Hybrid Optimal Routing Strategy (HORS) for Scale-Free Networks

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Summary
Scale-Free Networks have surfaced as a significant field in Network Science. The pervasiveness of scale-free networks has prompted many researchers to do an in-depth analysis of behavior and structure of these networks. Routing in these superlarge networks is a very exigent process due to huge traffic flow and dynamic network conditions. The paper presents a Hybrid Optimal Routing Strategy (HORS) which uses Betweenness Centrality and Queue length of nodes to determine the best possible path in a Scale-Free Network. The algorithm is adaptive i.e., all packets from source to destination do not follow the same path. The static and dynamic properties of all nodes are explored while computing the routing table in the network. Proposed algorithm achieves high network capacity, short average path length and low packet traveling time compared with Global Dynamic and Improved Optimal routing strategy.

Keywords:
Betweenness Centrality, Adaptive Routing, Preferential attachment, Scale-Free Network

1. Introduction

In recent decades, the size of networks such as the WWW, Transportation, Epidemic, and Trade networks has increased enormously. Many of these diverse real-world networks share network architecture similar to scale-free networks. A scale-free network is a subset of complex networks where the probability of connections between the nodes obeys the power law property. Growth and Preferential attachment guide the expansion of these networks[1-2]. When a new node enters the network, it is linearly biased to attach itself to the node with the highest degree centrality. As a result, the fraction of hubs to the other nodes in the network remains the same irrespective of network size[2]. An illustration of a scale-free network with 100 nodes and its corresponding degree distribution is given in Figure 1.

Scale-free networks are composed of thousands of nodes that need to communicate with each other. The overwhelming growth in the data traffic and changing network dynamics place a huge load on the network resources like routers and gateways. Several paths between a chosen set of nodes in a large complex network make routing a very daunting process. The traditional shortest path routing strategy [4] performs unsatisfactorily in these superlarge networks. Frequent transmission of packets through nodes with high degree or high betweenness increases congestion and degrades network performance [6]. There is a need for designing good routing strategies that optimize network capacity with minimum latency.

In this paper, a Hybrid Optimal Routing Strategy (HORS) for scale-free networks based on Betweenness Centrality and queue length is proposed. The strategy utilizes the statistical parameters of a node to effectively route a packet through the best path available in the network. Dynamic traffic conditions are taken into account to avoid network congestion by relocating load from nodes with high betweenness.

Section II of this paper discusses some of the existing scale-free routing algorithms. Section III contains the details of the proposed routing strategy. Section IV presents different simulation scenarios and performance of the proposed strategy. In the last section, the summary of the contributions of this paper and some future research directions are discussed.

2. Related Works

The most important task performed in any network is routing. A good routing strategy should be able to maximize traffic capacity with little end-to-end delay. Shortest path routing [4] is one of the simplest routing applied in Scale-free Networks. But due to its non-adaptive nature, it does not consider the node state while delivering packets. The path may be the shortest one yet congested causing unnecessary delay. Several optimizations of Shortest path routing have been proposed. In efficient routing strategy [3], traffic load from prime nodes is distributed to other nodes by choosing the path with a minimum sum of node degrees. Ling et. al [8] presented Global Dynamic routing strategy where path with a minimum sum of node queue length is selected for delivering packets. The network congestion is reduced but at the same time the time to deliver packets increases. Pheromone routing strategy utilizes the pheromone function based on queue length which is updated periodically to deliver packets. Several improvements over basic pheromone routing are given by Lin et al .[9] to deal with node duplication issue. In restrictive queue length optimization, a threshold on the queue length of the adjacent node is applied to avoid sending packet if queue length value exceeds threshold. Hop by Hop forwarding of packet on the basis of status of

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neighbors achieves low transmission efficiency and network capacity. In global hybrid routing strategy [15], a combination of normalized degree centrality and queue length is used to deliver packets to the targeted node. The waiting time at the nodes in the network has also been used extensively to decide routing paths in the network [7] [12].

