QOS MULTICAST ROUTING DESIGN USING NEURAL NETWORK

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Keywords: Quality of service, Hopfield neural network, Multicast routing.

Abstract: In this paper, an algorithm based on Hopfield neural network for solving the problem of determining minimum cost paths to multiple destination nodes satisfying QoS requirements is proposed. The schema of constructing the multicast tree with HNN is emphasized after the analysis of the attributes of the multicast tree. At last, the emulation explores the feasibility of this algorithm.

1 INTRODUCTION

With the rapid emergency of the multimedia applications on networks, especially for video conferences, the need for multicast QoS routing mechanism to satisfy the multimedia transmission requirements among conference participants is urgently rising.

Wang and Crowcroft have proved QoS routing with multi-constraint to be a NP-complete problem (Wang et al., 1996). Neural networks have often been formulated to solve NP-complete optimization problems. Tank and Hopfield (Tank et al., 1986) proposed the first neural approach applied in the TSP problem. The advantage of the Hopfield NN is the rapid computational capablility of solving the combinatorial optimization problem. Ahn and Ramakrishna (Ahn et al., 2001) proposed a near-optimal routing algorithm employing a modified Hopfield NN. In this paper, a new Hopfield NN model is proposed to speed up the convergence whilst improving the optimality of the multicast tree constructed under multi-constraint

2 PROBLEM FORMULATION

As far as multicast routing is concerned, a network is usually represented as a weighted directed graph $G=(V, E)$, where V, the set of vertexes, denotes the set of nodes, and E, the set of directed edges, corresponds to the set of links connecting the nodes.

Suppose the number of nodes is n, refer to the ith node as i for short, then the adjacency matrix **O** describing the initial state of the focused network can be defined as: $\mathbf{O}_{ij}=1$, if the link from i to j exists; elsewise, $\mathbf{O}_{ij}=0$.

We also appoint a node $s \in V$ to denote the source node of a multicast request. The source node acts as the root of the multicast tree to be build which has only out-degree. Correspondingly, let $\boldsymbol{d}=\{d_1,\ldots,d_m\} \subset (V-\{s\})$ denotes the set of the destination nodes with only in-degree. Then the constructed multicast tree, denoted by T and shown in Fig.1, should satisfy:

1) T is a subgraph of G;
2) The equal undirected graph T' is a tree;
3) s is the root of T';
4) $\boldsymbol{d} \in T$ and every leaf of T' is in $\boldsymbol{d}$;
5) Every vertex in T except s can be accessed from s.

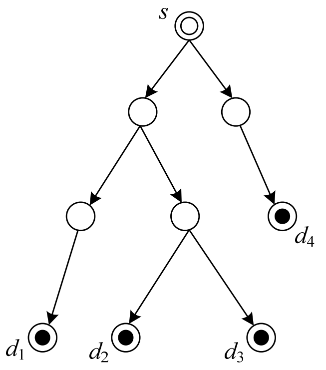

Figure 1: Indicating diagram of multicast tree.

Huang M. and Ming Zhu S. (2008).
QOS MULTICAST ROUTING DESIGN USING NEURAL NETWORK.
In *Proceedings of the Fifth International Conference on Informatics in Control, Automation and Robotics - SPSMC*, pages 213-216
DOI: 10.5220/0001476002130216

Let the adjacency matrix **A** describing the constructed subgraph *G'* of *G* after multicast routing is defined as: $\mathbf{A}_{ij}$=1, if the link from *i* to *j* is in *G'*; elsewise, $\mathbf{A}_{ij}$=0. Then let's prove the theorems below:

Theorem 1. In a multicast tree *T*, there will be one and only one path from *s* to *v* ($v \in T$ and $v \neq s$).

Proof: *Existence*. According to attribute 5) of T, *v* can be accessed from *s*, so there is at least one path from from *s* to d_i ($i=1,\ldots,m$);

Uniqueness. If there are two different paths from *s* to *v* in *T*, then there will be at least two dis-coincident sectors composed of directed edges in the two paths. Combined with the joint vertexes, the two sectors form a circle in the equal undirected graph of T. Refer to attribute 2) of multicast tree, the existence of the circle contradict the acyclic attribute of a tree. So there is only one path from *s* to *v* in *T*;

