Novel Topologies for Optical Fiber Based Communications Networks

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Prior to the advent of optical fiber as the transmission medium in communication networks, the most popular topologies were rings, busses, and trees, with some interest in stars. Since optical fiber has become the transmission medium of choice, the star topology is once again receiving considerable interest in the research community. This article presents several new topologies that combine rings and busses with stars into novel topologies and architectures. The purpose is to explore topologies and architectures to enhance communication capabilities of future communication networks. However, no protocols are proposed and no performance issues are addressed.

INTRODUCTION

Current research in computer communication networks is focusing on the use of optical fiber as the transmission medium for the next generation of networks. Part of this research is the design of new protocols that exploit the wide bandwidth offered by optical fiber. Optical fiber is a highly desirable transmission medium for several reasons, notably the 25-30 Terahz of bandwidth, very high reliability, lack of susceptibility to electromagnetic interference, and little loss signal strength over distance.

Before the advent of optical fiber as the transmission medium, several topologies dominated the Local Area Network (LAN)/Metropolitan Area Network (MAN) environment, namely the ring, bus, tree, and star, with rings and busses being the primary topologies used.

The first efforts at using the optical fiber was to use these proven topologies and to simply substitute optical fiber for copper cable. This was a simple and straightforward approach. Despite the vast bandwidth potential of optical fiber, however, certain new challenges surfaced.

The bus topology sees some power losses of the signal and supports only a few 10s of devices (Acampora and Karol 1989, Henry 1989, Ramaswami 1993). Optical amplifiers can be used to extend the number of devices that can be supported, but the gain spectrum of amplifiers is not flat. Using multiple amplifiers only decreases the amplification bandwidth.

The ring also sees power loss of the signal, but of much greater concern is the "electronic bottleneck" encountered with a ring (Henry 1989, Ramaswami 1993). The processing speed of electronics is only several gigabits per second, far below the 25-30 gbps speed capability offered by optical fiber. Initially the vast bandwidth of fiber was not fully used in a ring. One way this challenge is being addressed is to divide the bandwidth into multiple channels, or wavelengths by using wavelength division multiplexing (WDM), of only a few gigabits per second per channel.

Because of challenges of the above two topologies, the star has received much attention in the research literature. The star offers a one-hop, also called a broadcast and select, network. In a star, nodes are interconnected via a passive optical coupler connected to all nodes in the network. A transmission from one node is split at the passive optical coupler (POC) and sent to all other nodes in the network.

Though the star topology offers several

challenges of its own (Ramaswami 1993), notably lack of wavelength reuse, splitting loss of signal at the coupler, and scalability from LAN/MAN to the Wide Area Network (WAN) environment, the star topology is still of deep interest and a suitable topology for use with an optical fiber transmission medium for local and metropolitan area networks.

Whatever challenges exist for any of the above topologies, optical fiber is the transmission medium of choice for land based networks and will remain so. Whether or not these challenges are answered in the near future, networks will continue to expand into more and more areas. Therefore, it is time to look at current topologies and try to use them in some novel ways to design the networks of the future.

The objective of this article is to explore ways to combine the star with the ring and bus topologies to extend the communication capabilities of tomorrow's networks, to present some novel topological ideas, and to discuss some of the most obvious advantages and disadvantages of each topology.

No attempt has been made to devise new protocols for any of the topologies. There has been no attempt to do a performance analysis for the topologies because an analysis cannot proceed until a suitable protocol is designed.

The remainder of this article is organized in three sections. First, a number of topological options for communication networks is presented. Next is a discussion of some of the non-topologies aspects that need to be considered for protocol design, followed by my conclusions.

TOPOLOGICAL OPTIONS

This section presents several possible topologies and a short discussion of each. The discussion is limited to advantages and disadvantages of each topology. All options center on using a star topology with a POC to interconnect ring or bus subnetworks in various novel ways.

Option A

Option A is depicted in Fig. 1. This is a rather simplistic and straightforward approach consisting of a dual bus subnetwork with a Node G acting as a gateway to a POC at the center of the star. Node G has connections to the bus subnetwork and to the POC. All other nodes are connected only to the bus subnetwork. Thus, Node G, is the interface between the bus subnetwork and the star network.

