Availability-Aware Routing for Large-Scale Hybrid Wireless-Optical Broadband Access Network

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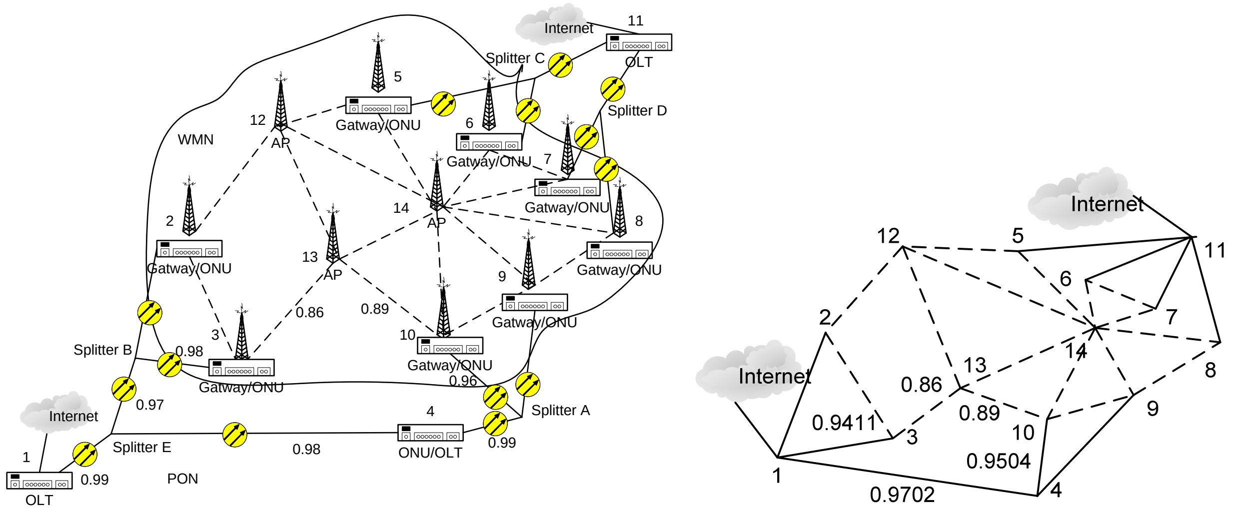
Abstract: In large-scale hybrid wireless-optical broadband access networks, the availability of wireless links and optical links varies considerably. Availability-aware routing can significantly improve availability and throughput by encouraging more usage of PON.

OCIS codes: (060.4250) Networks; (060.4257) Networks, network survivability

1. Introduction

Hybrid wireless-optical broadband access network (WOBAN) consists of a multi-hop wireless mesh network (WMN) at the front-end and an optical access network, e.g. a passive optical network (PON) at the back-end [1, 2]. PON uses inexpensive optical splitters to divide a single fiber into separate strands feeding individual subscribers. EPON is based on the Ethernet standard, which comes with the added benefit of the economies-of-scale of Ethernet, and provides simple and easy-to-manage connectivity both at the customer premises and at the central office. EPON is typically deployed as a tree or tree-and-branch topology, using passive optical splitters. A wireless mesh network (WMN) is a communication network made up of radio nodes organized in a mesh topology, which is reliable and offers redundancy, and the mesh architecture sustains signal strength by breaking long distances into a series of shorter hops. Intermediate nodes not only boost the signal, but cooperatively make forwarding decisions based on their knowledge of the network states. Compared with pure WMN or PON, hybrid WOBAN provides a more cost-effective way for broadband access network infrastructure and integrates the benefits from WMN and PON. As a hybrid of two distinct networks and technologies, hybrid WOBAN posts a lot of challenges for routing. As delay is a major concern for certain applications, authors in [3, 4] proposed a delay-aware routing algorithm, which can achieve minimal delay and effective congestion control. Apart from delay-awareness, some improvements on routing are focusing on integrated routing for load balancing and higher throughput [5, 6] for reconfigurable optical backhaul and WMNs.



(a). Physical layer topology. (b). Routing layer topology.

Fig. 1. Architecture of hybrid WOBAN, where the availability of wireless links and optical links varies considerably.

