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Design of All-Optical Networks and Web Hosting Service

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Abstract

People are demanding high-quality and bandwidth-intensive Internet applications. To support these applications, the Internet backbone must support high-speed communication and have a very large capacity. An *all-optical network*, which transfers data in optical domain within the network, is a promising candidate to act as the backbone network for the Internet. On the other hand, the world wide web is one of the most effective communication media on the Internet, and web hosting is a valuable Internet service to many small- and medium-sized enterprises. In this thesis, we focus on the design of all-optical networks and a web hosting service. We tackle four specific problems as follows.

1) **Logical Subnetting for Constructing All-Optical Multi-Fiber Networks:** In all-optical multi-fiber networks, each node may have many incoming/outgoing fibers and hence it may require large and expensive optical switches. In Chapter 2, we propose a *logical subnetting approach* for constructing all-optical multi-fiber networks so that these networks only require small optical switches. We use multiple *logical subnets* to compose a network, where a logical subnet has the same physical topology as but smaller dimensions than the network. In each subnet, each node has fewer incoming/outgoing fibers and hence it requires smaller optical switches. A lightpath can be setup through one of the available subnets. We propose two logical subnetting methods: (i) *homogeneous subnetting* in which all subnets are identical, and (ii) *heterogeneous subnetting* in which different subnets may adopt different node architectures and dimensions. Heterogeneous subnetting achieves better cost-effectiveness but involves larger overhead. Logical subnetting has three advantages: (i) the resulting network requires significantly smaller optical switches while its

blocking probability remains nearly the same, (ii) we can use logical subnetting and any existing node architectures for network construction so that we obtain their respective advantages, and (iii) an existing network can easily be scaled-up by adding additional subnets without modifying the existing ones. We demonstrate that it is cost-effective to use many subnets of small dimensions for network construction, so that the network requires small optical switches while it has a small blocking probability.

2) **Upgrading Unicast All-Optical Networks for Multicast Communication:** We address the problem of upgrading existing unicast all-optical networks to support multicast communication. In upgrading, it is necessary to modify the node architecture so that the resulting nodes can support point-to-multipoint optical switching. In modification, it is desirable to (i) retain and use the existing node components while adding a small number of components so that the *upgrading cost is small*, and (ii) avoid major modification of the existing node architecture so that the *upgrading overhead is small*. We propose three designs to fulfill these goals: (i) the *pre-splitting* design adds splitting modules before the existing optical switches to split the incoming light beams for point-to-multipoint optical switching, (ii) the *post-splitting* design adds splitting modules after the existing optical switches, and (iii) the *pre/post-splitting* design adds splitting modules before and after the existing optical switches. We demonstrate that (i) the pre-splitting design is the most cost-effective when there are many multicast sessions with a few destinations per session, (ii) the post-splitting design is the most cost-effective when there are a few multicast sessions with many destinations per session, and (iii) the pre/post-splitting design is suitable for all traffic patterns.

3) **Add-Drop Garbaging for Secure Communication in Optical Private Networks:** A large organization can lease optical channels to connect its branches to

form an optical private network for high-speed internal communication. Other parties may want to intercept and obtain the data transmitted through these channels (e.g., a rival company wants to collect confidential business information and it bribes a technician of the telecommunication company for interception). For security, the organization can encrypt the data before transmission. However, many existing encryption methods (e.g., DES, RC5, RSA, MD5, etc.) may be cracked through intelligent search-and-trial [100]. In Chapter 3, we advocate to exploit the enormous bandwidth of optical fibers to provide additional security for optical private networks. We propose the *add-drop garbaging* method by which the transmitter randomly adds *garbage bits* into the bit stream (ciphertext) before transmission and the receiver drops the garbage bits to recover the original ciphertext. In this manner, it is more difficult for the hackers to extract the original ciphertext and perform cracking. The garbage bits consume bandwidth but optical fibers have enormous bandwidth, and it is worthy to trade a small portion of bandwidth for better security. The add-drop garbaging method has several desirable properties: (i) it can complement any existing encryption methods to achieve better security; (ii) it adaptively adds more garbage bits for better security when the traffic is low; (iii) we can select to add more garbage bits for better security at the cost of using more bandwidth; (iv) it can be implemented by simply adding a *garbage adder* to the transmitter and a *garbage dropper* to the receiver.

4) **Web Hosting with Statistical Bandwidth Guarantee:** Web hosting is a promising service because outsourcing is a global trend to reduce cost. In the existing web hosting service, the web sites either share the system resources without any guarantee or are allocated dedicated resources with a probably low resource utilization. To relieve these shortcomings, we propose a web hosting service with statistical bandwidth guarantee. Each customer subscribes to a certain bandwidth to serve the

requests for her web site. The web hosting system guarantees to provide this bandwidth for this web site with probability *p,* where *p* is a design choice (e.g., $p = 0.99$). To realize this service, the system measures the traffic statistics of each web site so that it can administer statistical resource sharing among the web sites and perform admission control. We tackle the latter problem for two cases: the system is composed of (i) a cluster of servers and (ii) multiple clusters of servers. In the second case, it is also necessary to assign the web sites to the clusters for statistical resource sharing. We formulate this assignment problem, prove that it is NP-complete, and design two efficient assignment algorithms. The simulation results demonstrate that the proposed web hosting service: (i) provides statistical bandwidth guarantee to each web site and gives a high resource utilization, and (ii) allows the system to host more web sites.

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