This topology offers the following advantages:

1. It interconnects two or more subnetworks.
2. There is little to no effect on other nodes on the bus subnetwork.
3. It could be implemented quickly.

However, it offers the following disadvantages:

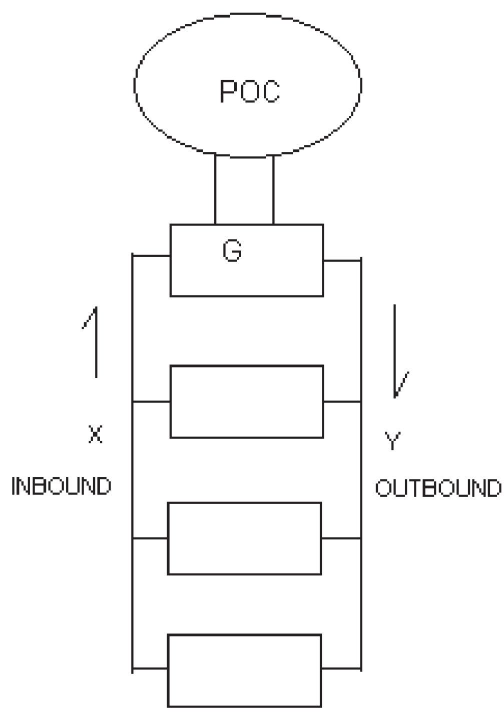

Figure 1. Option A.

1. The gateway may be very complex.
2. At the speeds of fiber, the gateway may become a bottleneck if significant traffic is offered between the bus and the star.
3. There is an issue of whether separate wavelengths are used for the bus and the star or if the wavelengths are reused on both networks. If the same wavelengths are used on both networks, Node G can become extremely complex because it must route traffic dynamically.

This topology may be the first attempt to interconnect bus subnetworks. The challenge will be the design of an effective gateway.

Option B

Option B is depicted in Fig. 2. This is slightly more advanced than Option A, though still simplistic and straightforward. In this topology, all stations are connected to both the bus subnetwork and the POC. Transmissions from the POC take place on the outbound Line Y, while transmissions to the POC take place on the inbound Line X.

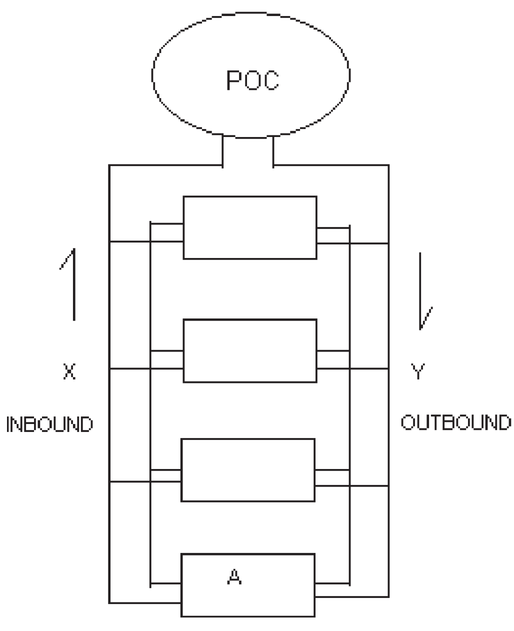

Figure 2. Option B.

Because all stations are connected to the POC, Station A must act as terminator for transmission from the POC and, as slot generator for transmissions to the POC. This is the same function performed by the headend of a Distributed Queue Dual Bus (DQDB) network.

This topology overcomes the disadvantages of Option A and offers the following advantages:
1. All nodes have direct access to the POC.
2. No node acts as a bottleneck.

However, it has the following disadvantages:
1. Each node has a connection to two networks, making hardware design more complex and costly.
2. Connections using two different protocols also require more complex software.
3. The connection to the POC is essentially a bus and, as such, will support only a limited number of devices.

In addition to the above disadvantages, several other factors need to be considered. Each node needs to know the following:
1. The location of every other node and which nodes can be accessed across the bus subnetwork and which across the POC.
2. How the wavelengths are allocated between the bus and the POC and if some wavelengths are used strictly on the bus and others strictly across the POC. This is a matter of whether separate wavelengths are statically assigned for use on either the bus or star, or whether any wavelength can be used on both the bus and star.