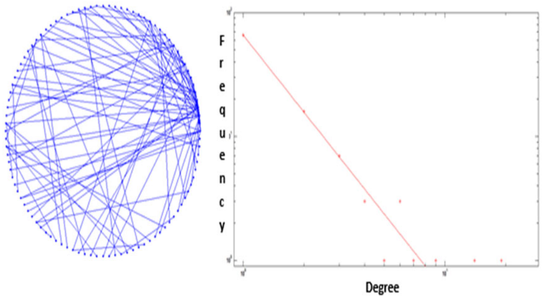

Fig 1: Scale Free Network with 100 nodes and its corresponding degree distribution

An important statistical characteristic of the network, Betweenness Centrality has been explored while selecting the most appropriate path between two nodes in the network[5][10]. Betweenness Centrality (BC) of a node represents the number of shortest paths passing through given node. It denotes traffic load characteristics of the network. Improved Efficient Routing (IER) strategy[13] routes the packet on the basis of minimum weight of BC of a series of links from source to destination. The efficiency of IER strategy has been further improved with Improved Optimal routing strategy (IOR) [14] where degree of nodes and betweenness centrality with tunable parameter is used to utilize peripheral nodes of the network effectively, thereby, improving network capacity.

Though several strategies have been proposed to optimize traffic handling capacity of scale-free network, yet there is scope for improvisation. Several existing routing schemes are based on static parameters like node degree which is not suitable for large-scale networks. To handle real-time traffic conditions, dynamic parameters like queue length, waiting time must be taken into account while finalizing the route for a packet. Therefore, a good routing function must consider both parameters while making routing decisions. To boost the traffic capacity and reduce average path length in Scale-Free Network, Hybrid Optimal routing strategy (HORS) incorporating dynamic changes in Betweenness centrality(BC) and queue length of the nodes is proposed in this paper.

3. Hybrid Optimal Routing Strategy

This section discusses various assumptions and the working of our routing strategy.

A. Assumptions

Scale-free network is formed with initial seed network of n_0 nodes, a new node with n links ($n <= n_0$) is introduced in network periodically. The new node attaches itself to the existing nodes' according to the preferential attachment rule based on node degrees. The assumptions regarding the network are as follows:

- A fixed number of packets are introduced in the system periodically with random source and destinations.
- Queue length of all the nodes is unrestricted and First In First Out order is used for dispatching packets
- Each node in the network can work as hosts as well as routers.

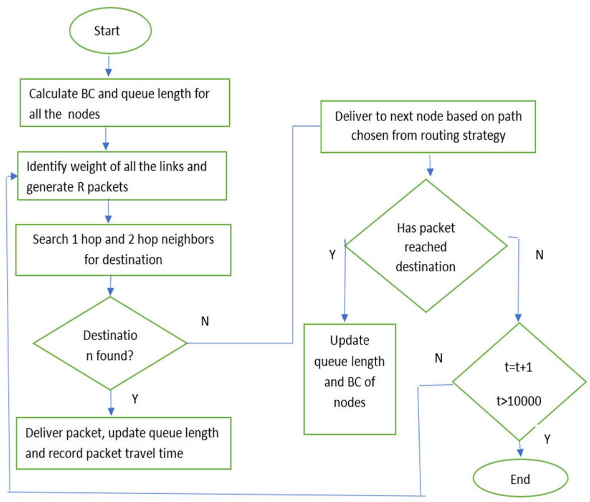

Fig 2: Flowchart of Routing Scheme

B. Proposed Routing Mechanism

A Hybrid routing mechanism designed using static and dynamic conditions of scale free network is proposed where route with least sum of the weight of links assigned according to equation (1) is chosen.

$$P_{sd} = \min \sum_{x=0}^{n} [\, \beta * N_{BC}(x) + (1-\beta) * N_{ql}(x)] \quad (1)$$

Where β is a tunable parameter which decide the weightage of Betweenness centrality and queue length. $N_{BC}(x)$ is the normalized betweenness centrality defined as (2) where BC(x) is betweenness centrality of node x and max (BC) is the maximum Betweenness centrality of all nodes in the network.

$$N_{BC}(x) = \frac{BC(x)}{\max(BC)} \quad (2)$$

$N_{ql}(x)$ is the normalized queue length of node x calculated as per (3), ql(x) is queue length of node x and max(ql) is maximum queue length of all nodes in the network.

$$N_{ql}(x) = \frac{ql(x)}{\max(ql)} \quad (3)$$

When value of β is 0, the routing strategy corresponds to Global dynamic routing [8] where route with least value of queue length is selected. When value of β is 1, route with minimum betweenness centrality is chosen. While selecting the routing path, relative impact of both betweenness centrality and queue length of nodes needs to be adjusted with caution as hub nodes cannot be ignored completely. Transmission of packets only through nodes with smaller queue length may adversely affect packet delivery time.

