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A Simple Model for Virtual Ring Routing

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***Abstract*—In this paper, we present a theoretical model of virtual ring routing to describe the routing mechanism and the impact on the routing performance. The identifier is a flat label to identify the node without any network location information. By routing directly on nodes' identifiers, any node in the ring can be reached. For routing and naming are tightly integrated, the node identifier will influence the routing efficiency. Through analyzing our theoretical model, for each node, maintaining a long path to its virtual neighbor can shorten the virtual ring routes. Likewise, the experimental results show that different identifier assignments indeed have an impact on the virtual ring routing path under the same size network. Furthermore, our theoretical model fit the process of virtual ring routing well, and provides the insight for us to improve the virtual ring routing..**

***Index Terms*—Model, Virtual Ring Routing, Naming, Performance**

I. Introduction

Virtual Ring Routing (VRR)[1] is a new network routing protocol with a unique design inspired by Distributed Hash Table (DHT) overlay like Chord, CAN, Pastry[2,3,4]. In VRR, nodes are organized into a virtual ring ordered by their identifiers and each node maintains a small number of routing paths to its virtual neighbors whose identifiers are numerically closest to it in the ring. VRR uses only location independent identifiers to route without flooding on the network. ROFL is aiming to route directly on host identities by VRR, and considers two situations routing in the intradomain and interdomain[5]. For ROFL names host as granularity, it is hard to implement for its scalability and efficiency. Our previous work [6], we utilize this VRR approach to provide a backup route for Border gateway protocol (BGP)[7], and then pay more attention to analyze the effectiveness of VRR, we find that different flat-name assignment policies have a great impact on it from the simulations. This paper presents a theoretical model of VRR to analyze the influence from identifier to its performance. Using this model, how many hops in the ring to reach a destination can be calculated according to numerical distance between identifiers of two nodes. We can find that the path length between virtual neighbors is a parameter to impact the hops in the ring. At the same time, the experimental results show that theoretical results of our model fit it very well. Therefore, our model would be useful in predicting and estimating the VRR performance in large network. It would infer us how to choose the identifier for achieving the higher efficiency of VRR.

II. Virtual Ring Routing

The essential of VRR is by each node just being in charge of maintaining a route to one or several other nodes, rather than the whole network topology information, and then routing by identifier ensures each node reachable within finite steps. Figure 1 shows a general case, each node has a unique identifier, and selects one or several nodes as its virtual neighbors according to its identifier. The nodes along a virtual neighbor path also keep track of this path in their routing table. In table 1, we illustrate the virtual ring routing table for the node with identifier 6. The first two entries are the paths to 6's virtual neighbors, the third entry is for the virtual neighbor paths that happen to be routed through 6, and the last three are paths to 6's physical neighbors. For node 6 is an endpoint in these paths, the identifier of the next hop towards the node is null.

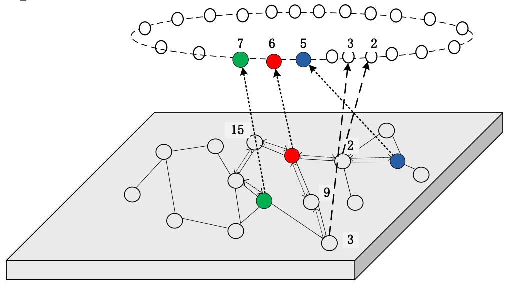

Figure 1 Example of virtual ring SMR

TABLE I.
The Sample Routing Table for the Node with Identifier 6

$Endpoint_A$	$Endpoint_B$	$Nexthop_A$	$Nexthop_B$
6	5	null	2
6	7	null	15
2	3	2	9
6	2	null	2
6	9	null	9
6	15	null	15

VRR uses these routing tables to route packets between any pair of nodes in the network: a packet is forwarded to the next hop towards the path endpoint whose identifier is numerically closest to the destination.

Actually, virtual ring is defined by the virtual neighborhood relations over the identifier of each node. According to the identifier, each node maintains a route

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to its virtual neighbor, and then it is seemed that a virtual ring is formed. By choosing which nodes to become its virtual neighbors, the identifier assignment is a way to pair up virtual neighbor.

