Approximation Method for Extended Routing with Clue (ERC) Protocol over Meshed Networks

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Abstract—*This paper compares the performance of the distributed IP lookup with conventional IP lookup process by applying to expandable meshed network. We simulated up to three meshed nodes network. Then, the performance matrices such as throughput, mean queue length (MQL) and utilization factor, are collected in order to explain the effect of expanding network (scalability) versus the performance of both networks. Results indicate that RC network outperforms vis-à-vis the conventional IP network in terms of expanding the network size. Moreover, the performance of the RC network is not dropping much compared to those of the IP network. This can be proven by extending the "O" notation as of a packet holding time, applying for both RC network and IP network. From mathematical point of view, the "O" notation as of time in packet holding for both networks will be derived. The calculations obtained from the notation are relevant to the simulation results. Furthermore, an approximation method is introduced. Results from the approximation method are close to results from simulation.*

Index Terms—*IP Routing, Routing with a Clue, Distributed IP Lookup, Mesh Topology and Extended RC.*

1. Introduction

ROUTING with a Clue[1] is the newly evolving routing technology introduced in the new millennium. Applying the distributed IP lookup process, the technique can reduce the excessive time used in redundant IP lookup for each node. Routing with a Clue utilizes a small overhead unit called "a clue" to transmit the IP lookup parameters from the current node to the next-hop node. The next-hop node learned from the clue shows where to start its lookup processes. Distributed IP lookup was already compared with the label switching process in Multiprotocol Label Switching (MPLS) [2], [15]. The two techniques share similar concept in adding a small unit, a label in MPLS and a clue in distributed IP lookup, onto the packet header to help routing the packet to the destination.

In this paper, an overview will be firstly introduced in section 2. The simulation will be briefly cited in section 3. Results from simulation are shown in section 4. An approximation method and the calculation are discussed in section 5. Section 6 will focus on the comparison between results from approximation and results from simulation. Conclusion is written in section 7.

2. Background

There are several directions to improve the throughput of routing packets from source to destination. For example, new hardware may be developed to increase forwarding interval [11] and IP lookup process [14], [16], parallel processing may be applied to process IP forwarding [10], new data structures may be used to store and manipulate the IP prefixes [6], [7], [9], [12], and new searching methodology [13] and algorithms [17] may be invented in order to process the packet faster. However, IP network is widely used and accepted worldwide. The new technique invented must be compatible with the conventional IP network.

Distributed IP lookup [1] is the extension of IP routing by adding 5 bits overhead into IPv4 packet [3]. The 5-bit clue is the encoded prefix of the packet destination address. The clue is used to acknowledge the next hop router where the router should begin searching. All prefixes are stored in a Trie [1] or Patricia data structure. The root of the tree represents the empty string. Each edge going to the left from a vertex represents 0, and an edge going to the right represents 1. Not all the vertices in the tree represent prefixes. The ones that represent prefix are specially marked. All the leaves of a trie are marked because those leaves that are not marked to be the prefix must be removed from the system.

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Traditional IP lookup is performed by scanning the destination address bit by bit and matching it along the path of a trie. The computational cost for IP lookup is O(log L) where L is an IP address length [4],[5].

In this paper, distributed and conventional IP lookup processes are firstly introduced then compared in the three different mesh networks. We applied a mesh network of 4 nodes, then, we cascaded another mesh network with an additional mesh consisting of 2 nodes each.

3. *Simulation Model*

In this paper, we simulate Routing with a Clue network and conventional IP network by utilizing the model as shown in figure 1. Only the first mesh consists of four nodes then another two meshes (consisting 2 nodes each) are attached to the first mesh. Each link has the maximum capacity limit to 1 Mbps. As the traditional RC network, at each node the packet holding time is next to zero and can be neglected. An extended RC (ERC) network with inclusive packet holding time will be discussed in section 4.