Different protocols could be supported for the price of the added cost and complexity of station design. A number of protocols exist for the dual bus configuration, such as DQDB (IEEE Std 802.6 1990) and Cyclic Reservation Multiple Access (CRMA) (Muller et al 1990, Nassehi 1990). Any of a multitude of protocols could be used on the star (Henry 1989, Borella and

Mukherjee 1995, Foo and Robertazzi 1995, Guo et al 1995, Lee and Un 1995, Levine and Akyildz 1995, Li et al 1995, Hua et al 1996, Muir and Garcia-Luna-Aceves 1996). The two protocols would be separate and distinct entities.

Option C

Option C is depicted in Fig. 3. Where the previous two options were shown on a dual bus subnetwork, this topology is really a folded bus topology for connection to the POC. Everything is built on the connection to the POC. There are no longer two separate network entities. Also in this topology, Node A must act as terminator for transmission from the POC on outbound Line Y and, as slot generator for transmission to the POC on inbound Line X. Once again, this is the same function performed by the headend of a DQDB network.

The one significant advantage with this architecture is its simpler node design because there is only one network entity. There is also one significant disadvantage to this topology: it is essentially a bus and will support only a limited number of devices.

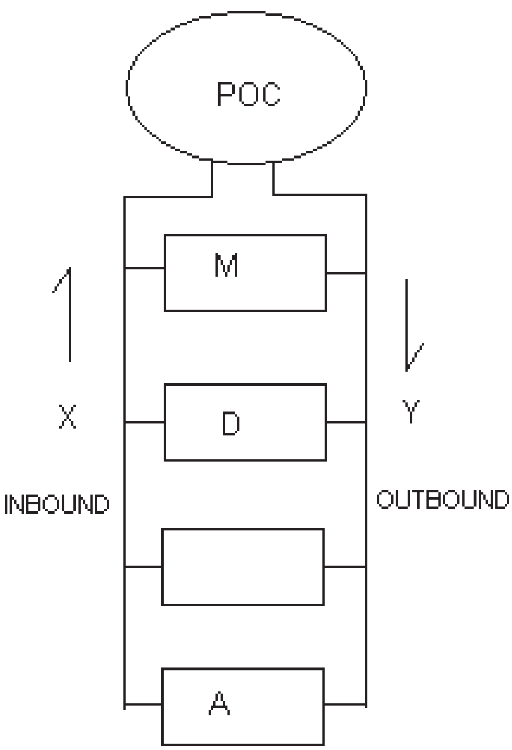

Figure 3. Option C.

Another aspect of this topology that needs to be addressed is the waste of bandwidth that is possible. For instance, Node D (Fig. 3) wants to transmit to Node M. The way the topology exists now, the transmission from D will go through the POC and be transmitted to all other stations. Only then will M be able to receive the transmission. It would be far more efficient if a transmission from a station on one subnetwork to another station on the same subnetwork did not have to go through the POC. Seemingly this is no improvement over the first two options because, in this case, everything must go through the POC. A way to address both of the challenges noted with Option C is with Option D below.

Option D

Option D is depicted in Fig. 4. This is Option C with Device Z added. Device Z performs two functions: it is an optical amplifier for signals going to and from the POC and a wavelength router.

The wavelength router works with those protocols in which each node is allocated a specific receive wavelength. The device is programmed so the wavelengths being used by the nodes on the same subnet are routed from inbound Line X to outbound Line Y. Thus, the valuable bandwidth between Router Z and the POC is not used by a transmission between stations on the same subnet. In other words, the wavelength assignment is static; one set of wavelengths can be used for transmission across the star, and a separate set of wavelengths can be used on the bus.

