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Virtual Node Algorithm for Data Networks

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Abstract: This study shows a new approach to create Virtual Nodes in Data Networks. The routing algorithm guarantees a loss-free delivery of data packets from congested sources and a deterministic bound on the route length in arbitrary topology networks. The routing decisions are based on assigning routing priorities to the links such that a packet is forwarded to the highest priority link which is not blocked. This study shows that routing decisions using a local-greedy method are not optimal and the number of hops can be reduced by introducing Virtual Nodes. The performance is studied computationally for various networks. In all experiments the proposed algorithm shows better results than local-greedy and also it creates 2(m-1) virtual nodes, m is the number of nodes in a graph. The contribution of this article is to propose a new algorithm to create Virtual Nodes and Virtual Rings which provides a global sense of direction for convergence routing.

Key words: Virtual node, virtual ring, routing

INTRODUCTION

The problem of finding efficient routing algorithms has been a fundamental research area in the field of data networks. There are two types of routing algorithms namely static routing (fixed) and nondeterministic routing (dynamic). In the static routing algorithm, a pair wise traffic function and link capacities are given.Thus the problem is to choose routes with minimum number of links a packet should traverse from source to destination, so that it minimizes the average packet delay. In static routing the selection of routes and the assignment of flows on the links are decided before the routing tables are downloaded into the network's switches and remain unchanged in time. In contrast, the nondeterministic (dynamic) routing algorithm requires changing routing decisions continuously according to the changes in the traffic and congestion conditions in the network. Earlier models of static and dynamic routing problems have been well studied by Gallanger and Bertsekas (1992), Greenberg and Goodman (1986) Bertsekas (1964), Baran (1982), Segall (1977) and others.

Earlier models of Static and Dynamic routing algorithm consider the shortest path routing algorithm to minimize the expected delay. Nondeterministic routing techniques such as hot-potato routing (Baran, 1964), deflection routing (Greenberg and Hajek, 1992) and convergence routing (Yorm and Modi, 1995) ensure no packet loss due to congestion inside the network with minimum buffer requirements.Such nondeterministic routing combines, in a dynamic fashion, the on-line routing decision based on distance (number of hops) from a source to destination.Convergence routing ensures that packets will reach their destinations without being routed on the same link twice.Thus it ensures a deterministic bound on the maximum route length in an arbitrary topology network (Bao and Garcia-Luna-Aceves, 2003).

Related work: The convergence method is close to the family of deflective routing. Started with Baran's "Hot-Potato" routing (Baran, 1964) this family of algorithm uses a method in which a node tries to get rid of the message, first in the known direct path to the destination, otherwise if possible to deflect the message to another node.

In deflection routing, the packets are deflected from the shortest path to a random location in the network, while the convergence routing on the other hand, is guided by a global sense of direction and deflects the message only if locally seems like there is a "global improvement". Global improvement and implicit self-routing is given by the method of "interval routing" of Santoro and Khativ (1985). The dynamic behavior of deflection routing has been studied on some regular topologies such as the Manhattan street network (Maxemchuck, 1982) and the hypercube (Greenberg and Hajek, 1992).

In MetaNet routing (Ofek and Yung, 1994; Yener and Ofek, 1994), algorithm the packets will reach their destinations unless physical failure has occurred. This property is not provided by deflection routing, which means that the packets can deflect indefinitely inside the

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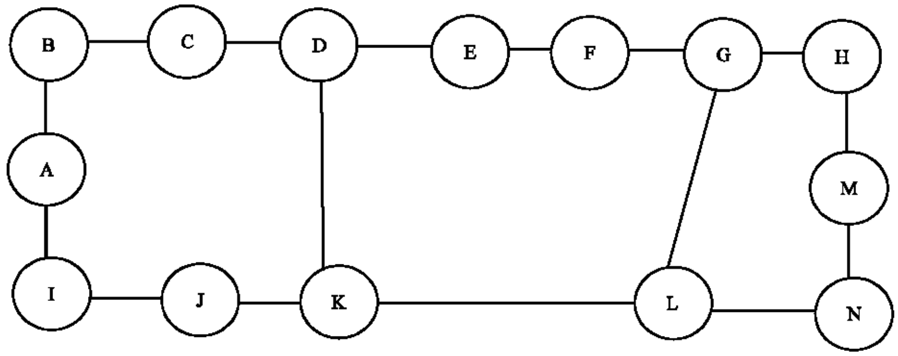

Fig 1: Given network topology

network. Therefore, in Baran's "Hot-Potato (Baran, 1964) routing there is hop-count field in each packet header, which is decremented by one after every hop. If the hop-count reaches zero the packet is discarded i.e., the packet may get lost due to congestion inside the network.