Theorem 2. Supposing s, $\boldsymbol{d} \in G'$ and the in-degree of *s* is 0, *G'* is a multicast tree T if and only if:

$$\left(\sum_{k=1}^{n}\left(\mathbf{A}^{k}\right)\right)_{sj}=1\text{, where } j \in G' \text{ and } j \neq s \tag{1}$$

$$\prod_{d\in\mathbf{d}}\left(\left(1-\left(\sum_{k=1}^{n}\left(\mathbf{A}^{k}\right)\right)_{id}\right)^{2}+\left(\sum_{j\in G'}\mathbf{A}_{dj}\right)^{2}\right)=0\text{ ,} \tag{2}$$

where $i \notin d$ or $\sum_{j\in G'}\mathbf{A}_{ij}>0$

Proof: *Necessity*. Based on the accessible theory in graph theory, Eq.1 denotes the number of paths from *s* to *j* within a length of *k*. Refer to Theorem 1, Eq.1 is obviously tenable. If $I \in T$, then *i* must locate at a branch of *T* except *i* is a leaf destination node itself. Suppose the branch ends at a leaf *θ*. According to Theorem 1, there is one and only one path from *s* to *θ* and *i* is in the path. Due to attribute 4 of multicast tree, $\theta \in \boldsymbol{d}$, therefore Eq.2 is got.

Sufficiency. Obviously, attribute 1 of multicast tree is qualified. Because of Eq.1, attributes 5 is qualified. Considering the in-degree of *s* is 0, *G'* is a tree with *s* as the root, i.e. attributes 2 and 3 is qualified. When Eq.2 is satisfied, for $I \in G'$, except *i* is a leaf destination node itself , there will be at least one leaf $\theta \in \boldsymbol{d}$ which can be accessed from *i* by one and only one path. So attribute 4 is qualified. Therefore, *G'* is a multicast tree.

3 NEURAL NETWORK MODEL

The Hopfield NN model for multicast QoS routing, which consists of $n \times n$ neurons connected with each other, is mapped from the corresponding directed graph *G* of the aimed network system with *n* nodes.

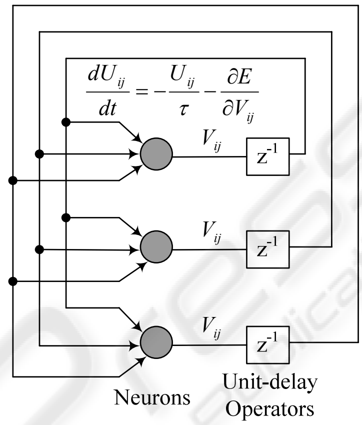

Figure 2: Model of Hopfield neural network.

The output of the neuron at the position (*i*,*j*) is denoted by V_{ij}, where V_{ij}=1, if the link from *i* to *j* exists; otherwise, V_{ij}=0. Obviously, the output matrix $\mathbf{V}=[V_{ij}]_{n\times n}$ is equal to the adjacency matrix **A** of G. Let U_{ij} denotes the input of neuron (*i*,*j*), and define the gain function *g* of the neuron as:

$$\left(\sum_{k=1}^{n}\left(\mathbf{A}^{k}\right)\right)_{sj}=1\text{, where } j \in G' \text{ and } j \neq s \tag{3}$$

$$\frac{dU_{ij}}{dt}=-\frac{U_{ij}}{\tau}-\frac{\partial E}{\partial V_{ij}} \tag{4}$$

Define several link state matrix as: $\mathbf{W}=[W_{ij}]_{n\times n}$, $\mathbf{B}=[B_{ij}]_{n\times n}$, $\mathbf{D}=[D_{ij}]_{n\times n}$ and $\mathbf{L}=[L_{ij}]_{n\times n}$, where W_{ij} is the cost of the link from *i* to *j*, B_{ij} is the bandwidth of the link from *i* to *j*, D_{ij} is the delay of the link from *i* to *j* and L_{ij} is the parcket loss rate of the link from *i* to *j*. The QoS constraints is denoted with B_w, D_w and L_w where B_w is the minimal available bandwidth of each selected link, D_w is the maximal available delay of each selected path and L_w is the maximal available packet loss rate of each selected path.

As shown in Fig.2, the dynamic Eq.4 governs the dynamics of the network. The design of the energy function should reflect the attributes of the selected multi-path below:

1) There is no non-existing link in the selected multi-path;
2) There is no input to the source node in the selected multi-path;

3) All destination nodes is in the selected multi-path;
4) According to Theorem 2, the two equations should be satisfied;
5) Satisfy the QoS constraints.
6) The total cost of the selected multi-path must be as low as possible;

