Implementation and Performance Evaluation of Packet Forwarding based on VS Routing Scheme

Prof. Rajesh S. Bansode[1] Mr.Tarun A. Kachhwah[2] Mr.Vishal S. Shethiya[3]
[1, 2, 3] Department of Information & Technology (IT)
[1, 2, 3]Thakur College of Engineering and Technology, Mumbai – 400101, India

Abstract---Highly scalable dynamic routing scheme can be helpful in reducing congestion hot-spots, balancing network loads, fast failure recovery and improve resource utilization for a small networks with just 25 nodes to large networks with over 1000 nodes having arbitrary connection topologies. Many dynamic routing schemes have been put forward in the recent past. The main issues in a dynamic routing algorithm are the scalability and the computational complexity involved taking into account the real time network conditions, the operational overhead and the stability of the algorithm. Along with this, the algorithm should also preserve the key properties of conventional routing algorithms like loop free routing, distributed route calculations, statistical multiplexing and consistency. A novel routing scheme based on Virtual Space (VS) configuration is presented here for use in high-speed packet networks. This paper presents a comprehensive treatment of the VS routing scheme, including its logical development, formulation, simulated performance analysis, and implementation. First, the VS embedding process transforms the network topology information into a multi-dimensional virtual space representation. The VS configuration of the network is a highly concise representation, which has excellent directionality property to enable simple geometric routing. Dynamic changes in link conditions and traffic loading states are expressed using link costs to enable fast adaptability and failure recovery. Thus, the VS routing scheme is highly scalable, dynamic, robust, and simple to implement. This paper presents an implementation scheme for constructing a VS routing. Domain that is compatible with IP networks. It describes routing and forwarding functionalities of VS domain and routing nodes. It further addresses applications of VS routing scheme to build overlay tools to enhance performance and functionality of existing networks. The existing protocols from the information exchange and scalability perspective.

Key words: routing, simulations, algorithm, scalability, network management

I. INTRODUCTION

Commonly used routing protocols can be categorized into two groups as, Distance-Vector algorithms (e.g. RIP, BGP), and Link-State algorithms (e.g. OSPF, CSPF, PNNI) In the former, each node maintains a distance-vector or a path-vector to reach every known destination node or subnet in the network in terms of the minimum number of hops or total cost of a packet to reach the destinations. In the distance- vector information is exchanged with the neighboring nodes and the routing entries are suitably updated leading to converged solutions. In the link-state protocols, each routing node broadcasts information about the links, which are directly connected to it to all other nodes in the network. Thus, each node can compute the optimum path, in terms of the least number of hops or least total cost, to every destination node by using Dijkstra's algorithm. Both the type of schemes rely on information about the network conditions to flow from the distant network nodes to any given node directly (link-state schemes)

Let us consider a partially-connected mesh network of N nodes with an average adjacency or connectivity of m. The total number of links in the network is E = mN/2, which becomes N (N-1)/2 for a fully-connected mesh. In a link-state algorithm, any changes in the condition of a single link would be broadcasted by the two adjacent nodes using link-state advertisements. The two broadcast messages traverse all the remaining links in the network in the forward direction, thus in total, mN messages are exchanged. In a fully-connected mesh network each link update leads to $O(N^2)$ messages, which is referred as an N-squared problem. The N-squared problem can be partly mitigated by using hierarchical networks to achieve $O(N^{4/3})$ scaling. This improvement is achieved by splitting the original network having N nodes into multiple administrative domains with reduced number of nodes in each. The routing updates can be periodic as well as event-driven such as, a link going down or coming up or changes in the link loading levels. Each update leads to recomputation and updating of routing entries at each node. The processing involved further increases with the size of the network. Thus, frequent updates lead to high consumption of resources in terms of CPU, memory, and bandwidth.

The network performance can be improved using VS routing to reduce congestion, improve resource utilization, and provide better end-to-end quality of service (QoS) support. Any dropped control packets may lead to a false interpretation as a loss of adjacency and lead to additional flooding of information and potentially an unstable situation. To improve scalability of the VS routing, use of higher priority for the control packets has been proposed. Presently, a typical core IP router may have look-up table entries in excess of 200,000. This makes the routing and forwarding tasks of the router rather complex and costly. As the network size and frequency of the dynamic updates increases, the routing information exchange becomes excessive. It leads to high overheads in terms of routing information exchange, processing, update, storage, and memory I/O. It may also lead to network stability problems. Thus, routing protocols have some major scalability and dynamic adaptability issues, which need to be addressed.

