligned}
\mu_R(Ad) &= g(Ad, -1, R_e, 0, R_w);\\
\mu_{WR}(Ad) &= f(Ad, WR_c, WR_{w0}, WR_{w1});\\
\mu_{NRA}(Ad) &= f(Ad, NRA_c, NRA_{w0}, NRA_{w1});\\
\mu_{WA}(Ad) &= f(Ad, WA_c, WA_{w0}, WA_{w1});\\
\mu_A(Ad) &= g(Ad, A_e, 1, A_w, 0).
\end{aligned}$$

Based on the above linguistic description, we make a Fuzzy Rule Base (FRB). The FRB forms a fuzzy set of dimensions $|T(Qs)| \times |T(Nc)| \times |T(Ac)| \times |T(Ur)|$, where $|T(x)|$ is the number of terms on $T(x)$. So, there are 24 rules in the FRB. The FRB is shown in Table 1. The control rules have the following form: IF "conditions" THEN "control action". The conditions are the input linguistic parameters and the control action is the output linguistic parameter. The input and output linguistic parameters are expressed by the membership functions shown in Fig.5. Statements on conditions go like "the Qs is satisfied" or "the Nc is positive". Likewise, statements on control action might be "reject" or "accept".

Table 1: FRB.

Rule	Qs	Nc	Ac	Ur	ccr
0	S	N	NE	sm	NRA
1	S	N	NE	me	WR
2	S	N	NE	bi	R
3	S	N	E	sm	WA
4	S	N	E	me	NRA
5	S	N	E	bi	WR
6	S	P	NE	sm	WA
7	S	P	NE	me	NRA
8	S	P	NE	bi	R
9	S	P	E	sm	A
10	S	P	E	me	A
11	S	P	E	bi	A
12	NS	N	NE	sm	R
13	NS	N	NE	me	R
14	NS	N	NE	bi	R
15	NS	N	E	sm	WA
16	NS	N	E	me	NRA
17	NS	N	E	bi	R
18	NS	P	NE	sm	WR
19	NS	P	NE	me	R
20	NS	P	NE	bi	R
21	NS	P	E	sm	WA
22	NS	P	E	me	NRA
23	NS	P	E	bi	WR

5. CMA

The CMA is a simple agent which manage a database for connectivity purposes of the routing algorithm. The CMA carries out the following processes:

- it manages a database with the names of the nodes of the individual domain and the other domains;
- has a connectivity management protocol which allows DMAs to exchange individual domain information.

6. DNDA

After the DMA of the source domain receives the connection request, the DNDA checks to find out if the destination and source nodes are or aren't in the same domain.

- If the source and the destination are in the same domain, the DNDA activates IntraD agent.
- If the source and the destination aren't in the same domain, the DNDA activates InterD agent.

7. RA

The RA has two components, IntraD agent and InterD agent.

7.1 IntraD Agent

The IntraD agent uses an Adaptive Routing method based on GAs (ARGA). In order to reduce the operation complexity of GAs, the IntraD agent transforms the network in a tree model. To explain this procedure, we consider a small network with 8 nodes as shown in Fig.6. The node A is

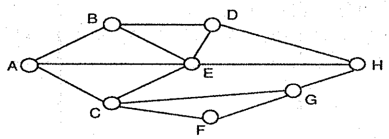


Figure 6: Network example.

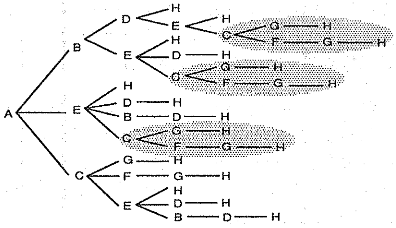


Figure 7: Tree model.

the source node and the node H is the destination node. All communication paths are expressed by the tree model shown in Fig.7. In the shaded areas are shown the same communication paths from node C to H. In order to decrease the gene number in a chromosome, the tree model of Fig.7 is reduced as shown in Fig.8. In the reduced tree model, each tree junction is considered as a gene and the communication path is represented by the chromosome. In the network tree model, each chromosome represents only one communication path. The chromosomes have the same size. Therefore, the crossover and mutation operations become simple.

The IntraD agent uses a source routing mechanism. In the source routing mechanism, a complete route from the source node to destination node is decided from the source node. The source node knows all communication routes and the complete information about the network. Therefore, it is possible to select a route efficiently. Furthermore, if the data is large in quantity, it is possible to divide the flow data by using different paths.