Alternatively, if the nodes are not allocated specific wavelengths, Router Z can be an active device with buffering and processing capabilities. Any transmission from the nodes on the subnet are processed by Z, looking for addresses on the same

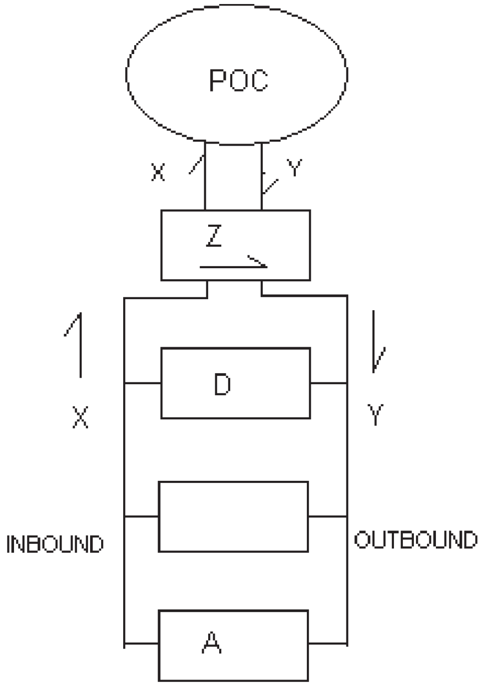

Figure 4. Option D.

subnet. Addresses on the same subnet are transmitted on outbound Line Y. Other addresses are transmitted on inbound Line X to the POC.

Option D offers the same advantage as Option C: simpler node design. This topology overcomes the disadvantages and potential challenges encountered with Option C:

1. Power loss is overcome with the optical amplifier in Device Z.
2. Bandwidth is saved by using the wavelength routing capability of Device Z.

Thus, this topology seems to offer possibilities for future research efforts, starting with the design of a protocol. Also, Option D has variations that could be explored.

Option E

Figure 5 is a high level depiction of the topology of Option E. TP1 through TP5 are transfer points whose function will be explained below, and S1 through S10 are nodes on the network. The set of nodes situated between transfer points is called a group or a segment.

Though the figure is symmetrical with an equal number of stations in each group, this is not a requirement. The figure suggests the stations and transfer points form a ring.

Figure 6 shows a detailed view of one group and the two transfer points to which it is attached. Further discussion of this topology will be with reference to Fig. 6.

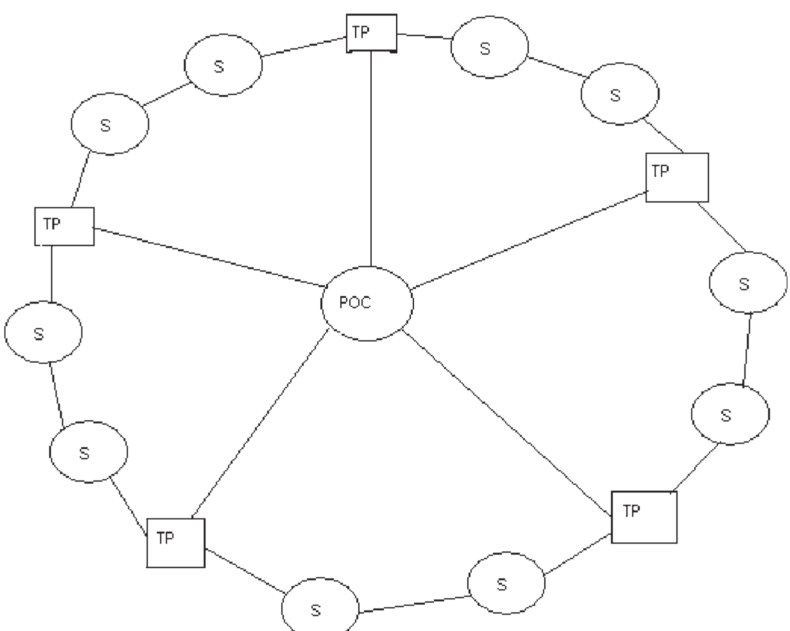

Figure 5. High Level Option E.