II. LOGICAL DEVELOPMENT OF VS ROUTING SCHEME

We start with a general observation about a typical network, that the dynamic changes in the network have two time-scales; a short time-scale of the order of milliseconds at which, a network node or link may go down or come back up or the links may undergo changes in traffic loading and a rather long time-scale of the order of days and months at which, new nodes or links are added or removed permanently. Thus, on a short time-scale the network topology, except for the status of the links and nodes, can be assumed to be quasi- static and any given link has two fixed nodes connected to it. The main advantage of this time-scale distinction is that the network information can be separated into quasi-static and dynamic parts. The quasi -static information need not be broadcasted or exchanged at the regular time intervals on a short time-scale. This cuts down on the redundant information exchange and processing.

In order to reduce information requirements further, the quasi-static network topology or connectivity information is expressed in the most compact form using the virtual space (VS) embedding. The resultant VS configuration is treated as fixed, known information to carry out dynamic routing on the short time-scale. Few minor changes in the quasi-static network topology can be absorbed in the current VS configuration. The dynamic information, in terms of the link or node status and traffic loading, is expressed using cost functions and updated on a regular short time interval (say, 10 or 25 milliseconds).

The most interesting property of the VS embedding is its directivity property that makes the VS configuration self-guiding at every node in the network. A directed VS distance from any node to a given destination in the VS configuration indicates available path options with the least or low number of hops. This enables simple geometric routing that is fast, simple, and efficient. It is similar to a planar map of a road-way network, where the directed distance vector to the destination indicates possible path options with short distances. However, the VS embedding requires multi-dimensional (say, 6-D) virtual space to achieve the directivity property. Thus, the VS configuration can be considered as a multi- dimensional map of the network that is compatible with the geometric routing. The most significant advantage of the directivity property of VS configuration is the total elimination of large routing tables and the associated tasks of routing information exchange, processing, route updates, storage, and memory I/O. Just like a map, the VS configuration also provides a notion of locality in terms of hop distances and not the physical distances. The locality defines the region of influence for any dynamic event in the network.

One important point that should be emphasized here is that the VS configuration has no relation to the physical topology or geography of the network. Thus, it is not similar to the variants of geographic or GPS routing schemes proposed in wireless ad-hoc or sensor networks [8 - 10], which are based on 2-D or 3-D topologies. In wireless environment the geographic locations have significant bearing on the routing decisions. Those assumptions are not valid for wired networks. The VS embedding does not make any such assumption to achieve its directivity.

An often-used term ‘Distance-Vector algorithm’ is also suggestive of the directivity property, wherein the least number of hops to reach any destination indicates the distance and the next-hop node along that path indicating the direction. However, the apparent similarity in the intent and method ends there, since the VS embedding achieves network representation that can exploit the directivity property in a ‘true sense’. A distance vector from any source to a destination in the VS configuration indicates the available path choices with the least or low number of hops. Thus, the VS configuration enables simple geometric routing based on its directivity. Configurations of a multi-body system with one central node and four neighbors in a node with a connectivity of four could have all links at an angle of only 90º in a 2-D structure, but the angle is about 110º in a 3-D structure as shown in Fig. 1. Similarly, a node with connectivity of five could have the connecting links at 72º, 90º, and 110º for the 2-D, 3-D, and 4 -D structures, respectively. Thus, the directivity property of the network can be improved by using virtual space with higher dimensionality. For common network topologies with large number of nodes having average connectivity of 4 to 6, the VS embedding typically uses virtual space with the dimensionality (N_d) of about 6 or 8.

We normalize the VS distances by choosing the length of each link segment to be approximately one unit. The directivity property of the network configuration can be ensured by satisfying two simple geometric conditions simultaneously; the first, the nodes that are directly connected should have one unit distance between them and the second, the nodes that are not directly connected should have a distance equal to the least number of hops between the two nodes. However, it is not possible to satisfy them exactly for all the node pairs in the network.