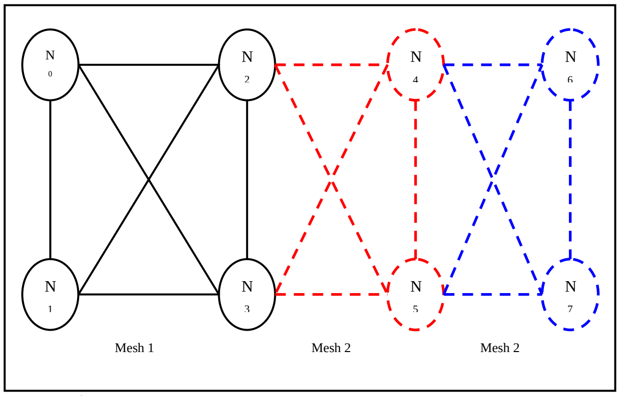

Fig. 1. Simulation model.

3.1 *Input Traffic*

We varied the input data rates for the simulation into several rates ranging from 500 kbps to 2 Mbps. The arrival process of the input traffic follows Poisson distribution. [2], [6].

3.2 *Queue*

All queues in front of each node found in this paper are assumed to be of First-In-First-Out (FIFO) discipline. Both queue capacity and the waiting time in queue are unlimited.

3.3 *Packet Holding Time*

The binary search is applied to the IP lookup [4] process resulting in the computational cost of O(N*log L) steps where L is the IP address length and N is number of prefixes used by hash tables. However, in distributed IP lookup, the processes are distributed to each node along the path then only O(log L) computational cost will become. Therefore, in ERC network, this packet holding time O(log L) is included in the account.

4. *Simulation Results*

4.1 *One Mesh*

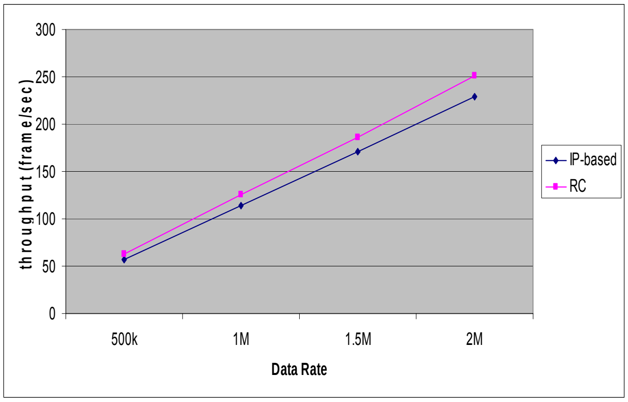

Fig. 2. Throughputs for 1 mesh.

From figure 2, the throughput of RC network is outnumbered by that of the conventional IP network in every input data rate. This is because the IP lookup process has been distributed to every node along the path and has to be repeatedly performed at every single node. Since this IP process repetition will not affect throughputs of both networks much, there will be no significant differences while the number of nodes is small as well as at low input data rates.

4.2 *Two Meshes*

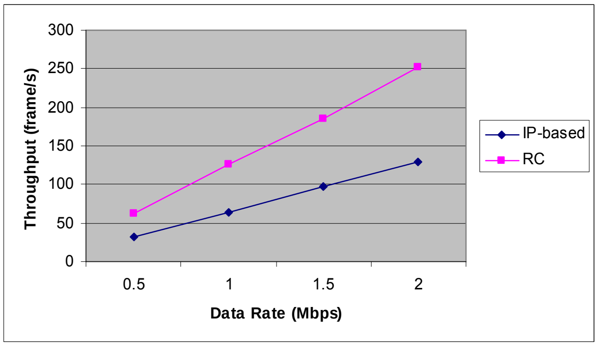

Fig. 3. Throughputs for 2 meshes.

In the two-mesh network, the difference between the throughputs of RC and IP networks can be observed more obviously than in one mesh network as shown in figure 3. As the node is increased, the throughput of IP network dropped, but RC network still maintained the level of its throughput to remain unchanged from the one mesh network. The reason is because RC network's performance relies only on address length, but for conventional IP network's performance relies on both the address-length and numbers of prefixes. In the two-mesh network, increase in number of nodes results the increasing of prefixes in data transmission.