In the proposed routing strategy, first Betweenness centrality and queue length of all the nodes is calculated in order to identify proportional weight of each link. Fig 2 displays the flow chart of proposed routing mechanism. When a new packet is to be transmitted in network, the source node checks its 1-hop and 2-hop neighbors for destination. If found, packet is delivered to that node. Otherwise, packet is sent to the most appropriate node selected on the basis of routing strategy given in Fig 2. Queue length of nodes is updated after specific time interval. After delivering the packet to destination, the packet delivery time is calculated. The simulation time is set to be 10000.

4. Simulation Results and Analysis

In this section, various simulation scenarios and associated simulation results are presented to compare the efficacy and accuracy of the proposed Hybrid Optimal Routing Strategy(HORS) with Global Dynamic routing and Improved Optimal Routing (IOR) strategy. Average path length, Network traffic capacity and Average packet traveling time are used to perform comparative analysis of routing strategies. Table 1 contains various parameters used for simulation.

Table 1: Simulation Scenario

Parameter	Value
Scale Free Model	BARABASI-ALBERT
No Of Nodes	200-1000
No Of Initial Nodes (M0)	4
No of edges of new node (m)	2
Node packet delivering capacity (C_i)	1
Routing Protocols	IOR, Global Dynamic, HORS
Simulation Time (t)	10000 sec

First, the performance of Hybrid Optimal Routing strategy with respect to the variations in tunable parameter 'β' is investigated. Fig 3 represents value of order parameter H with respect to different values of packet generating rate R. When the number of packets are less (R small), H is almost zero as there is no traffic congestion. As the value of R increases to critical packet generation rate R_c , the balance between inflow and outflow packets is disturbed and congestion starts to occur. It is apparent from figure, R_c reaches maximum ≈ 85 when β = 0.4 which can be the optimal value of parameter a. In Fig 4 , value of R_c for different variations in parameter a is presented with N= 500 and N=1000. It is observed that R_c reaches maximum value at 0.4 irrespective of network size. On the basis of above results discussion, the optimal value of parameter β is selected as 0.4 for Hybrid Optimal Routing strategy (HORS).

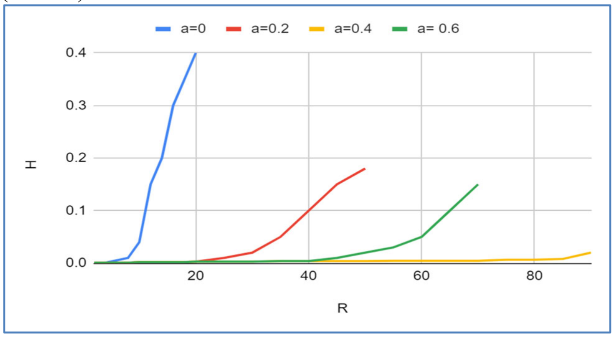

Fig 3:Order parameter H vs. different values of packet generating rate R with N = 600.

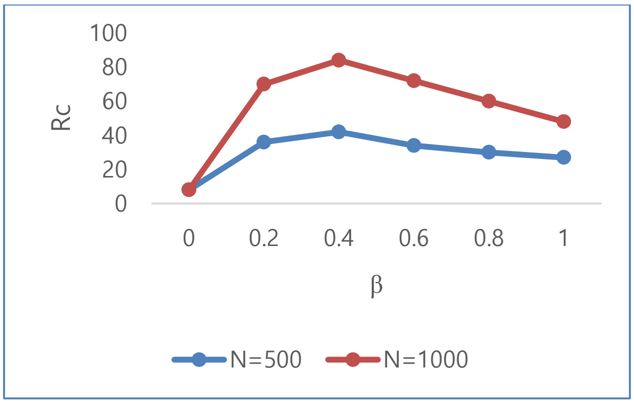

Fig 4: Critical packet generating rate R_c vs. β for N=500 and N=1000

One of the parameters to analyze network capacity can be critical packet generating rate (R_c) where the larger the value of R_c , the larger the capacity of network to handle packets without congestion. Fig 5a and 5b demonstrate the variation in network capacity with the number of nodes N and average degree <k> under different routing algorithms. The average degree being same <K>= 6, the traffic capacity improves with increase in Network size for all routing algorithms in consideration, but proposed HORS strategy clearly outperforms other two strategies. The increase in network capacity is again observed when the number of nodes is varied from 200-1000. The proposed HORS perform much better in terms of network capacity in both the scenarios as the unnecessary load on central nodes of the network is avoided by elegantly distributing the loads to other nodes in the network.