In "METANET Principles of an Arbitrary Topology LAN" (Yoram and Modi, 1995) they assumed that the physical layout of the network is a tree and a ring is embedded over it using Euler Tree Traversal (Yener, *et al.*,) without the Thread links. All the links of the tree are ring links and are part of Tree Embedded Ring (TER).

Proposed algorithm: In this study the performance of convergence routing can be improved by introducing virtual nodes in the network. The performance measure considered in this research is to find a path with minimum number of links a packet should traverse from source to destination, so that it minimizes the average packet delay.

The basic structure: In this study we describe the basic structure of the network topology. The network topology is assumed to be arbitrary and all links are bi-directional or full duplex.The network is represented by an undirected simple graph G=(V,E) such that each node in the network corresponds to a vertex and each full-duplex link is represented by an undirected edge. Let N and M be the number of nodes and links respectively.Each node has its own unique ID, denoted by a capital letter A,B,C,D,E… etc as in Fig. 1.

Simple Embedded Ring (SER): The SER traverses each physical node exactly once, thus every physical node has one virtual node. The simple embedded ring forms a Buffer Insertion Ring (BIR). Buffer insertion is an access technique to a unidirectional ring network. On the receiving side of each link, there is a Link Buffer (LB), which can store at least one maximal size packet. A node can start a packet transmission at any time as long as its link buffer is empty. If the ring traffic arrives when the node is in the middle of a packet transmission, then the ring traffic will be stored in the link buffer, until this packet transmission is completed. The node cannot transmit anymore until the link buffer becomes idle again, i.e. a nonpreemptive priority is given to the ring traffic.

Tree Embeded Ring (TER): The physical layout of the network is assumed to be a tree and a ring is embedded over it by Euler tree traversal (Yener, *et al.*, 1994). All the links of the tree are ring links and are part of the Tree Embedded Ring (TER)(Yener, *et al.*, 1994). The main difference between SER and TER is that on TER a packet does not have to routed to its destination around the ring, instead it can make short-cuts toward its destination. Short-cuts are performed between virtual nodes that belong to the same physical node (when possible). The objective of the short-cuts is to decrease the distance between source and destination (along the embedded ring) as fast as possible, i.e., to minimize the number of links a packet should traverse from source to destination.

Virtual ring embeding and routing

Virtual ring embeding: The links of the bidirectional network are divided into two types i) ring links and ii) thread links. The ring links are part of the embedded ring and the thread link are all the other links. Virtual nodes can be created in a graph with the following restrictions.

- All nodes must be traversed minimum once.
- Any node can be selected as starting node.
- All nodes must be visited.
- Traversal must be complete.

There are three embedding structures. They are (1) a simple circuit that is called Simple Embedded Ring (SER), (2) a traversal ring on a tree that is called Tree Embedded Ring (TER) and (3) a traversal ring on a graph that is called Graph Embedded Ring (GER).In this paper we concentrate on Graph Embedded Ring (GER).