4.3 *Three Meshes*

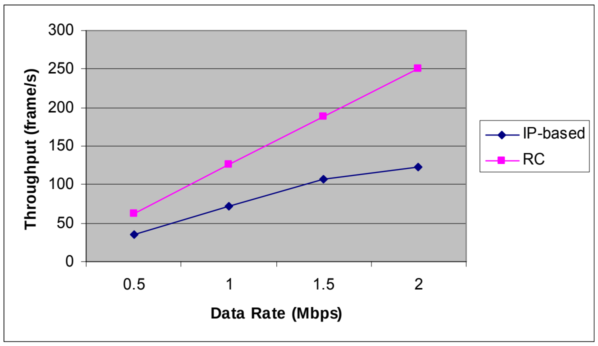

Fig. 4. Throughputs for 3 meshes.

The results from every parameter in every data rates and every node still indicate that distributed IP lookup outperforms compared to conventional IP lookup. RC throughputs are distinctly higher than IP. In the three-mesh network, the increasing number of nodes has a major impact on the performance of conventional IP network. The throughputs of IP network dropped dramatically because of the growing numbers of prefixes, while it has no effect on the RC network's performance. From figure 4, RC throughputs remain unchanged compared to those results from one-mesh and two-mesh networks.

5. APPROXIMATION METHOD

1.

In the previous section, the simulation of two address lookup techniques has been investigated. The results of simulation illustrate the difference of the two techniques. Several parameters have been carried out from the simulation program. However, to develop, to use, and to learn how to use the simulation programs are time-consuming processes. As the simulation is complicated and resource-consuming process, an approximation [18] tool can be an easy process that is less time-consuming and utilizes small numbers of calculation or computing process. The approximation method then will be introduced in this section.

Each node in the model as shown in figure 1 will be assumed to accommodate an input as Poisson arrival process.

$$f(x) = \frac{1}{x!}\lambda^x e^{-\lambda}, \quad x=1,2,3\ldots \quad (1)$$

where λ is a mean arrival time. In the simulation, input data rate λ will be ranging from 0.5 Mbps up to the capacity of the network 2 Mbps. Another assumption is based upon the service distribution in each node. Here the Erlang distribution is employed.

$$g(x) = \frac{\mu^n x^{n-1} e^{-\mu x}}{(n-1)!} \quad (2)$$

where x=1,2,3…and n is a positive integer.

In the simulation, μ will be ranging by the cost O(N log L), where N is total number of prefixes used by the forwarding table and L is the address length.

From the assumption of input (equation 1) arrival process and the service rate (equation 2), mean queue length (MQL_0) at the very first node can be estimated by

$$MQL_0 = \frac{\lambda^2 E[X^2]}{2(1-\lambda E[X])}. \quad (3)$$

Note that an output from a particular node will proceed to next node then becomes an input arrival process to next adjacent node.

$$MQL_k = \frac{\lambda_k^{\,2} E[X^2]}{2(1-\lambda_k E[X])}. \quad (4)$$

Similarly, utilization factor (ρ) at node k can be approximated by

$$\rho_k = \frac{\lambda_k}{\mu_k}. \quad (5)$$

Finally, throughput (THRU) at node k can be computed by

$$THRU_k = \lambda_k (1-E(T_k)), \quad (6)$$

where $E(T_k)$ is an average time T_k that IP frames reside in node k.

The iterative computation of each node's (k=0,1,2,…,k-1) performance measures (MQL_k, UTILIZATION(λ_k) and THROUGHPUT$_k$) using equation 1-6 has been developed. The node-by-node estimation is decomposed based upon the above calculation formulae. Algorithm used for this iterative computation is listed in figure 5. Results from approximation method by altering number of nodes (mesh) are then compared vis-à-vis simulation results. It can be seen clearly that approximation results are outperforming in the line of simulation as shown in figure 6.

```
/************ALGORITHM************/

BEGIN   /*** Use formulae to compute
             performance measures for
             each node in meshed network ***/
    FOR n = 0 TO k-1 DO /*** k nodes ***/
     Compute mean queue length MQLn
     Compute utilization factor UTILn
     Compute throughput THRUn

    END FOR

END
/***** END OF ALGORITHM **********/
```

Fig. 5: Algorithm of approximation method.