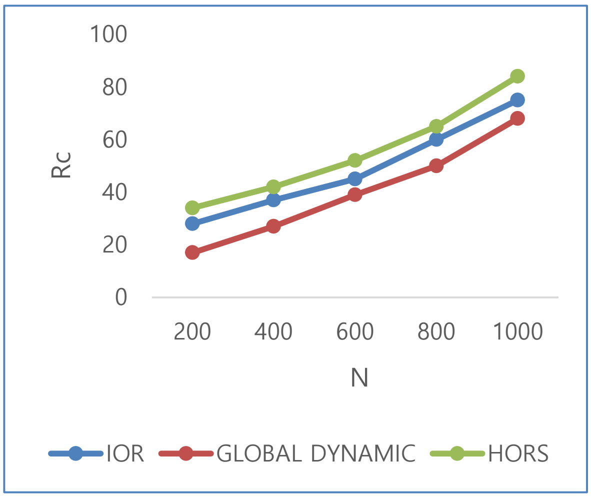

Fig 5a: Network capacity R_c vs. No. of nodes N for average degree <K> = 6

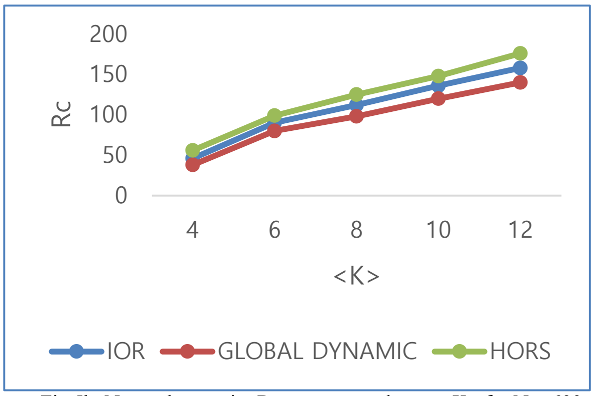

Fig 5b: Network capacity R_c vs. average degree <K> for N = 600

Other parameters to compare routing performance are average path length (APL) and average packet traveling time (APT). The APT denotes the time taken by a packet in traveling from source to destination and the time spent waiting at the intermediate nodes. Fig 6 represents variation in average packet travelling time with Network size for different routing strategies. Initially, packet traveling time is less for all routing strategies. As the number of nodes start to increase, traveling time also increases due to increase in congestion and waiting time at intermediate nodes. HORS strategy efficiently redistribute packets to the path with nodes with low betweenness centrality and low queue length, thereby avoiding traffic hotspots. Thus, it performs better when compared with other routing strategies. The performance with respect to average path length (APL) vs. Network size can be seen in Fig 7. HORS strategy again outperforms Global dynamic and IOR routing with smallest increase in average path length when network size increases from 200-1000 nodes.

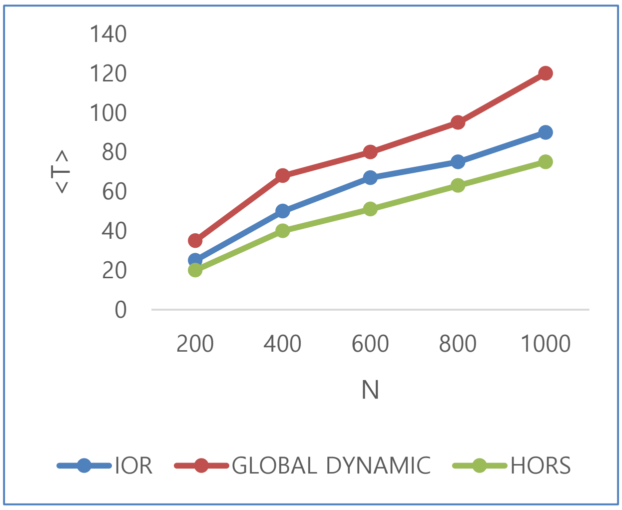

Fig 6: Average packet traveling time <T> vs. Number of Nodes N under different routing strategies

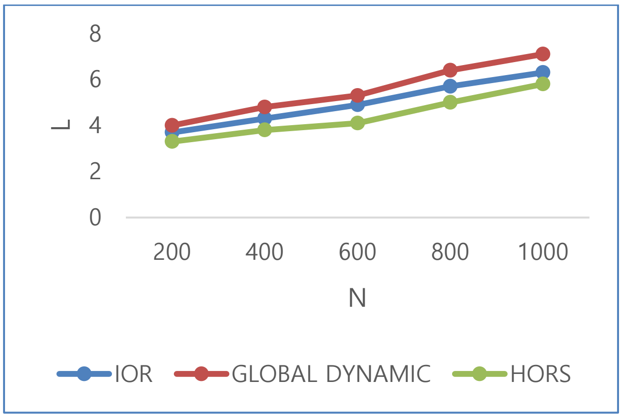

Fig 7: Average shortest path length <L> vs. Number of nodes N under different routing strategies

