Global Dynamic One-Step-Prediction Resource Allocation Strategy for Space Stereo Multi-layer Data Asymmetric Scale-Free Network

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Abstract. Many real communication networks possess space stereo multi-layer structure and the data transmitted in these networks is asymmetric. As the network resource is limited and resource allocation scheme is one of the most effective ways to promote the network performance, it is of great interest to explore a resource allocation strategy that can highly utilize the network resource and further improve the network capacity. In this light, the global dynamic one-step-prediction resource allocation (GDORA) strategy for the space stereo multi-layer data asymmetric scale-free network under the established directly proportional network framework is introduced in this work. Compared with the node degree and node betweenness resource allocation strategies, the GDORA scheme can achieve much higher network capacity and promote the network performance effectively.

Keywords: Capacity · Multi-layer network · Scale-free · Resource allocation

1 Introduction

The researches related to the complex network [1–3] have opened a new way to explore the traffic dynamics for the real communication networks. Recently, an interesting way to promote the network performance has been drawn more attention by researchers, which can be classified as network resource allocation strategy. In continuous flow level, a capacity distribution scheme is introduced in [4], including flow rate adjustment and network capacity rearrangement. However, in many real communication networks, such as self-organization sensor networks, the data transmission is in the form of packet and restricting the flow generation rate may influence the process of data collection and transmitting. A capacity allocation scheme by utilizing the node degree is presented in [5], and it was applied to the shortest path routing and local routing strategies. Meanwhile, as the betweenness can comprehensively describe the situation of packet delivery of nodes in the network, in [6], the resource allocation method based on the node betweenness is proposed. And also, another traffic resource allocation scheme grounded on the node betweenness is introduced in [7], and it proved that the shortest path routing scheme can bring the improvement for the network capacity.

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However, in the real communication networks, such as self-organized wireless sensor network, the sensors are distributed to the observation area randomly and the data generated by sensors is not uniform, the hot region is the interested area, which means that many nodes may deploy in the hot region, and these nodes will generate much more proportion of packets created by the network and deliver more packets to the sink node than the other nodes located in the disinterested region. The network is in the form of asymmetric data network. As the link from sensor nodes to their sink node is one-one correspondence, there are limited links between sensor nodes in the hot region and their sink node. It is obvious that by using the resource allocation scheme based on the node degree, these sink nodes may become bottleneck nodes easily. On the other hand, when utilizing the resource allocation scheme based on the node betweenness, after the selection of the source node, the nodes on its routing path to the destination will be considered in the model, and the resource for nodes will be pre-allocated before the packets arrived and the packets that go through one node cannot arrive at the same time, which means that some allocated resource is wasted.

At the same time, many real communication networks are self-organized and space stereo multi-layer [8]. Meanwhile, as the observation area usually consists of interested region and disinterested region, the data transmission in the network is asymmetric. Therefore, it is of great interest to explore a resource allocation scheme that can further improve the network capacity for the data asymmetric space stereo multi-layer network. Actually, no matter what kind of resource allocation method is used, its essence is how to deal with the packets accumulated in the nodes reasonably. Thus, starting from this view of point, in this paper, the global dynamic one-step-prediction resource allocation (GDORA) scheme is introduced to further improve the network performance.

2 Traffic Model

As many real communication networks are self-organized and stereo multi-layer in space, the space stereo multi-layer network structure described in [8] is used in this work, where the traffic model of space stereo multi-layer data asymmetric network is made up of three layers: upper layer, lower layer and inter-layer, and as the coverage of each node in the net is finite, the upper layer and lower layer are parted into several districts, source nodes in the lower layer will deliver the information to their destination nodes located in the upper layer through the corresponding inter-layer based on the given routing strategy. As the particularity of scale-free network, the data congestion appears easily in this kind network and many researchers spend a lot of energy on improving the scale-free network capacity. Similar to the properties of real communication networks, it easily can be seen that the nodes in the upper layer not only establish links to the nodes in the upper layer, but also set up links to the lower layer. Accordingly, the nodes in the upper layer will possess more possibilities to be congestion nodes. So, this work will mainly focus on the resource allocation scheme for the nodes in the scale-free upper layer. Meanwhile, for the nodes in the real network is usually self-organized, they may be deployed in the form of Peer-to-Peer or hierarchical [9, 10], then, this work further expands the study of space stereo multi-layer network on the resource allocation schemes, and investigates two kinds of network topologies for space stereo multi-layer data asymmetric scale-free network: (I) upper layer is Hierarchical, inter-layer is Hierarchical and lower layer is Peer-to-Peer. (II) upper layer is Hierarchical, inter-layer is Peer-to-Peer and lower layer is Peer-to-Peer. Without loss of generality, this work uses the BA model [11] to generate the hierarchical network based on the node degree K, and uses the ER model [12, 13] to generate the Peer-to-Peer network connecting two of them randomly with N nodes, until the conditions are satisfied. The shortest path routing strategy [7] is used in this work.