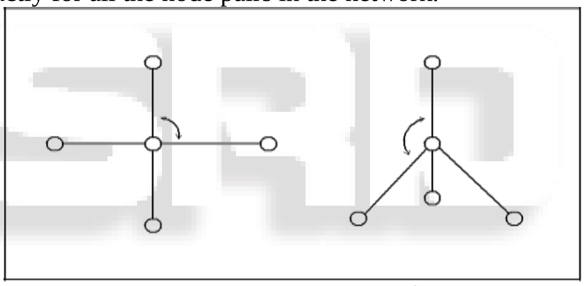

Fig.1 :(a) 2-D and (b) 3-D forms

III. VIRTUAL SPACE EMBEDDING

A major step in the virtual space routing is to first embed the network topology information into a VS configuration in geometric form. The VS embedding involves evolution of an equivalent multi-body configuration of the network under a set of pre-defined VS forces in the multi- dimensional virtual space. The final VS configuration is self-directing such that, a directed VS distance to a given destination node indicates the available path options with the least (or low) number of hops through the network. The definitions of the VS forces follows from the geometrical considerations mentioned above.

An example of the transformation of a planar 12-node arbitrary network into a 3-D VS configuration is shown. It shows that the nodes get rearranged to reflect the network topology information. The nodes 0 and 9 move apart, reflecting the least-hop distance between them. As an example of the directivity property, the directed distance vector from node 11 to node 5 in the VS configuration indicates the least-hop path given by 0-9-11-5. It also indicates other paths with one extra hop given by 0-1-2-3-4-5, 0-10-11-5, and 0-8-7-6. This enables the VS configuration to support simple geometric routing with multi-path option.

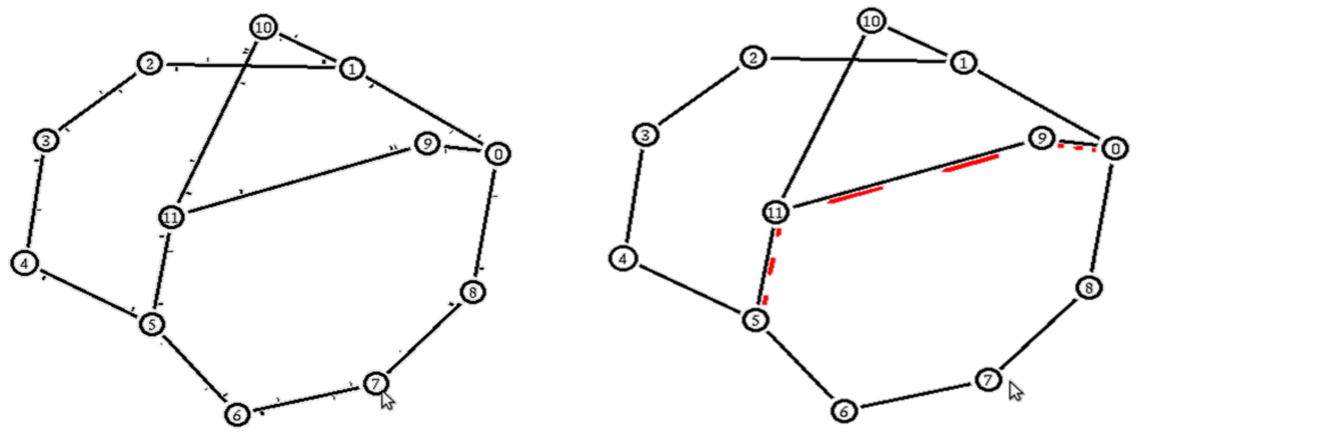

Fig.2: -node network topology with numbered nodes showing (a) the original planar network topology & (b) the final 3-D virtual space configuration with packet transferring scheme