The advantages of employing the approximation method are not only time consuming, but also involve computational cost. The approximation technique needs least computational cost because the output parameters can be iteratively computed by mathematic functions. In some cases, the approximation method may give an enormously different result due to a bottleneck situation (ρ_k is approaching 1). Unfortunately the approximation method will not be a useful tool for the case as such. It is also clearly seen that if the percentage of error between approximation and simulation can fall in the range of 10 percent then the approximation results will be very similar.

The approximation method will be applied for the distributed IP lookup technique introduced in the previous section, and will be compared to results from the simulation program. From our simulation model, we will work out the computational cost for both techniques, and calculate the percentage of error.

6. Comparisons

In this section, we will investigate the approximation and simulation results applying to the extended Routing with a Clue (ERC) network. Here the packet holding time is taken into account. The experiments are based on one- mesh to three-mesh network, and varying the data rates from 500 kbps to 2 Mbps.

6.1 One Mesh

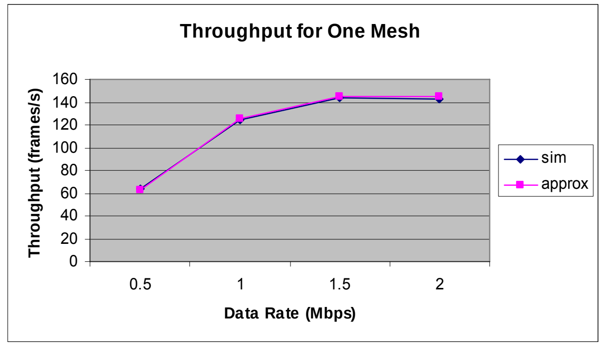

Fig. 6. Throughputs for 1 mesh.

From figure 6, we observe that approximation throughputs are very close to the simulation results. With the percentage of error shown in table 1, the approximation results error ranges from 0.22-1.7% which is very small compared to the simulation results.

Table 1. Throughputs Percentage of Error.

Data Rate (Mbps)	One Mesh Error (%)	Two Meshes Error (%)	Three Meshes Error (%)
0.5	**1.7**	**0.19**	**-0.68**
1	**-0.22**	**1.01**	**0.65**
1.5	**-0.57**	**-0.63**	**-1.9**
2	**-1.17**	**-1.45**	**-0.76**

6.2 Two Meshes

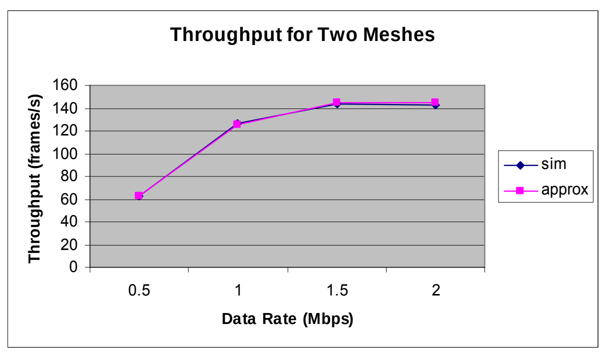

Fig. 7. Throughputs for 2 meshes.

We can obviously see from figure 7 that throughputs from both approximation and simulation techniques are still very close with the error between 0.17 to 1.4% as listed in table 1. Percentage of error for mean queue length and utilization factor is also listed in table 2 and 3.

Table 2. MQL Percentage of Error for Two Meshes.

Data Rate (Mbps)	One Mesh			Two Meshes		
	Sim	Approx	Error (%)	Sim	Approx	Error (%)
0.5	11	0	100	8	0	100
1	54	0	100	36	0	100
1.5	4125	4242	**-2.84**	150	0	100
2	4184	4200	**-0.38**	132	0	100

Table 3. Utilization Factor Percentage of Error for Two Meshes.