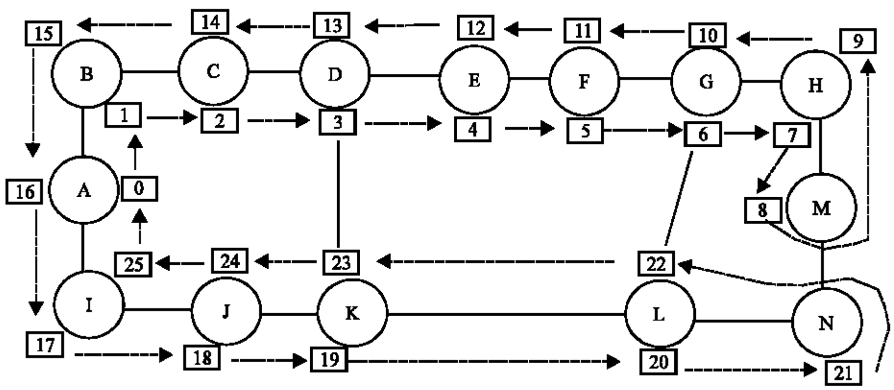

Fig. 2: A network topology with virtual ring

A virtual ring is embedded in a network by the proposed algorithm. Such a virtual ring is called the Graph Embedded Ring or GER and the links are called ring links. The virtual ring links are numbered sequentially from 0 to m-1.The number associated with each ring link constitutes a Virtual Node (VN) or a virtual address.Thus, m is the number of virtual nodes induced by the ring embedding (for example, in Fig. 2. m=26).The starting point can be chosen arbitrarily and the numbers are incremented by one each time a node is traversed.The ring should be closed i.e. ring link (m-1) should be connected to ring link 0(ring link 25 in Fig. 2). Thus the virtual nodes receive the embedding numbering 0,1,2…m-1.Therefore, a node that is traversed more than once is associated with more than one virtual node number. For example, in Fig. 2, node A has two virtual nodes 0 and 16.

A link, which is not included in the virtual ring, is called thread link. A thread link connects two virtual nodes, on two different (Physical) nodes, such that the distance between them, measured on the virtual embedded ring, is the minimum.Note that under this definition, each direction of a thread link may be associated with different virtual nodes.For example, the thread link from D to K, in Fig. 2, is connecting virtual nodes 23 and 19, but in the other direction, the thread from K to D is connecting virtual nodes 3 and 13.

Local-greedy distance measure: The distance measure in the original convergence routing algorithm is the number of hops to the destination computed as follows. Let m be the size of the virtual ring.To find the distance on the virtual ring from virtual node u to virtual node v, the following simple calculation is performed.

$$DIST(u,v) = v - (u \bmod m) \quad (1)$$

Similarly, the distance between two (Physical) nodes is measured between the two virtual nodes that are closest to one another on the virtual embedded ring (similar to the thread definition).The distance on the ring from node U to node V is calculated as follows.

$$DIST(U,V) = \min_{\forall (u \in U, v \in V)} \{v - (u \bmod m)\} \quad (2)$$

For example, in Fig. 2, the distance from node G to node N is 11 [ie the minimum of { 21 – 10 (mod 26), 21-6 (mod 26)} An intermediate node U computes the number of hops from its virtual nodes to the virtual nodes of the destination node V. However, note that the distance computation at node u is local. This version of convergence routing is the Local-Greedy algorithm.

Convergence routing operations In convergence routing a packet should always be routed toward its destination by using virtual embedded ring as a global sense of direction. A packet enters the virtual embedded ring via the virtual node that is closest to the destination. The destination field in the packet header contains the destination virtual node that is closest to the source virtual node. The packet is routed such that the distance from its destination at the next virtual node is always less than the distance from the current one.Thus, the algorithm guarantees convergence to the destination in finite number of steps, which is a very important feature of a routing algorithm in a dynamic context

The default routing operation in convergence routing is simply to follow the virtual ring, which will guarantee that the packet will reach its destination. This simple method is, of course, not very efficient. Therefore, the routing mechanism at every intermediate node tries to decrease the distance to the destination-as much as possible by the following two non-default routing methods.

- Short-cut via a virtual node on the same node that is "closer" to the destination node.
- Jump on a thread link from a virtual node (on one node) to virtual node (on a neighbour node) that is "closer" to the destination.

Example: Suppose that in Fig. 2, a packet arrives at 3 and its destination is 20 (node L), it may shortcut to virtual node 13 or jump via a thread link to 19.This kind of switching is possible only if the next ring link, which is reachable by the non-default operations, is available.

A link is defined to be available if it is (i) idle (ii) not marked by another packet as its default link.A link is marked by a packet if it is the default route for that packet, in order to avoid congestion and loss (Bertsekas, 1982).

