Abstract

The ubiquitous presence of internet and the advent of broadband services have raised the demand for high-bandwidth networks more than ever before. Optical fiber with its enormous bandwidth ($\sim$ 25,000 GHz) and extremely low transmission loss has ushered in the era of optical networks which is expected to serve this need of today's bandwidth-hungry society. One can explore the bandwidth of the optical medium by concurrent transmissions among the users by using wavelength-division multiplexing (WDM) technique. Use of WDM enables a single strand of fiber to carry several independently-modulated optical channels on distinct wavelengths, each operating at peak electronic processing speed. In addition, the technologies for the development of several WDM devices have matured significantly. Along with maximum bandwidth utilization, the WDM network can also support heterogeneous communications (i.e., different bit rates and network protocols can coexist on different wavelengths), and more reliability as most of the devices employed are passive. In addition to WDM, there have also been significant amount of research towards exploiting fiber bandwidth by means of two other possible techniques: optical time-division multiplexing (OTDM) and optical code-division multiple access (OCDMA). However, the technology and some fundamental issues restrict their applications mostly for local-area networks (LANs) or metropolitan-area networks (MANs).

WDM-based optical networks can be categorized basically in two groups, viz.,

broadcast-and-select (BS) networks, and wavelength-routed (WR) networks. In BS-based network architectures, the transmission from each node is broadcast to all the nodes of the network. From an architectural viewpoint, BS networks, originally conceived for optical LANs/MANs, can be further classified into single-hop and multihop networks. Generally, due to device constraints, the number of available optical wavelengths in such WDM networks is found to be less in comparison to the number of users. Thus, it becomes a challenge to design efficient medium-access control (MAC) protocols for such WDM networks with the constraint on number of wavelengths. Furthermore, the design issues for physical layer in WDM-BS networks need to be examined carefully, particularly when such networks cover large geographical area and serve large number of users necessitating the use of optical amplifiers.

In view of the above we have explored in this dissertation some of the relevant issues concerning the MAC protocols and physical-layer design of WDM optical networks. In our studies on MAC protocols, we have considered a network setting that captures the evolving scenario of today's high-speed LANs. It may be noted that, the growth of networks within an organization usually takes place in an evolutionary manner. In a typical situation, several copper-based LANs (employing coaxial cables or twisted-wire pair), usually spread around various departments in different buildings, might need an appropriate interconnection to form a single organizational LAN operating over a larger area with high transmission bandwidth. To make such network upgrading economically viable, existing coaxial LANs cannot be discarded right away, and hence, one can employ a high-speed backbone to interconnect the existing coaxial LANs, wherein the backbone, preferably using optical fibers, can provide the necessary support for both longer transmission distance and larger bandwidth. In such cases of internetworking one can visualize the network as several clusters of users, which are *linked* (i.e., interconnected) by high-speed optical backbone leading to a *linked-cluster* (i.e., two-level hierarchical) topology. Although one can employ single-wavelength transmission in such optical backbones, when the number of LANs and the traffic between different LANs (i.e., intercluster traffic) are increased, performance of the backbone may degrade. One possible way to overcome this limitation is to employ concurrent transmissions in the optical backbone by using WDM. In view of this, one of our studies has been to evaluate analytically the performance of MAC protocols in such LANs with linked-cluster topology, wherein each cluster consists of one coaxial LAN, and clusters are interconnected by single-wavelength or WDM optical backbone. The optical backbone with single-wavelength transmission has been assumed to employ slotted-ALOHA MAC. For optical backbone employing WDM, we have considered MAC protocols employing pretransmission coordination (PC), wherein transmission of data packets are coordinated by prior transmission of control packets on a dedicated wavelength (channel). In the next step of our studies, we have extended the above analysis to examine the delay of single-wavelength and WDM optical backbone for a more realistic linked-cluster topology, wherein each cluster consists of more than one coaxial LANs.

As indicated earlier, we have also investigated physical-layer issues in WDM based LANs with different network settings. One of the network settings considered for this purpose is a WDM LAN using PC-based MAC protocol wherein control packets are transmitted over data channels using subcarrier multiplexing (SCM). Use of SCM for control packets obviates the need to keep a dedicated wavelength for control packets, thus by reducing the control-wavelength bottleneck. For such network, we present an analytical model to examine the transmission error in control and data packets. We use the analytical model to design an appropriate power budget for the network which ensures similar error rates for control and data packets. It may be noted that similar packet-error rates for control and data packets optimize

MAC performance and thus our approach provides a design methodology for physical layer with due consideration to the influence of MAC performance.

The another network setting considered for the study on physical-layer issues employs hierarchical topology to get around the problem of limited number of wavelengths. In particular we examine a two-level hierarchical topology wherein all the stations, instead of being connected to a single passive-star coupler (PSC), are clustered in several groups. Each group (cluster) employs one separate PSC and is itself a LAN of geographically closer stations and forms the first level of hierarchical network. Several such first-level clusters are interconnected by a suitable optical backbone to form the second level of the network. In such two-level topology the intercluster packets undergo considerable signal loss, thus necessitating the use of optical amplifiers, usually erbium doped fiber amplifier (EDFA) for loss compensation. However, while providing loss compensation, EDFA introduces additional noise (i.e., amplified spontaneous emission (ASE) noise) and suffer from traffic-dependent gain saturation. This makes the power-budget design more challenging. We present an analytical model to capture these issues to evaluate error rates for control and data packets for both intracluster and intercluster communications. Finally, we conclude our thesis with highlights on our results and the future scope of the present work.