To evaluate the performances of introduced resource allocation scheme, in this work, the order parameter [7, 13, 14] is used

$$\eta(R) = \lim_{t \to \infty} \frac{\langle \Delta N_p \rangle}{R \Delta t} \tag{1}$$

where $\Delta N_p = N_p(t + \Delta t) - N_p(t)$ is the packets that stay in the network during time width $\Delta t, N_p(t)$ is the total number of packets in the network at time step t, <> means the average. When there is no congestion, the network is in the free step and $\eta(R)$ is around 0. With the increase of packet generation R created by the network, the network will be in the congestion step and $\eta(R)$ is obviously larger than zero. Therefore, the critical packet generation value R that makes the $\eta(R)$ around 0 can be used to evaluate the network capacity.

3 Global Dynamic One-Step-Prediction Resource Allocation (GDORA) Strategy

When the network works, it will generate R new packets and deliver them from source nodes to the destination nodes in each time step based on the given routing path. As the observation area could be interested region or disinterested region, network is data asymmetric space stereo multi-layer network. That is, the generation and distribution of R new packets on nodes in the lower layer are not uniform. Nodes in the lower layer located in the hot region may generate more part of R newly generated packets. As the network resource is limited, this work assumes that the total packets handling ability of the network is H and the handling ability of each node is H_i. When the new packets generated at time $t - 1$, they will reach to its next hop node according to the routing strategy at time t, then, the global dynamic one-step-prediction resource allocation strategy for the nodes located in the upper layer can be denoted as

$$H_i(t) = \frac{P_{bi}(t)}{\sum_{j=1}^{N} P_{gj}(t-1)} H \tag{2}$$

where $P_{bi}(t)$ is the number of packets accumulated in the buffer of node i in the upper layer at time step t, and $\sum_{j=1}^{N} P_{gj}(t-1)$ is the sum of generated packets of N nodes in the lower layer at time step $t - 1$.

To realize the global dynamic one-step-prediction resource allocation scheme, the number of packets $P_{bi}(t)$ will include the number of packets $B_{vi}(t)$ that will be delivered to the node i in the upper layer network and the number of packets $B_{ri}(t)$ that cannot be delivered to its next hop node for the limitation of delivery ability. Accordingly, the number of packets $P_{bi}(t)$ that used on resource allocation can be expressed as

$$P_{bi}(t) = B_{vi}(t) + B_{ri}(t) \tag{3}$$

From the global dynamic one-step-prediction resource allocation strategy, it can be seen that if there are more packets accumulated in nodes, there will be more resource allocated to them.

4 Simulations and Discussions

As mentioned before, nodes deployed in the interested region may generate more proportion packets generated by the network. This work assumes that the nodes in the lower layer which are the neighbors of nodes with larger node degree in the upper layer generate more part of R newly created packets. Under this directly proportional situation, the performances of GDORA, node degree and node betweenness resource allocation strategies are investigated. To realize the positive proportional environment, the following scheme is used:

(i) Sort the sequence for the nodes in the upper layer based on the number of links.
(ii) Let those upper layer top *Packet_scale_percent* percent nodes' neighbor in the lower layer generate more part of R newly created packets.

To realize the step (ii), the parameter *Packet_scale* is used to promote the packet generation probability for these upper layer top *Packet_scale_percent* percent nodes' neighbor located in the lower layer.