To fit the constraints above, we design the suitable energy function as:

$$E = \mu_1 E_1 + \mu_2 E_2 + \mu_3 E_3 + \mu_4 E_4 + \mu_5 E_5 + \mu_6 E_6 \tag{5}$$

$$E_1 = \sum_{i=1}^{n}\sum_{j=1}^{n}\left(\left(V_{ij}O_{ij} - 1\right)V_{ij}\right)^2 \tag{6}$$

$$E_2 = \sum_{i=1}^{n}\left(V_{is}\right)^2 \tag{7}$$

$$E_3 = \sum_{d\in\mathbf{d}}\left(\left(\sum_{k=1}^{n}\left(\mathbf{V}^k\right)\right)_{sd} - 1\right)^2 \tag{8}$$

$$E_4 = \sum_{\substack{j\in G' \\ j\neq s}}\left(\left(\sum_{k=1}^{n}\left(\mathbf{V}^k\right)\right)_{sj} - 1\right)^2 + \sum_{\substack{i\in G' \\ i\neq s \\ i\notin\mathbf{d} \text{ or } \sum_{j\in V}\mathbf{A}_{ij}>0}}\left(\prod_{d\in\mathbf{d}}\left(\left(1-\left(\sum_{k=1}^{n}\left(\mathbf{V}^k\right)\right)_{id}\right)^2 + \left(\sum_{j\in V}\mathbf{V}_{dj}\right)^2\right)\right) \tag{9}$$

$$E_5 = z_1 + H\left(z_2\right) + H\left(z_3\right) \tag{10}$$

$$H(z) = \int_0^z h(z)dz,\ h(z) = \begin{cases} z, \ if\ z > 0 \\ 0, \ otherwise \end{cases} \tag{11}$$

$$z_1 = \sum_{i=1}^{n}\sum_{\substack{j=1 \\ j\neq i}}^{n} H\left(B_{ij}V_{ij} - B_w\right) \tag{12}$$

$$z_2 = \sum_{i=1}^{n}\sum_{\substack{j=1 \\ j\neq i}}^{n} H\left(mD_w - \left(V_{ij}D_{ij}\sum_{k=1}^{n}V_{jk}\right)\right) \tag{13}$$

$$z_3 = \sum_{i=1}^{n}\sum_{\substack{j=1 \\ j\neq i}}^{n} H\left(\left(V_{ij}\left(1-L_{ij}\right)\sum_{k=1}^{n}V_{jk}\right) - m\left(1-L_w\right)\right) \tag{14}$$

$$E_6 = \sum_{i=1}^{n}\sum_{\substack{j=1 \\ j\neq i}}^{n}\left(W_{ij}V_{ij}\right)^2 \tag{15}$$

Obviously, E_1, E_2 and E_3 refer to constraints 1, 2 and 3 respectively. According to Theorem 2, when E_4 get minimal (i.e. zero), the constraint 4 is attained. E_5 represents the integration of QoS constraints on bandwidth, delay and loss rate. As z_1, z_2 and z_3 represents the deviation of the QoS constraints and the minus value is meaningless, so we filter the minus value with an integral computation in E_5. With z_1, z_2 and z_3, conditions of links near root will influence the deviation more severely.

4 EMULATION

Fig.3 shows the topology of the delegating network system. The source node which promotes the routing request and four destination nodes have already been signed out in the graph. Each link in the network is labeled with a link status vector consists of cost W, bandwidth B(MB), delay D(ms) and loss rate L. The QoS constraints are: B_w=2MB, D_w=8ms, L_w=10^{-3}.

In this case, we set coefficient μ_1 =80000, μ_2 =40000, μ_3=160000, μ_4 =500, μ_5 =400, μ_6 =400, λ=1, and Δt = 2×10^{-8}. By emulation, we could obtain the global optimal solution shown in Fig.3.

5 CONCLUSIONS

In this paper, we propose a new multicast tree selection algorithm to simultaneously optimize multiple QoS parameters which is based on Hopfield neural network. The result of emulation shows that the utilization of Hopfield neural network is an available method to solve QoS routing problems. Furthermore, by the massive parallel computation of neural network, it can find near optimal route quickly, so the real-time requirement of routing in high-speed network system could be satisfied.

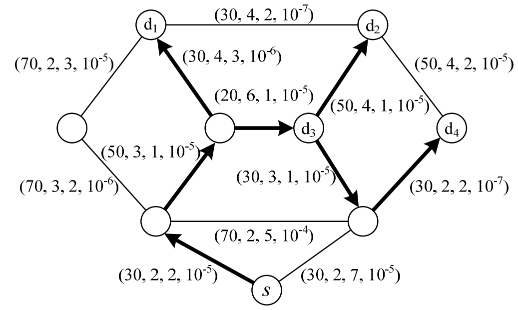

Figure 3: Topology of network system with parameters and selected multi-path.

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