III. NETWORK MODEL

This section describes the theoretical model of virtual ring routing. We suppose here that each node maintains ***one*** path to its virtual neighbor and the average path length is ***p***. For simplicity, we assume that the physical neighbors are not included in its routing table firstly, and the total number of routing table entries in an ***n*** node network is ***np***. Therefore, each node will have on average ***p*** entries in its routing table. The probability that a node which is selected randomly and uniformly has a path to a random pair of virtual neighbors in its routing table is ***p/n***. We define L(***s***,***d***) is the hops in the ring from source ***s*** to destination ***d***, just is how many the virtual neighbor paths with the different endpoints are passed by before arrival at destination, and the actual routing path length in the physical network is not more than L(***s,d***)****p***. ||***d-s***|| denotes the numerical distance between two nodes' identifiers. In the network model shown in Fig. 2, (a) shows that there is a path direct to destination ***d*** in source routing table, just as the hops from the node with identifier 6 to the node with identifier 2 or 3 in the table 1. For ***s*** gets to ***d*** through the one virtual neighbor path with the endpoint ***d***, we get the probability P(L(***s,d***)=1)= ***p/n***, for the random topology, the identifiers are mapping to a virtual ring randomly, the probabilities that a node can reach the other random nodes by one hop in the ring are same. So we can get P(L(***s,d***)=1| ||***d-s***||=k)= ***p/n***, k⩾2 (1)

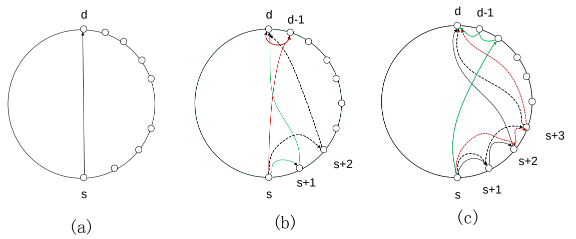

Figure 2 The model of network

(b) shows that a packet can reach the destination after two hops in the ring. There are a total of ||***d-s***||-2 cases, the first case is that ***s*** gets to ***d*** through the two virtual neighbor paths of ***s+1*** and ***d***, the probability is $(1-p/n)^{\|d-s\|-1}*(p/n)*p$ that there is no entry whose numerical distance to the identifier of ***d*** is closer than that of ***s+1*** in ***s***' routing table and ***d***' virtual neighbor path passes by one of nodes on the virtual neighbor path between ***s*** and ***s+1***. For the average virtual neighbor path is ***p***, the probability that one of the ***p*** nodes can be on the ***d***' virtual neighbor path is (***p/n***)****p***. The second case is that ***s*** gets to ***d*** through the two virtual neighbor paths of ***s+2*** and ***d***, the probability is $(1-p/n)^{\|d-s\|-2}*(p/n)*(p/n)*p$ that there is no entry whose numerical distance to the identifier of ***d*** is closer than that of ***s+2*** in ***s***' routing table as the virtual neighbor path between ***s+1*** and ***s+2*** passes by ***s***, and then ***d***' virtual neighbor path passes by one of nodes on the ***s+2***' virtual neighbor path. The rest case can be deduced by analogy. The last case is that ***s*** gets to ***d*** through the two virtual neighbor paths of ***d-1*** and ***d***, the probability is $(1-p/n)*(p/n)$ that ***d***' virtual neighbor path does not pass by ***s*** and ***d-1***' virtual neighbor path passes by ***s***. the summation of the probability in all cases is:

$$\begin{aligned}&P(L(s,\ d)=2)=(1-p/n)^{\|d-s\|-1}*(p/n)*p\\&+(1-p/n)^{\|d-s\|-2}*(p/n)*(p/n)*p\\&+\ldots+(1-p/n)*(p/n)\end{aligned}$$

where ||d-s||⩾3.

The simplification as follows:

$$P(L(s,d)=2)=(1-p/n)^2*(p/n)*p+(1-p/n)*p/n$$

The expression indicates that P(L(s, d)=2) has no relation with ||d-s|| when ||d-s||⩾3. This also explains the probabilities that a node can reach the other random nodes by two hops in the ring are same. So we can infer P(L(s, d)=2| ||d-s||=k)= P(L(s, d)=2), k⩾3.