5. Conclusion and Future Scope

In this paper, Hybrid Optimal Routing Strategy (HORS) is demonstrated where the routing path is selected on the basis Betweenness Centrality and queue lengths of nodes in Scale-Free network. The packet chooses path with minimum weight of links from source to destination. By adjusting the value of tunable parameter ‘β = 0.4’, maximum traffic capacity is achieved. With the surge in the number of nodes in network and frequent transmission of packets to the nodes with high betweenness, traffic hotspots are formed which lead to congestion and performance degradation of the whole network. The proposed algorithm tries to adjust the traffic load among all possible paths from source to destination while taking care of average packet traveling time and path length. In the simulation, network capacity, average packet traveling time and average path length have been analyzed. Results have shown that the proposed algorithm outperforms Global dynamic routing and IOR routing strategy. Considering the diverse set of applications of Scale-free Networks, this routing mechanism can be utilized for optimizing the routing process in many real-world networks like PowerGrid, Internet, and Transportation systems. If the congestion level in the network is very high, the forwarding node in the proposed scheme may not be able to find an appropriate node to forward packet, thereby reducing network performance. In proposed scheme, updation of queue length at regular intervals lead to increase in end-to-end delay but at the cost of better network performance. The future work aims to consider heterogeneous nature of nodes while making packet forwarding decisions. Priority-based packet delivery services can be incorporated to suit time-sensitive applications.

References

[1] L. Barabasi and R. Albert, "Emergence of scaling in random networks," Science, vol. 286, no.5439, pp. 509-512, (1999).

[2] Barabasi, A.L. and Bonabeau E. 'Scale-free Networks', *Scientific American*, vol. 288, pp. 50-60 (2003).

[3] G. yan, T. Zhou, B. Hu, Z. Q. FU and B. H. Wang, "Efficient routing on complex networks," Physical Review E 73, 046108, (2006).

[4] Zhao, L., Lai, Y., Park, K. and Ye, N. 'Onset of traffic congestion in complex networks', *Physical Review E*, vol. 71, 026125 (2005).

[5] Barthelemy, M. 'Betweenness centrality in large complex networks', *European Physical Journal B*, vol**.** **38**, pp. 163-168 (2004).

[6] Chen, S., Huang, W., Cattani, C. and Altieri, G. 'Traffic dynamics on Complex Networks: A Survey*',* *Mathematical. Problems in Engineering,* 732698 (2012).

[7] Dan Wang, Yanping Li, Wenwei Liu, Liang Dong and Lin Li," Routing strategy with waiting time on scale free networks," 11th International conference on control, automation, robotics and vision, (2010).

[8] Xiang Ling, Mao-Bin Hu, Rui Jiang and Qing-Song Wu," Global dynamic routing for scale –free networks,"Physical review E 81 (2010).

[9] Benchuan Lin, B., Chen, B., Gao, Y., Tse, C.K., Dong, C., Miao, L. and Wang, B. 'Advanced algorithms for local routing strategy on complex networks', *PLoS One*, vol. 11, 7 (2016).

[10] Zhi-Hong Guan, Long Chen and Tong-hui Qian," Routing in scale-free networks based on expanding betweennness centrality," Physica A elsevier, (2010).

[11] Fei tan and Yongxiang Xia ," Hybrid routing on scale-free networks," Physica A 392, Elsevier, (2013).

[12] Xiaojun Zhang, Zishu He, Zheng He and Lez Rayman-Bacchus," Probability routing strategy for scale-free networks," Physica A 392, Elsevier, (2013).

[13] Zhong-Yuan Jiang and Man-Gui Liang ,"Incremental routing strategy on scale-free networks," Physica A 392 (2013).

[14] Yibo Yang, Honglin Zhao and Jinlong Ma, "An optimal routing strategy on scale-free networks," International journal of Modern Physics C, vol. 28, no.6, (2017).

[15] Xiong Gao, Hongxiang Guo, Yanhu Chen, Yinan Tang, Cen Wang, Shengyao Xu and Jian Wu, "Global Hybrid Routing for Scale Free Networks," IEEE Access, (2019).

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