Internetworking of Multiwavelength Local Optical Networks Based on a Wavelength-Tolerant Receiver Technology*

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Abstract. Robust-WDM is a technique to realize wavelength division multiplexed (WDM) local area networks (LANs) in the presence of laser wavelength drifts. Various medium access control (MAC) protocols have been proposed for Robust-WDM LANs. Among these protocols, the one with Aperiodic Reservation and Lenient Token-Passing control channel (the AR/LTP protocol) is the most promising. We discuss three internetworking strategies for AR/LTP Robust-WDM LANs. The aim is to explore the possibility to scale the AR/LTP Robust-WDM concepts to the metropolitan domain by looking at some basic medium-access arrangements and specifying the advantages and limitations of each. Special Remote Access Nodes (RANs) are proposed to facilitate interconnection. It is shown that by some modifications in the basic AR/LTP local area protocol and by parallel processing of connection requests, commands and control signals, the waiting time performance of a Robust-WDM interconnection can be improved. The improvement would be accomplished at the expense of some control sophistication. Further improvement can be achieved by designing a set of point-to-point links among the RANs of different Robust-WDM stars. In this case, control is relatively simplified, but the design of a RAN is made more complex and expensive.

Keywords: optical networks, wavelength division multiplexing, internetworking, medium access control protocols, local area networks, metropolitan area networks, Robust-WDM

1 Introduction

Optical networking has become an essential foundation of next-generation communication systems. This fact is evident today in core and regional networks, but is also beginning to be recognized in access, enterprise and local networks. Interest in extending the fiber reach to the access arena has been increasing rapidly during recent years. Networking solutions such as passive optical networks (PON), fiber to the curb (FTTC), fiber to the home (FTTH) and hybrid fiber coaxial (HFC) are the focus of numerous research and development efforts. The role of wavelength division multiplexing (WDM) has also become so crucial. On the other hand, the continuing growth of the Internet has led to a situation where data is rapidly overtaking voice as the dominant traffic type in the public network. This situation has regenerated interest in some old transfer modes, such as burst switching (BS) [1] and fast circuit switching (FCS) [2], that are more tailored to handling bursty traffic at ultra-high transmission rates than asynchronous transfer mode (ATM) and traditional circuit/packet switching.

We have introduced robust wavelength division multiplexing (Robust-WDM) [3–11] as a networking technology that is suitable for local-area data networks and may be used in the public access loop. A Robust-WDM network is a passive-star-coupler based broadcast-and-select WDM network. The network deploys a form of FCS as a transfer mode. The robustness, i.e., adaptation of the network to wavelength drifts, is a distinct feature of this network that aims at enhancing the cost effectiveness of local

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WDM deployment. The idea is to design pertinent medium access control (MAC) protocols that are capable of exploiting a new WDM receiver technology which does not rely on extremely fixed wavelength channels. This, in turn, makes it possible to deploy inexpensive lasers and accessory components that are not required to perform stringently in terms of laser wavelength stability. The Robust-WDM receiver is an optoelectronic device that is based on a neural processing unit, i.e., the winner-take-all (WTA) unit. Instead of tuning to the optical wavelength of an incoming data stream, the receiver has a capability of recognizing the spatial port (PIN diode(s)) through which the data stream is coming. The MAC protocol exploits this capability by introducing a reservation mechanism and by using a single control channel to organize the right to reserve among nodes. If a connection needs to be established, a reservation period is invoked in the network. During this period, all data transmissions are suspended and all receivers are put in the WTA mode whereby a pair of nodes can select/identify transmission/receiving wavelength(s) and set up a connection. As soon as the connection is established, the reservation period is terminated and data transmissions are resumed. During normal operation, the entire network will be continuously switching from reservation to transmission and vice versa. Data-transmission times will be interlaced with short reservation periods. The frequency of this alteration process, its periodicity or aperiodicity differ from protocol to another.

Several MAC protocols have been designed for Robust-WDM LANs [6,7,9]. Among these protocols, the protocol with Aperiodic Reservations and Lenient Token-Passing control channel (the AR/LTP protocol) has been shown to give best performance characteristics [6–10]. The central principle in the Aperiodic Reservation (AR) approach is restricting the occurrence of reservations to the cases where it is absolutely necessary, thereby increasing the efficiency of medium access and the utilization of network resources. Further details about Robust-WDM networking and the AR/LTP MAC protocol are discussed elsewhere [5–10].

In the present study, we consider the inter-networking of AR/LTP Robust-WDM networks and the potential of deploying the Robust-WDM technology in the metro access area as a whole. The average waiting time (\(\bar{W}\)) of a typical connection request in an AR/LTP Robust-WDM LAN is given by [7,8,10]:

\[
\bar{W} = T_R + 2\tau + T_{res} + m_i T_{tr}
\]

assuming a symmetric star LAN with constant one-way node-to-node propagation delay of \(\tau\). \(T_{res}\) is the reservation time period which is function in \(\tau\) and some device parameters, \(T_{tr}\) is the average token-rotation time (token cycle), \(T_R\) is the average residual token rotation time (the time interval between the arrival of a connection request at a node and the immediately following arrival of the token at this node) and \(m_i\) is defined as the average excess token rotation factor. The excess token rotation factor identifies the random number of times the control token may be recaptured by a node before it can establish a connection (a situation that may result due to channel blocking). It has been determined that in most practical cases \(\bar{W}\) would be dominated by \(T_R\) and the following solution for the average waiting time \(\bar{W}\) has been obtained [7,8,10]:

\[
\bar{W} = \frac{N^2 (N - 1) \lambda^2 \tau^2}{2} \left[ \frac{1 - P_L}{1 - P_B} \right]^2 (1 + m_i) + N \tau m_i \\
1 - N \lambda T_R \left[ \frac{1 - P_L}{1 - P_B} \right] \\
+ \left\{ \frac{N \lambda T_R (2N \tau + T_R)}{2} (1 + m_i) - \frac{N \lambda^2 \tau T_R}{2} \right\} \left[ \frac{1 - P_L}{1 - P_B} \right] \\
+ \left\{ \frac{N}{2} \right\} + 2 \tau + T_{res}
\]

where \(N\) is the number of nodes in the network, \(\lambda\) is the arrival rate of connection requests per node per second, \(P_L\) is the probability of traffic loss and \(P_B\) is the probability of channel blocking [9]. In the following sections, we discuss the inter-networking of AR/LTP Robust-WDM networks by examining some fundamental access arrangements in this regards and specifying the advantages and limitations of each. In Section 2, we look at the general issue of scalability in passive-star-coupler based optical networks. Then, three basic Robust-WDM inter-networking strategies and the protocols based thereupon are presented and compared in Section 3. Finally, conclusions are given in Section 4.

2 The Scalability Issue in Passive-Star Based Networks

Due to its power budget, a passive-star-coupler based network is not regarded as a scalable one. The star coupler divides the power of an input signal equally