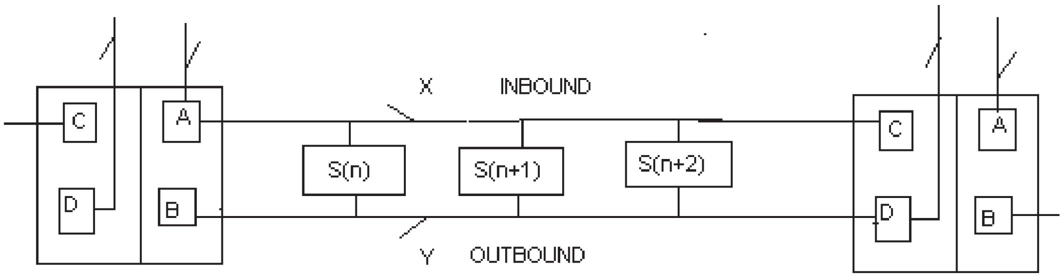

Figure 6. Low Level Option E.

Nodes transmit on inbound Line X and receive on outbound Line Y. Each transfer point performs the following functions:

1. A optical amplifier for boosting the optical signal before transmitting it across the segment of the ring
2. B slot generator that generates slots large enough to hold one packet of data
3. C terminator that removes data from the line after it is received
4. D optical amplifier to boost the optical signal before it is transmitted across the POC

Transmissions on inbound Line X eventually go through the POC and are transmitted to all other nodes through a transfer point and outbound Line Y. This topology presents several disadvantages:

1. This is not a single hop network, so delays can be expected to be longer than in a one-hop network.
2. Protocol design will be more complicated.
3. Transfer points add an extra device not previously needed.
4. Transfer points add to the delay of a packet.

But it offers the following advantages:

1. Node design is simpler.
2. Transfer points can be built with currently available technology.
3. Existing protocols can be adapted to this topology.
4. The topology may offer more flexibility than either the ring or the star.

One other disadvantage worthy of discussion is the bandwidth that may be wasted on transmission within a group. While it was an advantage in Option D, it may be lost in the move to Option E.

An additional advantage in Options C, D, and E is the increase in the size of the networks possible. In the well studied star topology, there is only one station at the end of the lines to the POC. In these new topologies, there are several stations connected by one fiber to the POC, which should allow many more nodes to be attached to the network. A variation of Option E allows greater flexibility in communication capability, as explained in Option F.

Option F

The variation introduced in Option F is the design and function of transfer points. This new design is depicted in Fig. 7, which shows the addition of a new function to the transfer point, Function E.

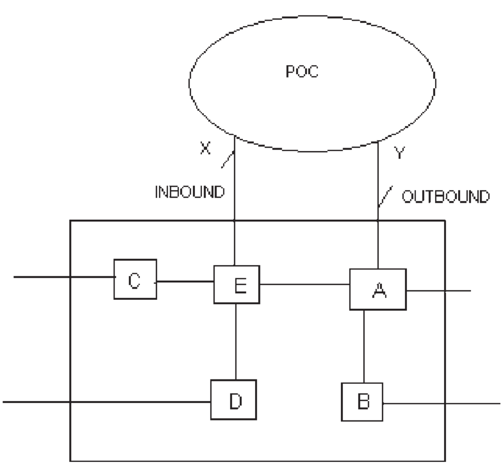

Figure 7. Advanced TP – Option F.

Function E exists to transfer the signal either to the POC or to the optical amplifier for inbound Line X of the next group. The addition of this function gives the network added communication options. If the signal entering E is sent to the POC, the network has the characteristics of a star LAN. If the signal entering E is sent to optical amplifier A, the network takes on the characteristics of a ring network.

Function C will need to allow signals to pass to Function E for continued transmission. How and when Device C needs to terminate signals and which signals to terminate requires communication between Functions D and C. The set of channels will need to be split so some channels will be allocated for transfer through the POC and some for transfer through Device A.

Function D could send information to Function C concerning which channels are currently being allocated to Function A. When a transmission on this channel is received by C, C will not terminate the channel's transmission.

This creates interesting possibilities in protocol design. It also offers some interesting ideas for types of services that could be offered by the network. The protocol could be designed so that applications that are more time sensitive would pass through the POC. Applications not time sensitive can be directed to the next group, as in a ring network. Alternatively, the transfer point could simply transfer one set of wavelengths across the star and a separate set of wavelengths around the ring. This could be either a static or a dynamic assignment of wavelengths.