The most important factor to achieve efficient genetic operations is gene coding. In the Genetic Load Balancing Routing (GLBR) method [6], the genotype and phenotype are the same. The genes are put in a chromosome in the same order the nodes form the communication route, so the chromosomes have different size. If genetic operations are chosen randomly, the new offsprings of a population may be unsuitable individual populations. As a result, a communication route between two adjacent nodes may not exist and some complicated genetic operations should be carried out in order to find a new communication route. Also, because the individuals of a population have different sizes, the crossover operations are complicated.

In order to simplify the genetic operations of GLBR method, in the ARGA method the network

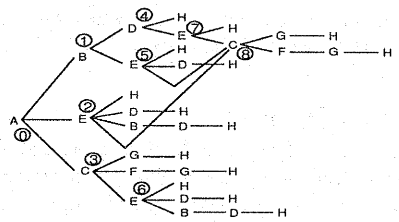
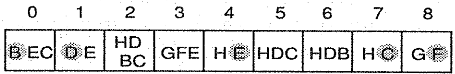


Figure 8: Reduced tree model.



0	1	2	3	4	5	6	7	8
BEC	DE	HD BC	GFE	HE	HDC	HDB	HC	GF

Figure 9: Chromosome examples for the route "A-B-D-E-C-F-G-H".

is expressed by a tree network. The genes are expressed by the tree junctions as shown in Fig.8. In Fig.9 is shown a chromosome example for the route "A-B-D-E-C-F-G-H". Each chromosome expresses only one route. The genetic operations are carried out only in the part of chromosome where a gene exists, which is called an "active" gene. Therefore, the number of genetic operations decreases. In each gene contains the information of the adjacent nodes. The communication route is represented by the chromosome. As is shown in Fig.9, the chromosomes have the same length. Therefore, the crossover operation becomes very easy.

In GLBR method, the interaction between the adjacent genes in a chromosome is necessary. On the other hand, in the ARGA method this interaction is not necessary. So, the mutation operation also becomes easy. Furthermore, the ARGA method is able to create various individuals, which result in faster evolution.

The ARGA method uses as genetic operations the selection, crossover and mutation. In the selection method, the ranking model and elitist model are used together.

The ranking model ranks each individual by their fitness. The rank is decided based on the fitness and the probability is decided based on the rank. When the rank is high, the probability of individuals is high. Because fitness is used as a measure for ranking, the difference between high rank individual probabilities and low rank individual probabilities is significant. In the elitist model, the individual which has the highest fitness value in a population is left intact in the next generation. Therefore, the best value is always kept and the routing algorithm can converge very fast to the desired delay time.

As the crossover method is used the single point crossover. The crossover point is selected in the same locus of two selected individuals. The mutation is carried out only in the genes which have nodes in the communication route (see loci 0,1,4,7,8 in Fig.9).

7.2 InterD Agent

The InterD Agent is activated when the source and destination nodes are in different domains. The InterD agent is a destination-based routing. In the source-based routing protocols, the source router has the detailed information of its own domain and the summarized information of other domains. Therefore, a nonoptimal path problem arises when the source does not know the detailed topology information of the destination domain. This happens, because the shortest paths from a source to different destination nodes in another domain may not necessary travel to the same border node at the destination domain. This is the reason why we use the destination-based routing for the interdomain connection.

After the DNDA discovers that the source and destination nodes aren't in the same domain, the source DMA sends an extended connection set up (S,D) message to all DMAs in the network. The S and D stand for source and destination, respectively. The set up (S,D) message has the distance information from the source to each border node in the source domain.

The destination node after receiving the set up (S,D) message obtains the distance information from the source host to the border nodes at the source domain, the detailed topology information of its own domain, and the summarized distance information of the intermediate domains. With all the information mentioned above, InterD agent uses Dijkstra routing algorithm to compute the Shortest Path (SP) from the destination to the source. The algorithm constructs a set of routing contracts for each DMA in the domains that SP transverses. Each routing contract specifies the requirements for setting up the partial paths within the involved domains.

8. Conclusions

In this paper, we proposed an agent-based distributed strategy for high speed large scale networks. First, we gave the agent properties. Next, the distributed network architecture was introduced. After that, RMA, CMA, DNDA, and RA were described in detail.

The proposed strategy is able to scale up the networks in order to deal with the growth of the users demands and the increasing number of switches to be interconnected to support a large number of hosts.

The detailed evaluation of this strategy is for the future work.

Acknowledgment

The authors are grateful to Japan Society for the Promotion of Science (JSPS) for supporting this work.

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