(c) shows that a packet can reach the destination after three hops in the ring, probability is

$$\begin{aligned}&P(L(s,\ d)=3)=(1-p/n)^{\|d-s\|-1}*[(1-(p/n)*p)^{\|d-s\|-2}*(p/n)*p\\&+(1-(p/n)*p)^{\|d-s\|-3}*(p/n)*p*(p/n)*p+\ldots\\&+(1-(p/n)*p)*(p/n)*p]\\&+(1-p/n)^{\|d-s\|-2}*(p/n)*\\&[(1-(p/n)*p)^{\|d-s\|-3}*(p/n)*p\\&+(1-(p/n)*p)^{\|d-s\|-4}*(p/n)*p*(p/n)*p+\ldots\\&+(1-(p/n)*p)*(p/n)*p]\\&+\ldots+(1-p/n)^3*(p/n)*((1-(p/n)*p)^2*(p/n)*p\\&+(1-(p/n)*p)*(p/n)*p)\\&+(1-p/n)^2*(p/n)*(1-(p/n)*p)\end{aligned}$$

where ||d-s||⩾4.

The simplification as follows:

$$\begin{aligned}&P(L(s,d)=3)=(1-p/n)^3(1-(p/n)*p)^2*(p/n)*p\\&+(1-p/n)^3(1-(p/n)*p)*(p/n)*p\\&+(1-p/n)^2(1-(p/n)*p)*p/n\end{aligned}$$

the expression also indicates that P(L(s, d)=3) has no relation with ||d-s|| when ||d-s||⩾4. This also explains the probabilities that a node can reach the other random nodes by three hops in the ring are same. So we can infer P(L(s, d)=3| ||d-s||=k)= P(L(s, d)=3), k⩾4.

In the same way, we can work out at P(L(s, d)=4), P(L(s, d)=5) and so on.

And then we calculate some particular probabilities

P(L(s, d)=k| ||d-s||=k) that there is no shortcut to destination and the hops in the ring is the longest.

$$\begin{aligned}&P(L(s,\ d)=k\,|\,\|d-s\|=k)\\&=(1-p/n)^{\|d-s\|-1}*(1-(p/n)*p)^{\|d-s\|-2}\ldots*(1-(p/n)*p)\\&=(1-p/n)^{\|d-s\|-1}*(1-(p/n)*p)^{(\|d-s\|-1)(\|d-s\|-2)/2}\end{aligned}$$

Where ||d-s||⩾2. Obviously, P(L(s, d)=1| ||d-s||=1)=1.

We attempt to use these particular probabilities to calculate all the other probabilities.

P(L(s, d)=1| ||d-s||=2)=1- P(L(s, d)=2| ||d-s||=2);

P(L(s, d)=1| ||d-s||=3)= P(L(s, d)=1| ||d-s||=2) as in formula (1);

So P(L(s, d)=1| ||d-s||=3)= 1- P(L(s, d)=2| ||d-s||=2);

P(L(s, d)=2| ||d-s||=3)=1- P(L(s, d)=1| ||d-s||=3)- P(L(s, d)=3| ||d-s||=3)

= P(L(s, d)=2| ||d-s||=2)- P(L(s, d)=3| ||d-s||=3);

Similarly, P(L(s, d)=3| ||d-s||=4)=1- P(L(s, d)=1| ||d-s||=4)- P(L(s, d)=2| ||d-s||=4)- P(L(s, d)=4| ||d-s||=4)= P(L(s, d)=3| ||d-s||=3)- P(L(s, d)=4| ||d-s||=4)

We can prove that for any node s and d, P(L(s, d)=m| ||d-s||=k)= P(L(s, d)=m| ||d-s||=m)- P(L(s, d)=m+1| ||d-s||=m+1) (k>m);

Therefore, average L(s, d) is

$$\overline{L(\| d-s \|)} = \sum_{k=1}^{\|d-s\|} k * P(L(s, d) = k \mid \| d - s \|)$$

$$= 1 + \sum_{k=2}^{\|d-s\|} (1 - p/n)^{k-1} (1 - (p/n) * p)^{(k-1)(k-2)/2}$$

In the above formula, ***n*** is the number of nodes in the network, with the size of a network increasing, average hops between two nodes will increase. ***p*** is the average path length between virtual neighbors, for each node, if the path to its virtual neighbor is longer, correspondingly, the total number of routing table entries will increase, therefore, average hops in the ring decrease theoretically. In next section, we discuss whether this model reflects experimental results correctly.