DISCUSSION

The previous sections were devoted to presenting topological options for communication networks. Only the topologies were addressed. There was no consideration given to the potential cost, complexity, or feasibility of the topology; nor was there any serious considerations of protocol or analysis. While it is necessary to have some discussion related to potential protocols, and it is assumed the network will use wavelength division multiplexing, designing a good protocol can be a complex task. It is beyond the scope of this article to propose any completely new protocols; however, some of the issues to be encountered can be addressed.

Issues involved with this topological Option A have already been addressed in the previous sections. Each bus subnetwork can be treated as a single node attached to a POC, for which many protocols already exist (Henry 1989, Borella and Mukherjee 1995, Foo and Robertazzi 1995, Guo et al 1995, Lee and Un 1995, Levine and Akyildz 1995, Li et al 1995, Hua et al 1996, Muir and Garcia-Luna-Aceves 1996).

Whereas, in Option B, if WDM is used on a fiber for both networks, some decisions must be made concerning the use of wavelengths between the bus subnet and the star network. One idea would be to divide the range of wavelengths into two groups, W_B for use on the bus and W_S for use on the star, a static wavelength assignment strategy. This would allow for reuse of wavelengths on different bus subnetworks.

Another issue is the information needed by each node. It is important for each node to know which nodes are on the same subnet and which are not. With this information, each node can use the correct network for communications with the desired destination.

Topological Option C offers different issues that need to be addressed. Because most protocols designed for WDM on a star use a control channel in a Time Division Multiplexed (TDM) fashion, the concern is how to use the control channel in a TDM fashion to be fair to all stations.

If the nodes have a straight TDM allocation on the control channel, some nodes will have an unfair advantage in transmission access. The most straightforward way to TDM the control channel is to assign slots to nodes in order from the slot generator towards the POC. Thus, nodes nearer the slot generator will forever get first transmission opportunities.

One solution is to assign slots to stations on a cyclic permutation basis, dividing access to the control channel into cycles. One cycle gives access of nodes to slots in a cyclic permutation of the previous cycle.

For example, if there are three nodes on the network, S1, S2, and S3, in the first cycle, nodes have access to slots in order (S1, S2, S3). In the next cycle, nodes have access in order (S2, S3, S1). In the next cycle, nodes have access in order (S3, S1, S2). The cyclic pattern is then repeated. Using this scheme, nodes will have fair opportunity for transmission.

Topological Option D has the same challenging solution as Option C. Additionally, Device Z must have some way of deciding which channels need to be routed to outbound Line Y and which to the POC. It can be a completely passive process using a wavelength sensitive router if wavelengths are statically allocated to nodes to receive transmissions. Devices already exist for just this purpose (Rubin and Hua 1995).

However, if wavelengths are not statically assigned to nodes, Device Z's task is an active one. Device Z must buffer at least part of the packet to inspect the destination address. This will allow the packet to be routed, but it will add some complexity and delay to the transmission. Either solution is possible, but the simpler one is preferred.

Topological option E also presents the same challenges as Option C and requires the same solution. In addition, it presents added delays for a packet to traverse a group.

The final topology, Option F, offers the same challenge encountered in Option B, the challenge of wavelength use on what is effectively two different networks. The solution could be as simple as the solution offered for Option B: divide the range of wavelengths into two groups, W_B and W_S. With this approach, Function E can perform a wavelength sensitive routing function.

However, there is still the challenge of stopping a packet from circulating forever. A potential solution is to let Function C inspect each packet. A packet with a source address in the group preceding Device C is removed.

The above discussion is by no means exhaustive of all the issues encountered when designing a protocol for the proposed topologies. Hopefully, it has brought up the issues of most concern.

CONCLUSIONS

This article has presented a number of new topologies that combine POC star with ring and bus networks. Only further research will tell which, if any, of these topologies are worth further investigation or development. Some advantages and disadvantages of each topology were mentioned. The article did not attempt to devise new protocols for the topologies, nor did it address any performance issues. Performance will be dependent on the design of suitable protocols.

A short discussion was provided which addressed some of the issues that may be encountered when designing protocols for the topologies. The purpose of this work is to generate interest in exploring new topologies to expand the communication capabilities of future networks.

The options that currently seem to offer opportunities for further research are Options D and F. Research would begin by designing a protocol suitable for the topology followed by a preliminary performance analysis.

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