

Minimization of Power Consumption in IP Networks

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Abstract—This paper proposes an energy-aware packet delivery operation through network node clustering for green communications. Energy consumption has become a key factor for the evaluation of performance index in telecommunication industry. In order to prevent a waste of energy in wired network, the proposed algorithm configures energy-aware cluster consisting of one header node and multiple member nodes. Then only the header node performs packet routing and its member nodes forward packet using tag. Simulation results show that the proposed algorithm introduces more energy efficient performance than previous works.

Keywords—power consumption, wired network, network node clustering, energy efficiency, green network

I. INTRODUCTION

Recently, energy consumption has become a key factor for the evaluation of performance index in ICT industry. In telecommunication networks, as the volume of traffic occurred by various devices is increased rapidly, power consumption required to handle them grow exponentially [1][2]. However, most elements in current networks are not usually optimized for power efficiency as described in [3]. Thus network elements should always be powered on for the connectivity regardless of the network volume, status, etc. According to [4], the network load proportional to traffic volume is quite various between peak and off-peak period. To avoid wasting energy consumption in different period, differentiated strategies in network operation are strongly required in the aspect of energy efficiency. [5][6] propose sleeping and standby approaches according to network status. However, it sometimes requires additional components such as a proxy and can consume more power when nodes are going from power-on to power-off and back. According to [7], power consumption at layer 3 for packet forwarding engine processing IP headers for destination and quality of service queuing occupies 62% of total power consumption in router. Thus it is expected to reduce the total power consumption of the network if the processing of each layer in the router can be manageable independently according to network conditions such as peak and off-peak period, etc. This assumption has become realized with the development of cloud (or virtualization) related technologies such as Network Functions Virtualization (NFV) [8] which propose using IT virtualization related technologies, to virtualize entire classes

of network node functions into building blocks that may be connected, together to create communication service.

In this paper, we propose a packet delivery mechanism in order to minimize power consumption during off-peak period in wired network. Assuming the functions of layers in network node can be controlled independently, the proposed mechanism first selects header nodes (HNs) for general IP routing and configure clusters with the center of HNs. Then the other nodes, referred as member nodes (MNs), temporally sleep their function in layer 3 and instead of IP routing, perform packet forwarding using defined tag.

The rest of paper is organized as follows. Section II overviews the related works and the proposed algorithm including problem definition is presented in Section III. The simulation results are introduced in Section IV and conclusion is followed in Section V.

II. RELATED WORKS

The energy efficiency has been in common topics in wireless environments such as sensor network, mobile communication and lots of research are proposed and studied to extend the battery life. Authors in [9] analyzed the trade-off between spectrum efficiency and energy efficiency and introduced various studies within a framework of energy-efficient resource allocation in 5G wireless network. However, recently triggered by the exponential growth of network traffic volume, the spreading of internet access, and the expanding new ICT services being offered by service and network providers, the energy efficiency has become a high-priority object also in the area of wired networks. To analyze green technologies in wired network, the authors of [10] introduced base approaches such as re-engineering, dynamic adaptation and sleeping/standby. Related with this issues, a number of researches have been made for the last decades.

As a re-engineering approach focusing on designing energy-aware elements, [11] introduced an investigation of the potential savings achievable through power-aware network design and routing. The authors measured the power consumption of various configurations of widely used routers. Then, they create a general model for router power consumption based on measurement results to explore the potential impact of power-awareness in a set of example networks.

For the dynamic adaptation approaches aim at modulating capacities of packet processing engines and of network

Finally, sleeping/standby approaches are used to selectively drive network equipments to low standby modes, and to wake them up only if necessary. Authors in [14] investigated how a network connectivity proxy could enable significant energy savings by allowing idle hosts to enter a low-power sleep state and still maintain full network presence.

2) *Clustering with one HN and multiple MNs*: After HN selection procedure, nodes selected as HNs send advertising message to adjacent nodes. Receiving message from HNs, nodes update neighbor table and select one HN which is the least utilized among HNs. If MNs receive advertising message from other HNs, then MNs discard message. The procedure of cluster configuration is described in Algorithm 2.

Algorithm 2 Pseudo code for clustering

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1: for header nodes  $i = 1$  to  $i = N$  do
2:   sendToMN( $node_{i \rightarrow j}, u_i, u_{i,j}$ )
3:   MNreceiveFromHN( $node_{j \rightarrow i}, u_i, u_{i,j}$ )
4:   updateNeighborTable( $node_j, u_i + u_{i,j}$ )
5: end for
6: MNjoinsHN( $node_j, node_i$ )
   member node  $j$  selects the least utilized header node  $i$ .