Data Rate (Mbps)	One Mesh			Two Meshes		
	Sim	Approx	Error (%)	Sim	Approx	Error (%)
0.5	43	43.12	**-0.28**	43	43.12	**-0.28**
1	88	86.25	**1.99**	88	86.25	**1.99**
1.5	100	100	**0**	98	100	**-2.04**

6.3 Three Meshes

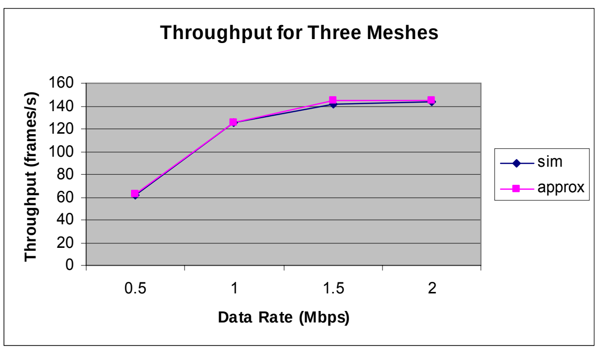

Fig. 8. Throughputs for 3 Meshes.

The throughputs of three meshes coming from both techniques still confirm the close of approximation technique with small percentage of error less than 2% as shown in figure 8.

With the data in table 5, the error percentage for approximation techniques is less than 3%.

From experiments on throughputs and utilization factor, the percentage of errors ranges from zero, exactly the same as the simulation results, to 4%. In MQL approximation, there are some cases that the result of the technique equal to zero which directly affect the calculation of percentage of error. The result from zero value in MQL approximation causes 100% of error. Except in the special case of zero MQL, the approximation technique results are less than 9% of error as listed in table 4.

Table 4. MQL Percentage of Error for Three Meshes.

Data Rate (Mbps)	One Mesh	Two Meshes	Three Meshes
	Error (%)	Error (%)	Error (%)
0.5	100	100	100
1	100	100	100
1.5	**8.74**	100	100
2	**-3.78**	100	100

Table 5. Utilization Factor Percentage of Error for Three Meshes.

Data Rate (Mbps)	One Mesh	Two Meshes	Three Meshes
	Error (%)	Error (%)	Error (%)
0.5	**-2.67**	**-0.28**	**2**
1	**0.86**	**0.86**	**-0.29**
1.5	**0**	**-2.04**	**-3.09**
2	**0**	**0**	**-2.04**

With acceptable error percentage, approximation technique needs no computational cost or simulation time according to table 6. In simulation technique, up to 100 sec of simulation time is used to conduct the simulation output, but no time is needed for approximation technique. Moreover, to develop or to learn how to use the simulation program is a complicated task, and time-consuming process. We propose the application of the easier approximation method, which requires only mathematical knowledge to solve some formulae derived from techniques needed for performance comparison. The error of 4-9% from the technique can be overcome by quick results achieved from the technique.

Table 6. Computational Cost for Simulation and Approximation Techniques.

Data Rate (Mbps)	One Mesh		Two Meshes		Three Meshes	
	Sim (s)	Approx (s)	Sim (s)	Approx (s)	Sim (s)	Approx (s)
0.5	100	0	100	0	100	0
1	100	0	100	0	100	0
1.5	50	0	100	0	80	0
2	40	0	40	0	40	0

7. Conclusions

When the data rates are increased, throughputs in both RC and IP networks also increased, but the throughputs of RC network are better than that of IP network. The network traffic fluctuated into the first mesh causing nodes in the first mesh to process more traffic than the following meshes, so performance parameters for nodes in the first mesh are not as good as those in the following meshes. We can obviously perceive that nodes in the last mesh will have very low traffic, so there are very few packets waiting in their queues. Moreover, in the meshed network, as we increase the number of nodes by cascading another two nodes to the existing mesh network, RC network can maintain its throughputs in all meshes. In ERC network, RC network with O notation for packet holding time, the performance relied only on the address length of the packets. In contrast, the performance of IP network relied on both address length and number of prefixes in the table. As number of nodes increases, the number of prefixes in the hash table also increases, so we can assume that number of nodes directly influences the performance of IP network. This results in the IP network's throughputs to be lower as the number of nodes in the backbone is increased.

With simulation technique, excessive time has been used for developing the simulation programs, and for simulating events in the model before we could get the performance measures from the simulation program. An approximation method has been proposed. Three performance measures, throughputs, MQL, and utilization factors can be collected from the approximation method. It applies mathematics to carry out all performance measures in no time. The error from the approximation compared to simulation technique ranges from 4% to 9%.

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