Ⅳ. EVALUATION

The major focus of the paper is to model the VRR and analyze its performance. We compare the model with the real condition. Experimental parameters and evaluation are given below.

We simulate four random topological graphs with the numbers of nodes 200 and 1000. We discuss two conditions: under the different size network maintaining the same average path length between virtual neighbors and under the same size network maintaining the different average path length between virtual neighbors. Figure 3, 4 are the first condition and figure 5, 6 are the second condition. From figure 3, the theoretical result fits the experimental result very well, and in the network with 200 nodes short hops have higher probability than that in the network with 1000 nodes. This probability distribution also reflects the result in figure 4 that the hops in the ring increase with the growth of the number of nodes in the network under the condition of the same average virtual neighbor path length. Figure 4 also shows that hops in the ring tend to stable with the numerical distance of identifiers increasing just as the theoretical result of our model. Figure 5, 6 describe the second condition in the network with 1000 nodes that longer average path length between virtual neighbors can bring more routing information to shorten the hops in the ring. Contrary results were obtained in reference [6] that long virtual neighbor path can not reduce the hops in the ring for the topology of network is real AS-level rather than a random graph.

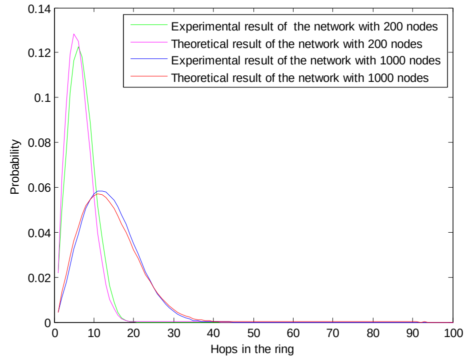

Figure 3. The probability distribution of hops in the ring under the different size network

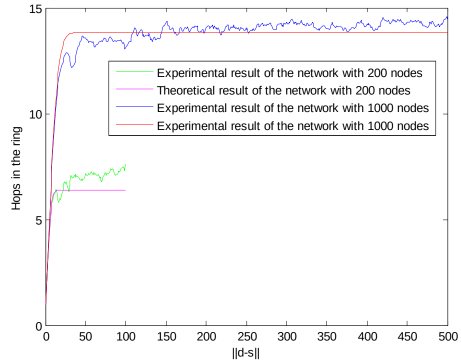

Figure 4. Average hops in the ring for numerical distance of identifiers under the different size network

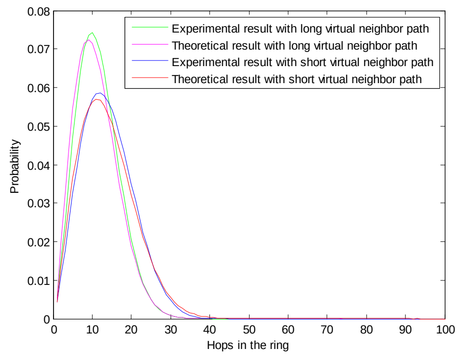

Figure 5. The probability distribution of hops in the ring under the same size network maintaining the different average path length between virtual neighbors

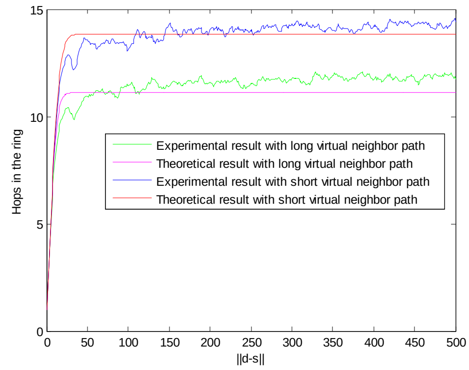

Figure 6. Average hops in the ring for numerical distance of identifiers under the same size network maintaining the different average path length between virtual neighbors

V. CONCLUSION

Based on virtual ring routing, we take an analysis of modeling this routing mechanism. And then, we evaluate this model by comparing the experimental results with the theoretical results which give a very good fit to it. The identifier of each node has a certain impact on the performance of virtual ring routing as explained by our theoretical model. This model can estimate the average hops in the network, and guide us how to improve VRR. A natural next step is to consider adding the physical neighbors to our model.

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