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3) *Tag Allocation and Distribution*: After clustering, MNs send routing information to its HN and HN adds their routing information to routing entry for identifying reachability where to arrive through MNs. In this step, there can be several routing entries for same next hop. After adding MNs information, HN selects the shortest and not overlapped next hop among multiple path headed for same destination and updates routing entry. Then HN assigns tags to next hop which can be reached via MNs and tags are distributed to cluster MNs as illustrated in Fig. 2. The tag is a specially designed identifier within a cluster for switching instead of IP routing and includes the outgoing interface of node. On receiving tags from HN, MNs temporary put routing related function in layer 3 to sleep and perform packet switching using tag. If MNs receive packets without tag, packets are directly forwarded to cluster HN.

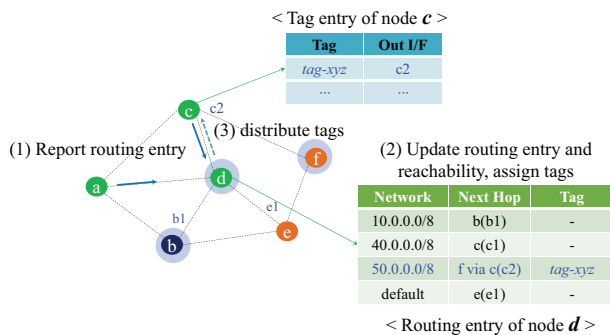


Fig. 2. Tag allocation and distribution

4) *Packet Delivery using Tag*: For operation between node a from source and node f to destination in Fig. 3, node a receives packets without tags and forwards them to node d . As an assumption to operate, MN forwards packets to HN if there is no tag information in routing entry of MN. On receiving packets, node d looks up the routing entry, encapsulates it with the tag and forwards them all to node c . Node c forwards the packet to the next hop, node f after tag switching. Finally packets with the tag arrive at node f which removes the tag, and routes the packets to the destination.

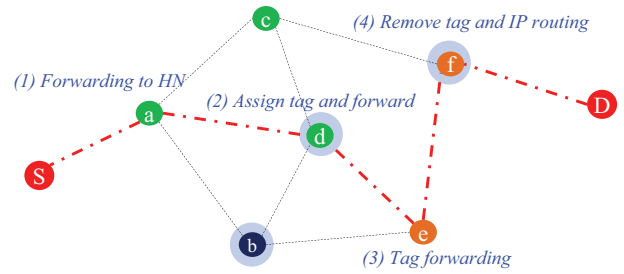


Fig. 3. Energy-efficient packet delivery operation

IV. PERFORMANCE ANALYSIS

In order to investigate the performance of the proposed algorithm, we run several simulations using the NS-2 simulator under the well-known NSFNet topology with 14 nodes and 42 links. Additionally, as described in Table I we include real network topologies from the Rocketfuel project given by [15]: the Exodus (3967) and Ebone (1755) networks are composed of 79 nodes and 294 links, and 87 nodes and 322 links, respectively.

For the evaluation of energy consumption, we assume the consumed power of the node is 600W; 420W is used for the IP routing while the rest is used for the tag switching [7]. Also, the power consumption of link is 235W according to [10]. Under these environments, we measure the energy efficiency which is defined as the ratio of the links to be switched off to all links. Especially, we compare the energy efficiency of the proposed algorithm with the ones of the OSPF, GreenOSPF [2], and ILP [3] algorithms. Figure 4 illustrates the energy efficiency when the offered load is given by 0.2.