In this work, the upper layer and the lower layer are assumed to be divided into 4 square districts, and each district is unit length. Both the network sizes in the upper layer and lower layer are N and these nodes are distributed randomly. The topology average is executed to evaluate $\eta(R)$. The resource allocation is proportional to the node degree for node degree resource allocation scheme. The total packets handling ability of the network H is equal to the network size N. The *Packet_scale* = 1.5, *Packet_scale_percent* = 30% and the network size $N = 300$. The average degree of upper layer is 7 and the average degree of inter-layer is 4.

Figure 1 shows the order parameter $\eta(R)$ vs R for the node degree, node betweenness and GDORA resource allocation strategies, where the constructions of upper layer and inter-layer are both hierarchical. It can be seen that the performance of $\eta(R)$ is node degree resource allocation strategy < node betweenness resource allocation strategy < GDORA resource allocation strategy. Under the directly proportional situation, the nodes in the hot region will generate more part of R newly created packets to their destination nodes. Along with the growth of the newly created packets R by network, the number of generated packets may larger than the established links and the number of accumulated packets may exceed the node's processing ability easily for

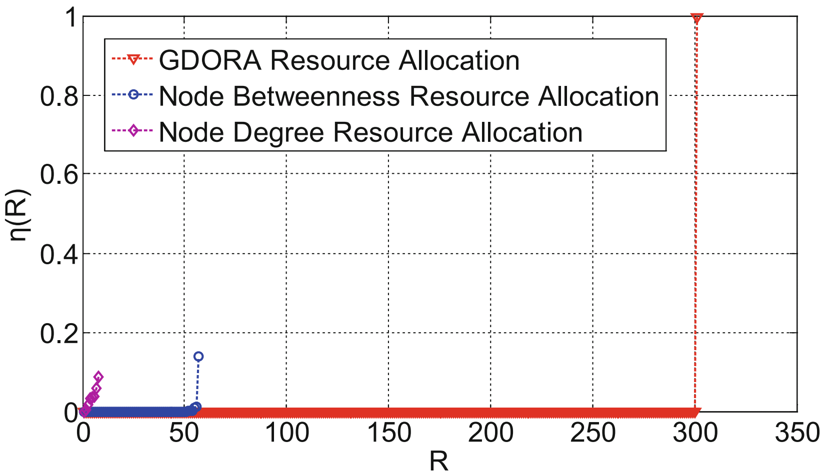

Fig. 1. The order parameter $\eta(R)$ vs R under different resource allocation strategies. The upper layer and inter-layer are both hierarchical.

node degree resource allocation strategy. Then, the nodes in the upper layer cannot resist the influence of data asymmetric generation, and the congestion will easily occur in the network, so the network capacity is low. For the node betweenness resource allocation scheme, if more packets go through one node, more network resource will be assigned to this node. Then, under the directly proportional circumstance, with the growth of the newly created packets R by network, nodes will obtain reasonable network resource to handle the network congestion. However, as mentioned before, the packets that go through one node cannot arrive at the same time, some network resource is wasted. Different from the two former strategies, the GDORA scheme gets the highest network performance. For the GDORA strategy, the packet handling ability of one node is based on the number of packets accumulated in this node. The whole network resource will be distributed proportionally to the accumulated number of packets that need to be handled in one node. Consequently, the network capacity is further improved.

Figure 2 gives the order parameter $\eta(R)$ vs R for three kinds of resource allocation strategies. The network structure of upper layer is hierarchical and the inter-layer is Peer-to-Peer. From Fig. 2, it can be seen that the performance tendency of $\eta(R)$ is still node degree resource allocation strategy < node betweenness resource allocation strategy < GDORA resource allocation strategy. When the inter-layer network framework is Peer-to-Peer, the distribution of network structure is homogenous corresponding to the hierarchical network structure. Subjecting to the restriction of node degree allocation scheme, in the Peer-to-Peer inter-layer network frame, the packet processing ability assigned to node is still very low, thus, the network capacity is poor. Corresponding to the node degree resource allocation scheme, even though the distribution of network links in the Peer-to-Peer inter-layer network structure is more uniform, however, based on the properties of node betweenness, the node betweenness