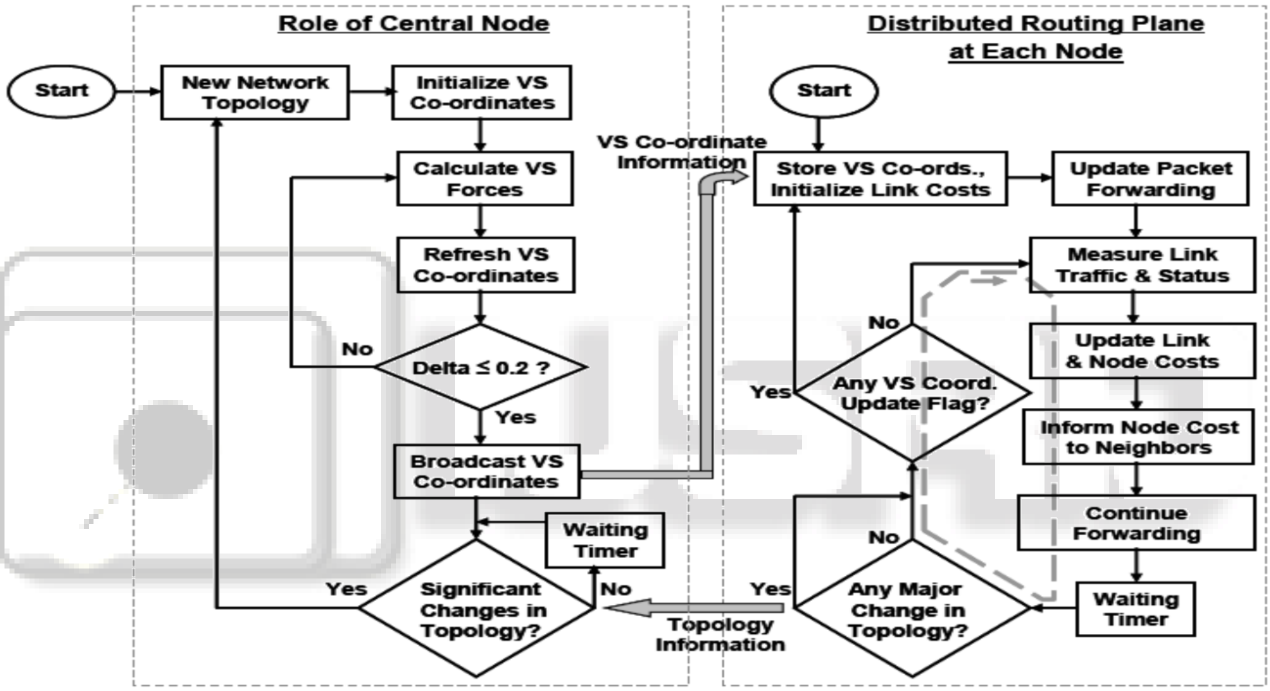

Fig. 3: Routing plane functionality in the VS routing scheme showing roles of the central node and distributed routing nodes

IV. SUMMERY & DISCUSSION

VS routing scheme is based on a very concise representation of the network topology information using multi-dimensional Virtual Space configuration. The VS embedding involves evolution of equivalent multi-body representation of network topology using an iterative scheme. It uses optimized VS force definitions to enhance directivity property of the VS configuration. The logical development of the evolution process is consistent with many natural systems that evolve using multi-body interaction and energy minimization. The resultant VS configuration is highly directional to enable simple geometric routing. It also has a sense of locality that is used to define a region of influence for the dynamic information. The formulation of VS routing is based on very simple and intuitive navigational ideas. The combination of these ideas leads to a new paradigm-shift in the way the routing information is expressed and processed. Hence, the VS algorithm has a very attractive scaling property of order nearly *log* (N).

One limitation of VS routing is that of being a heuristic algorithm and the performance results are based on extensive simulations. It does not promise 100% packet delivery under arbitrary conditions, but comes very close to that with over 99% throughput.

However, the VS routing scheme exhibits excellent dynamic performance to score over the common routing protocols. Interplay between the dynamic routing information exchange and network response can be viewed as a controls problem with feedbacks. In common routing protocols the feedback is received from all distant nodes leading to a large set of coupled equations and information delays. When the high level of coupling and delays are combined together, it can lead to long convergence times and instability problems. These are exhibited by out-dated routes, forwarding loops, route flaps, load oscillations, or system crash due to processing overloads. In contrast, the VS routing has only limited and fast information exchange, since the dynamic information is utilized locally and updated more frequently. Thus, it adapts quickly to dynamic situations such as link failures or loading changes.

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