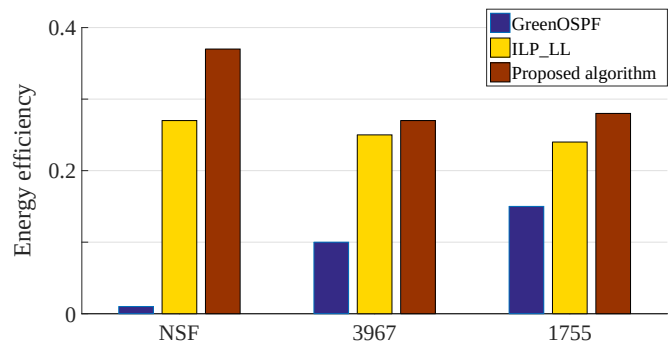


Fig. 4. Power efficiency under various topologies w.r.t. algorithms

All previous algorithms try to reduce the energy consumption by turning off the nodes and links. Therefore, the energy efficiency of ILP is much higher than OSPF and GreenOSPF because ILP decides the nodes and links to be turned off via complicated optimization technique. Generally, turning off the network equipments lets incoming flows, which passing by the elements, be rerouted to another candidate paths which are much longer than shortest paths. It causes the traffic to be aggregated on the links that still turn on, and hence the average link load for that links naturally increases (see Fig.

4). If some nodes start to experience the congestion due to the rerouting, the algorithm may no longer support the energy consumption. That is the reason why the energy efficiency of ILP stops at 25%. Contrarily to previous approaches, the proposed algorithm just turns off the L3 routing function while maintaining the network connectivity to the HN. Accordingly, the candidate paths are not longer than original shortest paths and it leaves room for reducing the energy consumption much more than previous. As seen in above figure, the proposed algorithm can reduce the energy consumption at about 30%.

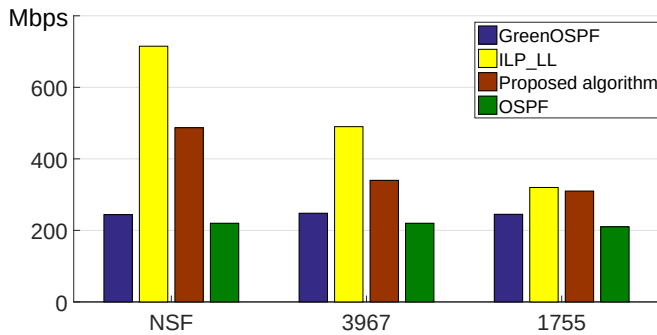


Fig. 5. Average link load under various topologies w.r.t. algorithms

Figure 5 plots the average link load estimated over all links that turn on when the offered load is given by 0.2. As we described earlier, in case of the ILP algorithm, the average link load is a quite high at about 700Mbps, it means that ILP has to take much longer paths compared to shortest paths. Contrarily, the candidate paths of the proposed algorithm are not much longer. Note that the average link load affects the end-to-end delays of the flows. As the load is proportional to delay, the proposed algorithm can support more moderate quality of services than the ILP algorithm while reducing the energy consumption efficiently.

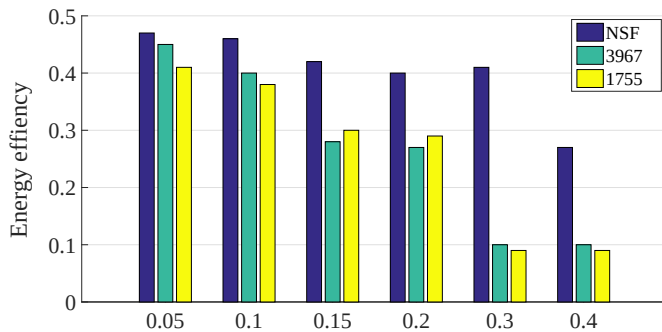


Fig. 6. Energy efficiency of proposed algorithm under various topologies

Figure 6 shows result obtained to evaluate the performance of the proposed algorithm in various network topologies. As the offered load increases, energy efficiency is reduced in all network topologies. In case of Exodus and Ebone as an example of scale-free network, however, the energy efficiency

is rapidly decreased when offered load is greater than 0.3. On the other hand, we can find less reduction in NSF random network as the load increases. This behaviors is caused by traffic congestion at hot spot nodes in Exodus and Ebone topology with less offered load. In NSF, less congestion occurs because nodal degree is relatively evenly distributed in between 1 and 4. Thus the proposed algorithm shows better performance in random network than scale-free network regardless of offered load. Overall, the proposed algorithm can be applied to both random and scale-free network topologies as we aim at reducing power consumption in off-peak period.

V. CONCLUSIONS

Energy efficiency is becoming a key factor in green ICT industry. As a research for green network, we provide an algorithm to minimize power consumption in wired network in this paper. It configures clusters consisting of one HN and multiple MNs according to selection method, forwards packets using tags. Simulation results show that the proposed packet forwarding scheme can get more energy efficient performance than precious works.

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