Global sense of direction with Directed Acyclic Graph (DAG): The assignment of virtual address to the nodes according to the virtual ring embedding results in a linear ordering of the nodes. The linear ordering of nodes is used for global sense of direction and all of the routing operations by using a Direct Acyclic Graph (DAG). DAG-based representation enables us to model and to formulate convergence routing precisely.

The Directed Acyclic Graph (DAG) for source i and destination k, denoted by DAG_i^k to be the union of all the forward paths from i to k.Now, let us demonstrate with an example how convergence routing operates on a DAG.

Suppose that node G wants to send a packet to node N as in Fig. 2. Then according to Equation (2), DIST (G,N) = DIST (6,21)and therefore, the packet will enter the virtualring via 6 for destination 21.The resulting DAG is shown in Fig. 3. The different kinds of links are shown in Fig. 3.

- Ring links is displayed as bold arrows. These links form a straight line from 6 to 21 and show clearly the global direction imposed by the virtual ring embedding.
- Shortcut links is displayed as dotted arrows.A shortcut link (i,j) indicates that a shortcut routing operation is possible from virtual node i to j.

Example: (6,11) (5,12) indicates the possible short cut from 6 to 11 via 10 and 5 to 12 via 11, respectively.

- Jump links is displayed as normal arrows.A jump link indicates a possible jump from virtual node i to virtual node j.

Example: (8,21) indicates a possible jump from 8 to 21.

Notice that the ring and jump links are existing links in the original network topology, while the shortcut links are artificial.Thus when we say that a packet is routed on the shortcut link (6,11), in Fig.3, we really mean that there is a shortcut to 11 via 10 and the packet is actually routed on the link (10,11).

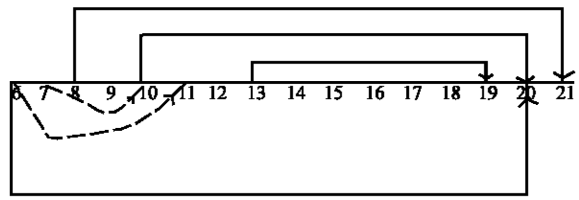

Fig. 3: Directed acyclic graph for virtual node 6to 21

Table 1: Distance (in hops) from source node to destination node for local greedy algorithm and proposed algorithm

		Number of hops	
Source node	Destination node	Local greedy alg	Proposed alg
E	K	7	2
E	L	8	3
E	N	9	4
E	M	4	4
F	K	8	3
F	L	9	2
F	N	10	3
F	M	3	3
G	K	9	2
G	L	10	1
G	N	11	2
G	M	2	2
H	I	8	5
H	J	9	4
H	K	10	3
H	L	11	2
H	N	12	2
H	M	1	1

Algorithm to create virtual nodes in a network

Step-1: Input-the given network in adjency matrix form, number of physical node and starting node.

Step-2: Set the starting node to current node.

Step-3: Find adjacent nodes of current node that are possible to visit.

Step-4: Set the selected node to current node.

Step-5: Traverse the current node.

Step-6: If all nodes are not traversed-go to step-3.

Step-7: Display the virtual node matrix.

Erformance analysis of the algorithm: The performance measure used in our experiments is to find a path with minimum number of links a packet should traverse from source to destination, so that it minimizes the average packet delay. All our experiments show better result than local-greedy routing. It is simple to show that the performance of convergence routing with the Local-Greedy routing is not necessarily the best one since it considers only the local traffic conditions. Distance (in hops) from source node to destination node for local greedy algorithm and proposed algorithm are given in Table 1.

CONCLUSION

The Local-Greedy routing algorithm has certain deficiencies due to its limited use of information about the traffic load conditions across the network during the routing process.As a remedy, Virtual Node Algorithm is proposed.Virtual Node is embedded into the network by the proposed algorithm which provides the global sense of direction in convergence routing. A series of experiments were performed on various networks. In all the experiments the proposed algorithm routed the packets to its destination with minimum number of hops than local greedy algorithm, which minimizes the delay in the network.

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