In this paper, we focus on large-scale hybrid WOBN, which may cover even larger area by mixing WDM PON, EPON, WiFi, WiMax and other access network technologies. Fig. 1 (a) shows an illustrative example of physical layer topology of a large-scale hybrid WOBAN while Fig. 1 (b) shows the topology from routing point of view. As passive devices, splitters will not participate in the routing decision and forwarding, where the routing domain covers both PONs and WMNs. Therefore, the topology of routing layer may be different from physical topology. The shortest path in routing layer may not be the best choice from physical topology point of view. *In this paper, we motivate the needs of considering availability in routing decisions.* Availability is the probability that the connection will be found in the operating state at a random time in the future [7]. It is affected by many factors, such as network component failure probabilities, failure repair times, etc. There are basically two motivations for us to study availability-aware routing for large-scale hybrid WOBAN: 1) It is well known that the availability of optical links and wireless links varies significantly, so routes along different links may have very different availability and thus affect the stability of services; and 2) Availability is an important parameter in Service Level Agreement (SLA) between a network operator and network service subscribers, so it is necessary to have an availability-aware routing to minimize availability along the route or at least avoid highly unstable routes. Obviously, *the main challenge of availability-aware routing for large-scale hybrid WOBAN is that routing will not only be calculated purely based on routing layer topology, but also need to consider physical constraints, e.g. availability of components and segment of links (for example, availability of fiber from Optical Line Terminal (OLT) 1 to Splitter E in Fig. 1(a)).*

2. The proposed availability-aware routing for large-scale hybrid WOBN

If we know the mean time to failure (MTTF) and mean time to repair (MTTR) of a component, link, or connection, its availability can be calculated as

$$a = MTTF/(MTTF + MTTR) \qquad (1)$$

Let a_i denote the availability of link i along a path. The availability of path k can be calculated as

$$A_k = \prod_{i\in P_k} a_i \qquad (2)$$

For example, as shown in Fig. 1(a), the availability of fiber from OLT 1 to Splitter E is 0.99, the availability of fiber from Splitter E to Splitter B is 0.97, and the availability of fiber from Splitter B to Gateway/ONU 3 is 0.98. Using Equation (2), the availability of the optical link from node 1 to node 3 is calculated as *0.99×0.98×0.97=0.9411*, as shown in Fig. 1(b). To calculate the most available path with *the shortest-path (SP) algorithm*, e.g. Dijkstra's algorithm, we can use

$$-\log(A_k) = -\log(a_1) + \cdots - \log(a_P) \qquad (3)$$

In other words, using Equation (3), we can add weights on links of networks, and thus apply the shortest-path algorithm for computing the most available path. Note that *the most available path (MAP) is defined as a path with the highest availability from the source to the destination of a connection request.* The most available path will be equal to the shortest path provided the availability of each link is the same. For example, using Equation (3), we can calculate that the route 13-10-4-1 is 0.8206 and route 13-3-1 is 0.8092. Apparently, the most available path from node 13 to node 1 is 13-10-4-1 while 13-3-1 is the shortest path.

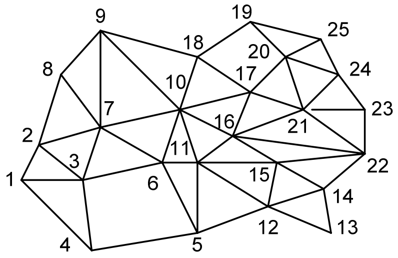


Fig. 2. Routing layer topology of 25-node SFNet.

Table 1. Comparison under empty 25-node SFNet.

Distribution of link availability	Parameters	14-node topology		25-node topology	
		AAR	SPR	AAR	SPR
$0.9 < a_i < 1$	Average hops	2.535	2.049	3.234	2.627
	Average availability	0.927	0.904	0.924	0.879
	Improvement over SPR	2.5%	N.A.	5.1%	N.A.
$0.7 < a_i < 1$	Average hops	3.048	2.044	3.546	2.634
	Average availability	0.769	0.701	0.783	0.670
	Improvement over SPR	9.7%	N.A.	14.4%	N.A.

3. Simulation results and discussions

We first use the 14-node topology, as shown in Fig. 1, and then a much larger network, i.e., the 25-node SFNet in San Francisco city area[2], [4], as shown in Fig. 2, under different link availability parameters. The availability of link is uniformly distributed from 0.9 to 1, i.e., $0.9 < a_i < 1$ and from 0.7 to 1, i.e., $0.7 < a_i < 1$. The simulation program was written with Matlab and the final result is the average of at least 30,000 connection requests. An arrival request is equally likely to be arrived at and destined to any node in the network. First, we compare the *availability-aware routing (AAR)* and the *shortest-path routing (SPR)* under empty networks, i.e., routing is totally based on network topology without considering traffic distribution. Simulation results in table 1 show, as expected, AAR is less capacity efficient than SPR, and *AAR steadily outperforms SPR in average availability with the increase of variation of link* *availability*.