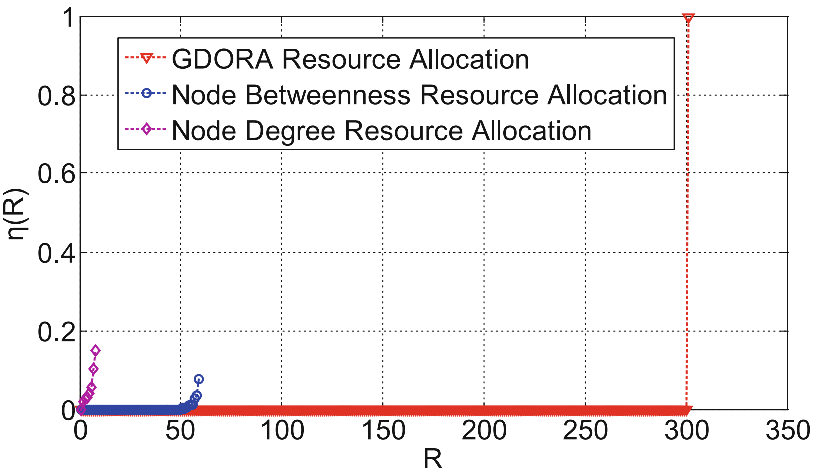

Fig. 2. The order parameter $\eta(R)$ vs R under different resource allocation strategies. The upper layer is hierarchical and the inter-layer is Peer-to-Peer.

resource allocation strategy still perform better than node degree resource allocation strategy. From Fig. 2, it can be seen that the GDORA scheme still gets the highest network performance. This result profits from the features of GDORA strategy, where the network resource allocation essence is the number of packets that one node needs to be handled rather than the packets routing path or the number of links.

For the congestion is also an interesting characteristic for the network, then, the packet probability distribution $P(K)$ vs node degree K is investigated for GDORA strategy when the network is in the congestion phase under two kinds of network frames. From Fig. 3(a) and (b), it can be found that for different node degree K, the distribution of packet probability $P(K)$ is asymmetric, and when the network is in the

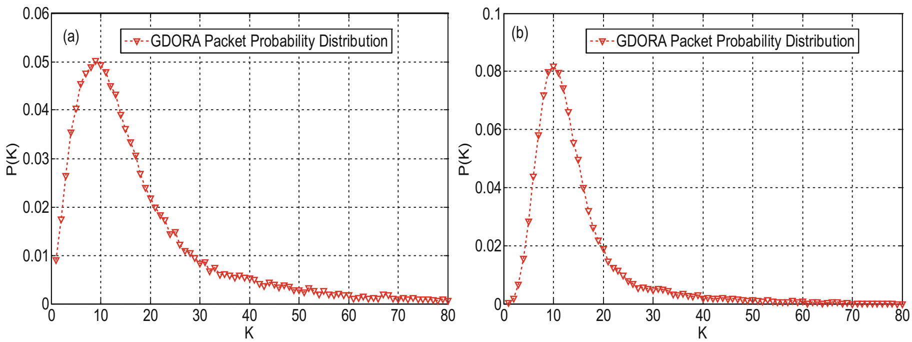

Fig. 3. The packet probability distribution $P(K)$ vs node degree K in the congested network for the GDORA scheme. (a) The upper layer and inter-layer are both hierarchical. (b) The upper layer is hierarchical, and inter-layer is Peer-to-Peer.

congestion situation, the packets may have higher probability to accumulate in the nodes with small node degree. This indicates that when the network congestion happened, the nodes with small node degree may bring greater impact on the network capacity than the other nodes.

5 Conclusion

Many real communication networks are space stereo multi-layer and how to improve the network capacity has been widely studied. As the reasonable utilization of network resource is one of the most effective ways to promote the network performance, the resource allocation schemes have been drawn more attention recently. In this paper, the GDORA resource allocation strategy is introduced for the space stereo multi-layer data asymmetric scale-free network and the directly proportional circumstance is established. The resource allocation of GDORA strategy is based on the number of packets accumulated in the node's buffer. Numerical simulation results show that the GDORA strategy reaches much high network capacity compared with the node degree and node betweenness resource allocation strategies. As the network resource allocation is important on promoting the network performance, such insights might be useful on investigating the real communication networks in the future.

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