Second, consider the scenario of different traffic distributions on the network. For simplification, assume every link has the same capacity and one connection request over a link will consume one capacity of the link. For dynamic traffic, the arrival of traffic to the network follows Poisson distribution with rate λ connection requests per unit time and connection-holding time is exponentially distributed with a mean value of one unit time. We use dynamic routing, where the shortest path or most available path is calculated according to current network states. Due to limited resource, some connection request may be rejected if the path cannot be found. Blocking probability is defined as the number of rejected connection requests against the total number of connection requests. Fig. 3 - Fig. 4 plot simulation results. Fig. 3(a) and Fig. 4(a) show that SPR always has the lowest blocking probability due to its capacity efficiency, Fig. 3(b) and Fig. 4(b) show that AAR will use more hops than SPR does, and, furthermore, Fig. 3(c) and Fig. 4(c) demonstrate that *the average availability of AAR is much better than that of SPR especially when load is low*.

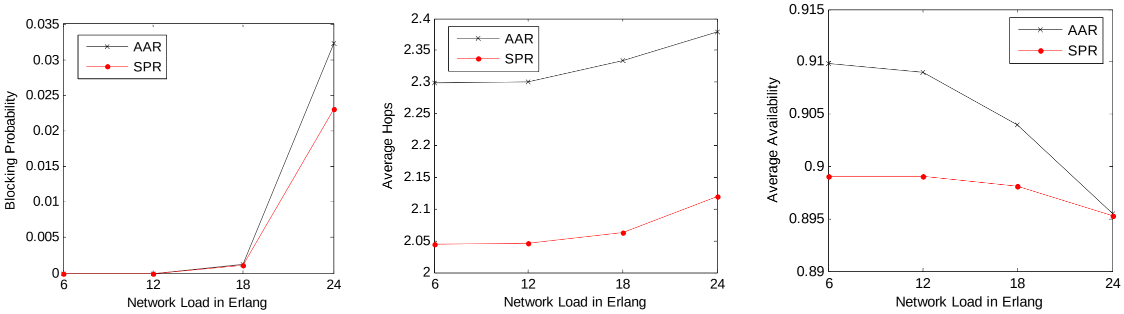


Fig. 3. Simulation results (14-node topology, $0.9 < a_i < 1$, and capacity per link is 10)

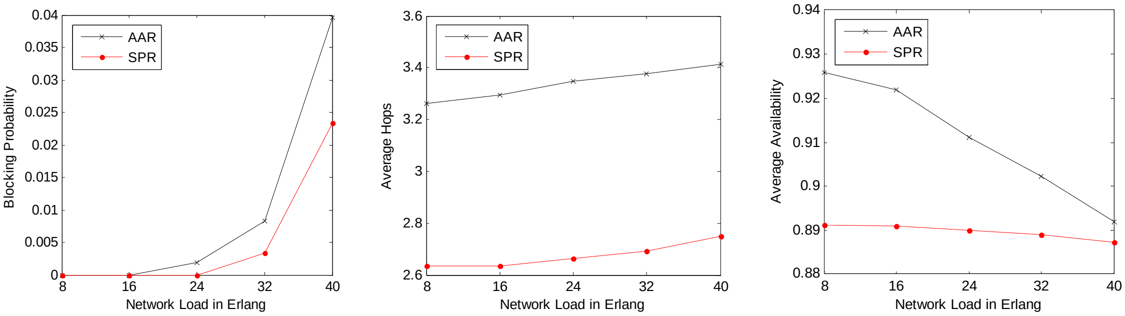


Fig. 4. Simulation results (25-node SFNet, $0.9 < a_i < 1$, and capacity per link is 10)

4. Conclusion

In large-scale hybrid WOBAN, the availability of optical links and wireless links varies significantly. Traditional availability-unaware routing using the shortest path will lead to bad performance of path availability. Availability-aware routing can significantly improve availability and throughput by encouraging more usage of PON.

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